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AN EVALUATION OF THE PAVEMENT CONDITION INDEX PREDICTION MODEL FOR RIGID AIRFIELD PAVEMENTS

Michael W. Dronen, Captain, USAF

LSSR 64-82

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The United States Army Corps of Engineers, Construction Engineering Research Laboratory (CERL) has been working for several years on the development of an airfield pavement maintenance management system. As an integral element to this system, Pavement Condition Index (PCI) prediction models have been formulated for rigid and flexible pavements. The purpose of this thesis was to evaluate the PCI prediction model for rigid Air Force airfield pavements. The model was tested using a new data base, from which it was determined that the predicted PCI values correlated fairly closely with the actual measured PCI values. The model was determined to be a reasonable predictor of the condition of rigid airfield pavements. It was further observed that by enlarging the data base used to develop this original model, the predictive capability of the model improved. Investigating the possibilities of multivariant interaction and nonlinearity in the response surface led to the creation of an improved PCI prediction model for rigid airfield pavements. CERL is working to develop new and progressive prediction models, for both rigid and flexible pavements, and the results obtained from this study should supplement their efforts.

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AN EVALUATION OF THE PAVEMENT CONDITION INDEX PREDICTION MODEL FOR RIGID AIRFIELD PAVEMENTS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

By

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TABLE OF CONTENTS

		Page
ACKNOWLEDGMENTS		iii
LIST OF TABLES		vii
LIST OF FIGURES		ix
CHAPTER		
I.	INTRODUCTION	1
	Problem Statement	5
	Research Objectives	6
	Research Approach	6
II.	LITERATURE REVIEW	8
	Introduction	8
	Early Evaluation Methods	12
	Rigid Pavements	13
	Flexible Pavements	19
	PCI Rating System	21
	PCI Development/Rigid Pavement	26
	PCI Development/Flexible Pavement	34
	PCI Procedure	38
	Model Development	44
	Conclusion	74

CHAPTER		Page
III.	RESEARCH METHODOLOGY	77
	Scope and Delimitation	77
	Data Collection	78
	Pavement Condition	81
	Pavement Design/Construction	82
	Aircraft Traffic	82
	Climate Conditions	84
	Calculated Variables	87
	Edge Stress	87
	Pavement Fatigue	89
	Pavement Damage	90
	Predicted PCI Values	92
	Analysis	97
	Assumptions and Limitations	9[illegible]
IV.	FINDINGS AND ANALYSIS	101
	New Data Base	101
	Prediction Model Evaluation	102
	Modified Prediction Model	109
	Improved Model	112
	Improved Model Evaluation	118
	Modified Improved Model	120
	Modified Improved Model Evaluation	124

CHAPTER		Page
V.	CONCLUSIONS AND RECOMMENDATIONS	127
	Recommendations	132
APPENDICIES		134
A.	RIGID PAVEMENT EDGE STRESS CHARTS	135
B.	SUMMARY OF THE PAVEMENT CONDITION SURVEYS PERFORMED AT WRIGHT-PATTERSON AFB	155
C.	DATA OBTAINED FROM THE CONSTRUCTION ENGINEERING RESEARCH LABORATORY	168
D.	DATA COLLECTED AT WRIGHT-PATTERSON AFB	174
E.	DEVELOPMENT OF A MODIFIED PCI PREDICTION MODEL	176
F.	DEVELOPMENT OF AN IMPROVED PCI PREDICTION MODEL	180
G.	DEVELOPMENT OF A MODIFIED IMPROVED PCI PREDICTION MODEL	184
SELECTED BIBLIOGRAPHY		188
A.	REFERENCES CITED	189
B.	RELATED SOURCES	191
BIOGRAPHICAL SKETCH		192

LIST OF TABLES

Table		Page
2-1	Feature Characteristics	15
2-2	General Guide for Establishing Rigid Pavement Condition	18
2-3	Types of Distress in Airfield Pavement	25
2-4	Descriptive Rating Scale	29
2-5	Summary of Data for Concrete Pavement Features With and Without an Overlay	48
2-6	Summary of Data for Asphalt Pavement Features With and Without an Overlay	49
2-7	List of Independent Variables Considered in the Development of the Concrete Pavement PCI Prediction Models	52
2-8	List of Independent Variables of Asphalt Pavement	56
2-9	List of Raw Data Variables Considered in the Development of the Concrete Pavement PCI Prediction Model	63
2-10	List of Raw Data Variables Considered in the Development of the Asphalt Pavement PCI Prediction Model	65
2-11	Means and Ranges of Key Concrete Pavement Variables	67
2-12	Means and Ranges of Key Asphalt Pavement Variables	68
3-1	Units Assigned to Patterson Field/Wright-Patterson AFB	85
3-2	An Example Calculating the PCI Value for a Rigid Airfield Pavement Feature	94

Table		Page

Table		Page
4-1	Wright-Patterson AFB Pavement Loading	103
4-2	A Summary of Data Collected at Wright-Patterson AFB	106
4-3	A Summary of Data Used in Developing the Modified PCI Prediction Model	111
4-4	New Variables Created in Developing an Improved PCI Prediction Model	114
4-5	A Summary of Data Used in Developing the Improved PCI Prediction Model	116
4-6	A Summary of Data Used in Developing the Modified Improved PCI Prediction Model	123

LIST OF FIGURES

Figure		Page
2-1	Distress Symbols and Sample Field Recording	16
2-2	Airfields Surveyed for Testing and Validation of the Pavement Condition Index	22
2-3	Jointed Concrete Pavement Deduct Values	28
2-4	Asphalt or Tar-Surfaced Pavement Deduct Values . . .	36
2-5	Steps for Determining the PCI of a Pavement Feature .	40
2-6	Corrected Deduct Values for Jointed Concrete Pavements	42
2-7	Corrected Deduct Values for Asphalt or Tar-Surfaced Pavements	43
2-8	Airfields Surveyed for Developing the Initial PCI Prediction Models	46
2-9	Airfields Surveyed for Developing the Improved PCI Prediction Models	61
3-1	Rigid Airfield Pavement Features Surveyed at Wright-Patterson AFB	80
4-1	Scattergram of Actual Versus Predicted PCI Values for the PCI Prediction Model	108
4-2	Scattergram of Actual Versus Predicted PCI Values for the Improved PCI Prediction Model	119
4-3	Scattergram of Actual Versus Predicted PCI Values for the Modified Improved PCI Prediction Model	125
5-1	A Comparison of Actual and Predicted PCI Values . . .	129

Chapter I

INTRODUCTION

Airfield pavements are an essential element to the basic mission of the Air Force and an integral part of this nation's defense posture. For these reasons, one of the primary responsibilities of Air Force Civil Engineering is to construct, repair and maintain the highest possible quality airfield pavements. By reason of sheer quantity, this is a difficult task. The Air Force currently owns, or is responsible for, over 247 million square yards of rigid and flexible airfield pavements (1), most of it aged (i.e. approximately 70 percent over 25 years old), and rapidly approaching the end of its design service life. As a result, the maintenance and repair requirements to keep these pavements operational have increased in recent years and are projected to continue increasing in the foreseeable future. To illustrate this point, approximately 52.7 million dollars was spent on maintenance and repair work for Air Force airfield pavements worldwide in 1981, as compared to 36.3 million dollars in 1977 (2). In addition, current forecasts indicate that between 1983 and 1988, the Air Force will spend 450 million dollars on 850 maintenance and repair projects, encompassing 85 million square yards of pavement

(5). In light of these facts, the Air Force has identified the need for development of a comprehensive airfield pavement maintenance management system which can provide the civil engineering officer with a systematic maintenance and repair selection method that will ensure the optimum use of limited funds. Although the total funding for this type of work is increasing, as previously indicated, funds are in fact limited. The backlog of airfield maintenance and repair work (i.e. work which has been validated and approved, but not funded) more than doubled in scope between 1975 and 1980, increasing from 31 million dollars to 77 million dollars (5). As airfield pavements continue to age, this backlog of necessary work is expected to grow.

A first step in developing an adequate pavement maintenance management system was to establish an analytical procedure for evaluating the present condition of airfield pavements. Prior to 1975, the technique used for conducting a pavement condition survey relied heavily on individual engineering judgement (11:6-16), particularly for evaluating flexible pavements, and therefore lacked a consistency factor that is typically found in most standard measurement tools. As a result, the United States Army Corps of Engineers, Construction Engineering Research Laboratory (CERL), under contract with the Air Force Engineering and Services Center (AFESC), was tasked to develop a standard condition survey procedure for evaluating airfield pavements (11:1). This procedure has been perfected and allows for the rating of jointed concrete and asphalt or tar-surfaced airfield pavements through the determination of a Pavement Condition Index (PCI). The PCI is a numerical indicator, ranging from zero to 100, which reflects the structural integrity and operational service condition of the pavements (11:121). Its calculation is based upon the types of distress identified in the pavement, their severity levels, and their overall densities (4:1). This PCI has proven to be both an accurate and objective tool for assigning airfield pavement condition ratings (11:121). Today, evaluating airfield pavements by performing a PCI survey is a requirement established in Air Force Regulation 93-5. The Air Force has been the only federal agency to fully adopt the PCI rating system thus far; however, the Navy is currently evaluating this procedure for possible use. In addition to the military, several cities, nationwide, are considering utilizing the PCI rating system for evaluating streets and parking areas (6).

Having established a standard method for measuring the condition of airfield pavements, a second step in developing the pavement maintenance management system was to establish a technique for forecasting the PCI, given various situational factors. In essence, this is the core of the airfield pavement maintenance management system. The Army's Construction Engineering Research Laboratory has been working to develop useful prediction models for pavement condition indicies since 1977 (13:1). They have undertaken a number of studies, measuring a variety of independent airfield pavement related variables and comparing them with calculated PCI's, in an effort to formulate valid statistical predictive models. To date, several models have been formulated which appear to reasonably forecast the pavement condition indicies, given the test data utilized. The first model applies to jointed concrete pavements, with or without an asphalt or tar-surfaced overlay, and the second model to asphalt or tar-surfaced flexible pavements (9).

A basic assumption is that these predictive models can be applied credibly to all Air Force airfield pavements, producing valid results. If this assumption is correct, the models may in turn be used to assist the civil engineer in selecting the most economical maintenance and repair strategy for extending the service life of a given pavement feature, by predicting the consequences of various actions on the PCI value. A decision may include strategies such as routine maintenance and repair, extensive patching, or applying an overlay, depending upon which is the most cost effective and advantageous for the Air Force. This accomplishes but one of the major objectives for having an airfield pavement maintenance management system. The models also satisfy a second major objective, that being to provide a capability for predicting the future performance of the airfield pavements, in order that long term maintenance and repair needs can be established and prioritized. To be able to accurately forecast the PCI of a given pavement feature, over a period of time, allows for the consequences of various maintenance and repair alternatives to be predicted and the time required before initial or subsequent maintenance and repair work determined (15:1). To reiterate, the basic philosophy behind the pavement maintenance management system is contingent upon the validity of the PCI predictive models (i.e. the assumption that the models will accurately forecast the Pavement Condition Index).

Problem Statement

At present, the most current Pavement Condition Index forecasting models have not been validated to ensure that they are applicable for accurately predicting PCI ratings for all Air Force airfield pavements. The need exists to confirm the validity of these models prior to incorporating them into the airfield pavement maintenance management system.

Research Objectives

The objective of this research is to validate the 1981 Corps of Engineers' PCI prediction model for rigid airfield pavements. The following questions will be specifically addressed:

1) When applying a new data base, does the forecasting model reasonably predict the actual pavement condition indicies?

2) What effect does adding new field data to the original data base have on the PCI prediction model?

3) Given the data available, can the prediction model be improved upon?

Research Approach

In an effort to satisfy the stated research objectives, this study will follow a sequential approach as outlined below:

1) An extensive review of the literature addressing the pavement condition index rating system and development of the PCI predictive models will be conducted.

2) Field data will be collected from an airfield different from any of those used in developing the PCI predictive model for rigid airfield pavements. A condition survey, in accordance with Air Force Regulation 93-5, will be conducted on various airfield pavement features, to determine current PCI values. In addition, a

review of the records maintained by Civil Engineering and Base Operations will be conducted to extract data concerning past pavement condition, or directly related to the situational variables incorporated in the prediction model.

3) Based upon these pavement related variables, estimated PCI values will be calculated using the current rigid pavement condition prediction model. Additional calculations will be made to determine what impression the new data has on the prediction model. To accomplish this, the new data will be combined with the existing data base and a multiple regression analysis of the variables will be accomplished, with the results depicting any change to the current prediction model.

4) A comparison of the actual and calculated (i.e. model estimated) PCI values will be made, to analyze the validity of both the current and refined prediction model in estimating PCI values for rigid airfield pavements. Improvements to this model will be suggested where deemed appropriate.

Chapter II

LITERATURE REVIEW

Introduction

The Air Force Civil Engineer maintains responsibility for an extremely large inventory of airfield pavements. The magnitude of this airfield pavement system, and its obvious influence on the mission accomplishment of the Air Force, has made it necessary to adopt an aggressive airfield pavement evaluation program. The objectives (17:4-5) for having this airfield pavement evaluation program are to,

> . . . obtain, compile, and report pavement strength, condition and performance data on all airfields with present or potential Air Force missions. The pavement evaluation data can be used to provide operations and civil engineering functions with a source of airfield pavement information which can be used as a tool for proper management and control of an airfield system. The results of pavement evaluation studies can be used to provide inputs for:
>
> 1) Determining the sizes, types, gear configurations, and gross weights of aircraft which can safely operate from a given airfield without damage to the pavements or the aircraft.
>
> 2) Developing operations usage patterns for a particular airfield pavement system (i.e., parking plans, apron utilization patterns, taxiway routing, etc.).
>
> 3) Projecting or identifying major maintenance and/or repair requirements for an airfield pavement system to support present or proposed aircraft missions, and in the event that pavement rehabilitation is required, furnishing the engineering

data to aid in project design.

4) Assisting in base mission and contingency planning functions through the development of airfield layout and physical property data.

5) Developing and validating design criteria.

6) Supporting programming documents as justification for major pavement projects.

7) Supporting flying safety programs by providing pavement surface descriptions that indicate pavement surface traction and pavement roughness characteristics.

The airfield pavement evaluation program essentially consists of four major subprograms: detailed pavement evaluations, runway skid resistance surveys, runway roughness evaluations, and condition surveys (17:4). The pavement evaluation procedure is essentially pavement design in reverse. The method of evaluation utilizes known or calculated physical pavement properties to determine allowable aircraft loadings (17:13). The skid resistance survey determines the traction characteristics of the runway, while the roughness evaluation compares an established standard roughness against the measured roughness of the runway (17:7). For now it will suffice to define the pavement condition survey as a visual inspection of the airfield pavement to observe and quantify any deterioration in condition. Each of these subprograms plays an integral part in the overall airfield pavement evaluation program. However, with the exception of the condition survey, each subprogram requires specialized training and/or equipment, not readily available to the base pavements engineer. Because of these limitations, the Air

Force has focused considerable attention on the condition survey, in an effort to improve the usefulness of this tool to assist in maintaining airfield pavements.

For the last six years the Air Force has been involved in the development of an airfield pavement maintenance management system, designed to ensure the effective use of limited maintenance and repair funds. At the heart of this system lies the evaluation of airfield pavements based upon the condition survey, performed by the base pavements engineer. As a result of the continually increasing number of maintenance and repair requirements,

> . . . the Air Force has identified the need for an adequate method of describing and/or determining the relative condition of airfield pavements; and for developing procedures for evaluating the consequence of using various maintenance strategies to extend the service life of existing pavements. In addition, improved methods are needed for assignment of maintenance priorities to assure optimum use of available maintenance funds [11:1].

The specific objectives (11:1-2) necessary to establish this pavement maintenance management system include:

1) Improved and field-validated condition survey procedures for jointed concrete, and asphalt or tar-surfaced airfield pavements.

2) Objective methods for determining pavement condition indices based on data obtained from pavement condition surveys.

3) A revised version of Air Force Regulation (AFR) 93-5, Chapter 3, entitled 'Airfield Pavement Condition Survey Report.'

4) Methods for evaluating the consequences of using various maintenance strategies; the methods will provide procedures for selecting the best specific maintenance strategies based on pavement condition.

5) Methods for assigning maintenance priorities which will assure efficient and economic use of available maintenance funds.

6) A computer package consisting of a data bank and computation system based on all the developments resulting from work described in 1 through 5. The computer package will provide an up-to-date pavement maintenance management system and will be easily adapted to any existing computers used by the Air Force.

7) Field demonstration of the final version of the pavement maintenance management system at one Air Force base will be required.

To date, the first three objectives have been successfully accomplished (i.e. improved condition survey procedures have been developed, an objective method for assigning pavement condition indicies has been introduced, and a revised version of Air Force Regulation 93-5, Chapter 3, has been written). Techniques for determining feasible maintenance and repair alternatives for a given pavement section have been proposed, along with a procedure for performing economic analyses to compare various maintenance and repair (M&R) alternatives (14:1). A key element, however, in this phase of the airfield pavement maintenance management system is the capability to accurately predict the condition of the pavement, given ". . . the consequence of applying various M&R alternatives, as well as the consequence of not applying any M&R [13:1]." Currently, several iterations of pavement condition prediction models have been formulated. This leads into the essence of this research, specifically to assess the validity of the rigid airfield pavement condition prediction model.

The objective of this literature review is to summarize the process leading up to, and including the creation of the pavement condition prediction models. To fully understand these models, it is essential to understand the history behind their development. The body of this chapter, therefore, begins with a review of the condition survey method used prior to the implementation of the pavement condition index rating system. Following a brief discussion of the limiting factors surrounding this early condition survey procedure, the process used in developing the improved condition survey technique and index rating will be addressed. Finally, the iterative process employed in creating the pavement condition prediction models is examined.

Much of the information contained in this chapter is relatively new. While some of it has been accumulated from regulations, manuals, and technical reports, a significant portion comes from drafts of unpublished technical reports and discussions with individuals involved in developing the system.

Early Evaluation Methods

Prior to Air Force implementation of the pavement condition index rating system, there did not exist an effective analytical method for evaluating the condition of airfield pavements at base level. It was for this reason that the PCI (i.e. pavement condition index) rating system was developed (11:1). Previous editions of Air Force Regulation 93-5, "Airfield Pavement Evaluation Program," had outlined in general terms, the procedures for conducting an airfield condition survey and the methods for collecting and evaluating the data. These early procedures placed considerable emphasis on engineering judgement, resulting in a degree of inconsistency stemming from factors which included, among other things, the educational background, experience level, and general attitude of the evaluating engineer. To follow is a brief explanation of the methods used for conducting a pavement condition survey and evaluating the relative condition of the pavement, prior to the Air Force adopting the PCI rating system. Prior to conducting the survey, all airfield pavements were classified as either rigid (i.e. jointed or reinforced concrete) or flexible (i.e. asphalt or tar-surfaced). The methods for surveying and evaluating each pavement type differed.

Rigid Pavements

The pavement condition survey was normally accomplished by a survey team, headed by the base pavements engineer. The first step in conducting the survey was to identify the different pavement features, each being evaluated separately (16:p.3-1).

> An airfield pavement system cannot be evaluated as a single entity because of the variability of the pavement type, use, thickness, construction history, traffic area, and condition. In pavement evaluation, the pavement system must, therefore, be broken into basic units with common characteristics, called 'features' [17:14].

The differing characteristics of a feature are described in Table 2-1.

Having segregated the pavement into features, a pictorial representation, or layout plan, of each feature was developed. This plan resembled a grid, with each block on the grid corresponding to a single concrete slab in the pavement (16:p.3-1). The survey team visually inspected each slab of every feature, annotating the type of distress present by placing symbols for the given distresses in the grid block corresponding to the particular slab (16:p.3-2). The types of distress typically identified in rigid pavements and the symbols used to record them are depicted in Figure 2-1 (a). Figure 2-1 (b) illustrates a sample field recording.

After completing the pavement condition survey, and having recorded the types of distress found in each particular feature, the results were tabulated and summarized. From this information, a percentage of "slabs with no defects" was calculated. This was a simple computation based on the number of empty blocks in the layout plan. In addition, a second calculation was made to determine the percentage of "slabs with no major defects" (16:p.3-2). A major or structural defect was defined for the pavement engineer as:

TABLE 2-1

Feature Characteristics (17)

Characteristics	Description
1) Pavement Type	Pavement types typically consist of flexible, jointed concrete, rigid overlay on rigid, non-rigid overlay on rigid, rigid overlay on flexible, composite and reinforced rigid payments (refer to Air Force Manual (AFM) 88-24).
2) Pavement Use	Airfield pavements are divided into at least three major uses: runways, taxiways, and parking aprons.
3) Pavement Thickness	Pavements are divided into separate features when their thicknesses vary.
4) Construction History	Different construct histories are dependent upon the date of construction, the types of materials used and the specific contractor performing the work.
5) Traffic Areas	Features are segmented according to traffic areas, based upon the lateral distribution of aircraft traffic and effective gross load. Traffic areas are designated as A, B, C, D, or E (Refer to AFM 88-24).
6) Pavement Condition	This includes other characteristics of the pavement, aside from those mentioned above, which warrant its separation and classification as a specific pavement feature.

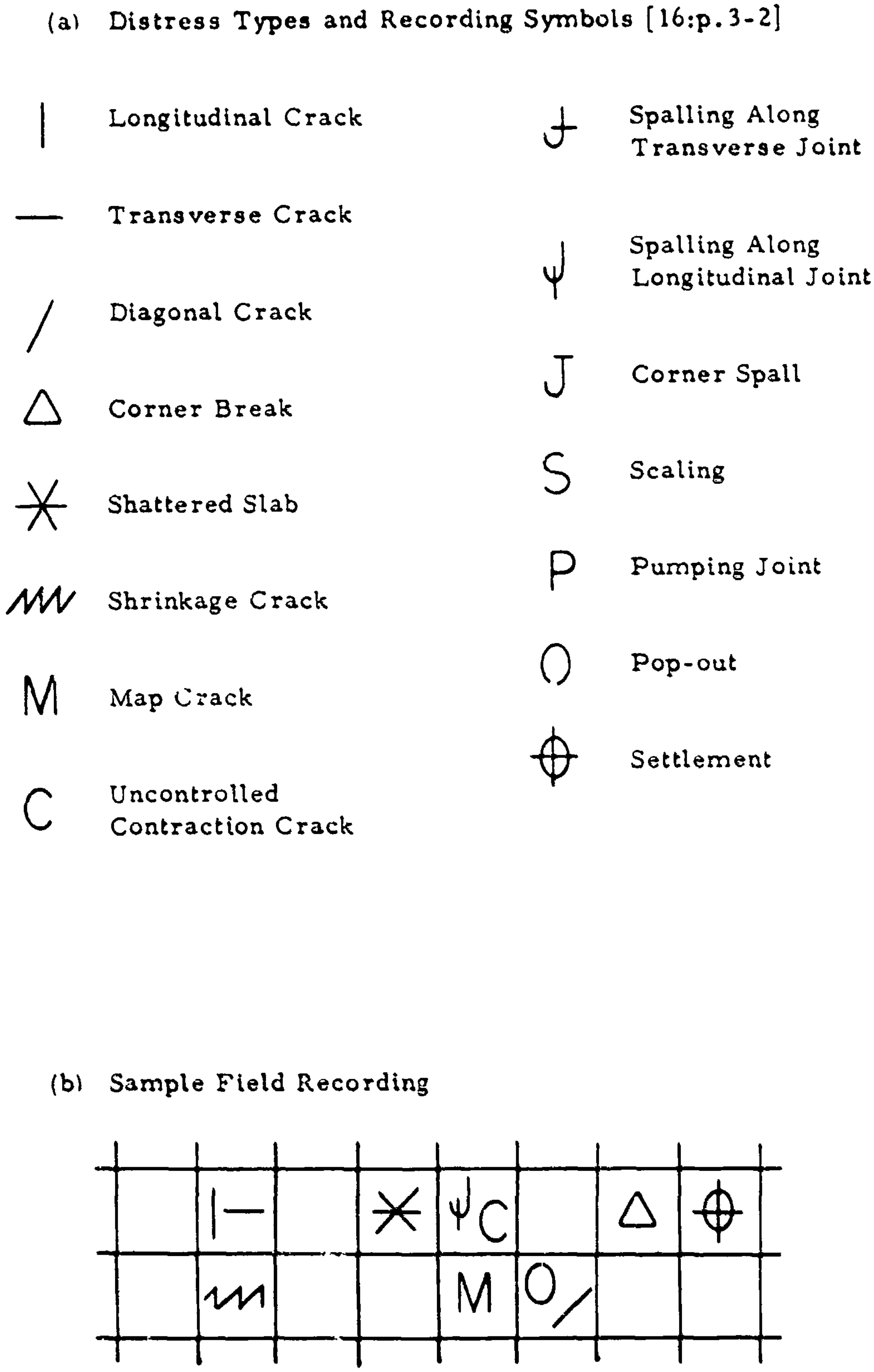


Fig. 2-1. Distress Symbols and Sample Field Recording

A crack or break in the concrete slab that will impair the load-carrying capacity of the pavement. The major defect or crack usually extends throughout the depth of the slab and thus subdivides the integral slab into two or more parts [16:p.3-2].

Based upon the percentages calculated, the condition of the pavement feature was classified. To assist in this classification, general guidelines for establishing the condition of rigid pavements had been developed at the United States Army Corps of Engineers, Rigid Pavement Laboratory (16:p.3-2). This classification is depicted in Table 2-2. Later evidence indicated that 95 percent of the time, the reported condition of the pavement was based solely on the percentage of slabs with no major defects (11:12).

The pavement condition rating system used for concrete airfield pavements had two major shortcomings. First, the method identified the type of pavement distress, but gave no consideration for its level of severity. Second, to evaluate a pavement feature in terms of the percentage of slabs with no defects or the percentage of slabs with no major defects was inadequate, as this evaluation approach did not take into account, for instance, the differences a shattered slab would have on a feature's condition rating, as compared to a slab with only minor cracking (11:12). Although far from being perfect, this evaluation method did provide the means of rating the condition of rigid pavements in order that trend and comparison studies could be conducted with a reasonable degree of validity. The

TABLE 2-2

General Guide for Establishing Rigid
Pavement Condition [16:p.3-3]

% Slabs No Defects		Pavement Condition
K = 25 to 200	K > 200	
90-100	80-100	Excellent
80-98	70-90	Very Good
70-90	60-80	Good
60-80	50-70	Fair
<60-70	<50-60	Poor

% Slabs No Major Defects		Pavement Condition
K = 25 to 200	K > 200	
98-100	90-100	Excellent
90-98	80-90	Very Good
80-90	70-80	Good
70-80	60-70	Fair
<70	<60	Poor

K = Number of Slabs in the Feature

method used to evaluate flexible pavements did not accommodate this possibility.

Flexible Pavements

The procedure used for evaluating flexible pavement was less definitive than that used for rigid pavement, relying heavily on subjective interpretation by the evaluating engineer. As indicated in Air Force Regulation 93-5,

> The condition survey accomplished on flexible airfield pavements consists essentially of a visual inspection of the pavement for evidence of distress. Unlike the crack count method for rigid pavement rating, there is no present technique for assigning a condition rating for flexible pavement condition [16:3-3].

To assign a condition rating to flexible pavement, the engineer laced his or her own knowledge on the subject with the information collected during a visual pavement inspection. Each distress was evaluated in terms of the effect it had on the structural integrity and operational surface condition of the pavement. Load induced distresses were speculated as being the result of either shear failure (i.e. plastic flow) or densification of the pavement structure. Longitudinal cracking, transverse cracking, rutting, and pavement deformation were singled out as structural distresses resulting from load induced stress in the pavement (16:p.3-2,p.3-3). Based upon the information available to the engineer, a pavement condition rating of good, fair, or poor was assigned to the feature. A rating system developed by the Air Force Engineering and Services Center, originally to be used by its pavement evaluation teams, was provided to major commands to assist the evaluating engineer in rating flexible pavement (16:p.3-4). The guidelines (16:p.3-4) used were as follows:

> Good. Pavements in better than average condition with no conspicuous evidence or deformation or incipient failures, and with few (if any) longitudinal, transverse or shrinkage cracks. All existing defects are being properly maintained.
>
> Fair. Pavements with a higher percentage of transverse, longitudinal, or pattern cracking and minor defects, such as weathered or oxidized surface, random cracking and minor deformation or rutting.
>
> Poor. Severe surface deformation, such as rutting, shear failure, densification, heave or raveling, excessive cracking or evidence of surface water intrusion into moisture-sensitive subsurface layers. A reduction in allowance gross loading should be accomplished for pavements rated as poor.

The major shortcomings of this method of evaluating flexible pavements include its high degree of subjectivity and inadequacy as a useful tool for programming maintenance and repair requirements (11:16).

In summary, it was determined that the procedures for evaluating flexible and rigid airfield pavements produced results which correlated poorly with those obtained by experienced pavement engineers. Reasons for this are first, the existing Air Force procedures failed to account for distress severity and second, the procedures used for assigning pavement condition ratings were inadequate. Based upon these conclusions, it was deemed necessary to develop an objective pavement rating system, dependent not only upon the types of pavement distress, but also a function of the distress density and severity level (11:25).

PCI Rating System

Due to a number of inadequacies identified in existing pavement condition survey and evaluation procedures, the Air Force felt it necessary to obtain a method which would objectively and accurately evaluate airfield pavements and assign condition ratings. At the request of the Air Force, the U.S. Army's Construction Engineering Research Laboratory, during fiscal years 1975-76, instituted a study to examine this problem. The ultimate result of their research led to the development of the pavement condition index rating system. Within the scope of this study, improved methods for performing pavement surveys and applying condition ratings were field tested, revised, and validated at nine airfields having varying environmental and operational conditions (11:2). Figure 2-2 identifies each of these bases and their location.

A condition survey for both flexible and rigid pavement features consists primarily of visually inspecting the pavement and measuring the magnitude of each identified distress. Vital airfield pavement information is principally obtained through this condition

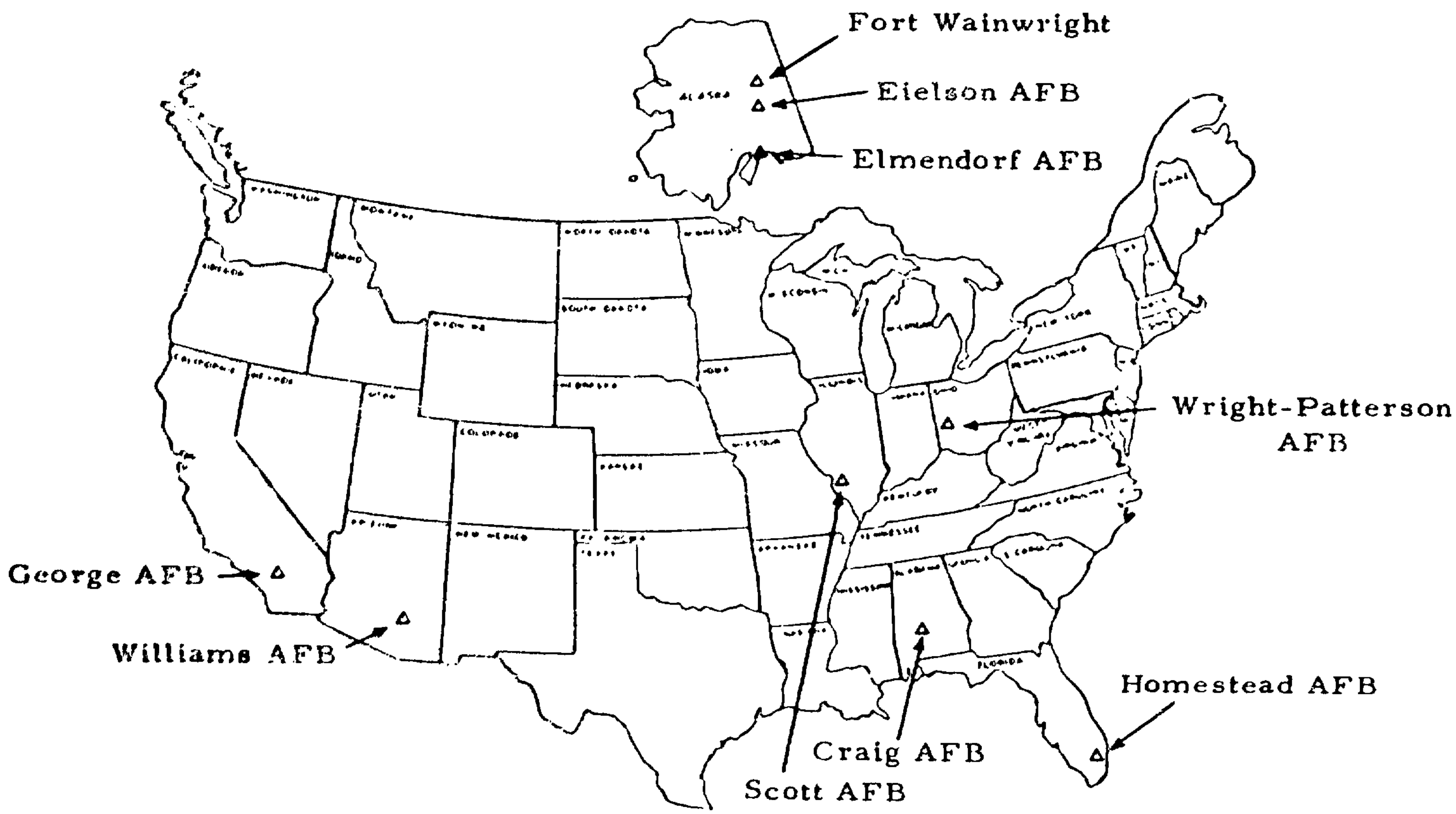


Fig. 2-2. Airfields Surveyed for Testing and Validation of the Pavement Condition Index [11:3]

survey and determination of the appropriate Pavement Condition Index 917:22). The five specific objectives (11:2) for having this pavement condition rating procedure include,

1) To indicate the present condition of the pavement in terms of structural integrity and operational surface condition.

2) To provide the base civil engineer with an objective and rational basis for determining maintenance and repair needs and priorities, and with a warning system for early identification and/or projection of major repair requirements.

3) To provide the major commands with a common index for use in comparing the condition and performance of pavements at all operational bases within their jurisdictions and in determining justification for major repair projects, and to provide a basis for in-depth pavement evaluation by the AFCEC [now the Air Force Engineering and Services Center, AFESC].

4) To provide Headquarters, U.S. Air Force (HQ, USAF) with a rational basis for assigning priorities for in-depth pavement evaluations by AFCEC [AFESC] specialty teams.

5) To provide feedback on pavement performance for validation or improvement of current pavement design procedures and maintenance practices.

The Pavement Condition Index is a composite rating, contingent upon the degree of deterioration identified in the pavement feature. This deterioration is a function of the type, level of severity and density of the distresses found in a given pavement section (11:30-31). Therefore, prior to developing the pavement condition index rating system, it was essential to first identify the types of distress existing in both concrete and asphalt or tar-surfaced pavement.

A comprehensive airfield pavement analysis was performed on 123 separate pavement sections from the nine airfields identified in Figure 2-2. Of these 123 sections, distress types, severities and densities were identified and measured from 40 jointed concrete pavement sections. The results indicate that 20 percent of the concrete slabs contained longitudinal/transverse/diagonal cracking, scaling/map cracking/crazing and patching less than five square feet. In addition, five percent of the slabs contained corner breaks, shrinkage cracks, joint spalling, and corner spalling, while three percent of the slabs were shattered. Popouts and "D" cracking were apparent in a few pavement sections and concrete pavement joint seal damage existed at most airfields. All distress types identified were found to occur at various levels of severity and density (11:27-28).

Block cracking was the most common type of flexible pavement distress identified in this analysis, appearing in approximately 20 percent of the area surveyed. Of the 83 asphalt and tar-surfaced pavement sections examined, alligator or fatigue cracking, longitudinal and transverse cracking, and raveling/weathering each occurred in three percent of the area. All distress types identified existed at varying levels of severity and density (11:28).

In all, 15 types of distress were identified in jointed concrete pavement and 16 types of distress were identified in asphalt or tar-surfaced pavement. These different types of distress are listed in Table 2-3. A complete description and severity level definitions

TABLE 2-3

Types of Distress in Airfield Pavement (12)

	Rigid Pavement	Flexible Pavement
1)	Blow-up	Alligator Cracking
2)	Corner Break	Bleeding
3)	Longitudinal/Transverse/ Diagonal Cracking	Block Cracking
4)	"D" Cracking	Corrugation
5)	Joint Seal Damage	Depression
6)	Patching (<5 sq ft)	Jet Blast
7)	Patching/Utility Cut	Joint Reflection Cracking
8)	Popouts	Longitudinal & Transverse Cracking
9)	Pumping	Oil Spillage
10)	Scaling/Map Cracking/Crazing	Patching
11)	Settlement/Faulting	Polished Aggregate
12)	Shattered Slab	Raveling/Weathering
13)	Shrinkage Cracking	Rutting
14)	Spalling--Joints	Shoving from PCC Slabs
15)	Spalling--Corner	Slippage Cracking
16)	N/A	Swell

for each type of pavement distress were developed (12).

Identifying the types of distress found in both rigid and flexible pavements provided the foundation necessary for developing an objective method of evaluating the relative condition of a pavement feature and assigning an airfield pavement condition rating.

PCI Development/Rigid Pavement

The development of a pavement condition rating procedure for rigid pavement involved an iterative process including three separate field tests and a final validation. The initial step was to review the available literature on concrete pavement distresses and then observe airfield pavement condition first hand. Tinker Air Force Base was chosen for this purpose. Based upon a preliminary survey of the pavement and a discussion with the engineering personnel at Tinker AFB, pavement features were divided into sample units of approximately 20 slabs each. This was determined a manageable area to examine, yet large enough to provide meaningful results (11:39).

Within each sample unit inspected, the density of a given distress type was calculated as the percentage of the sample unit (i.e. the number of slabs) having a particular distress at a specific level of severity. As indicated previously, definitions were developed to provide a standard reference for determining types of pavement distress and severity levels. Based upon this information, curves were derived, illustrating the relationship between subjectively estimated deduct and density values for each distress type and level of severity (11:39). Figure 2-3 is an example of a density versus deduct value curve for corner breaks. The deduct value is a quantitative indicator assigned to a particular type of distress and level of severity, based upon the overall impact that the distress has on the condition of the pavement (11:34). Composite deduct values were set consistent with the scale in Table 2-4 (11:38).

Once the distress types had been defined, and a relationship established between the density of a given type of distress, at a given severity level, and the deduct value, an expression was derived for calculating the Pavement Condition Index (11:40).

$$PCI = 100 - \sum_{i=1}^{P} \sum_{j=1}^{M_i} a(T_i, S_j, D_{ij}) \qquad [2\text{-}1]$$

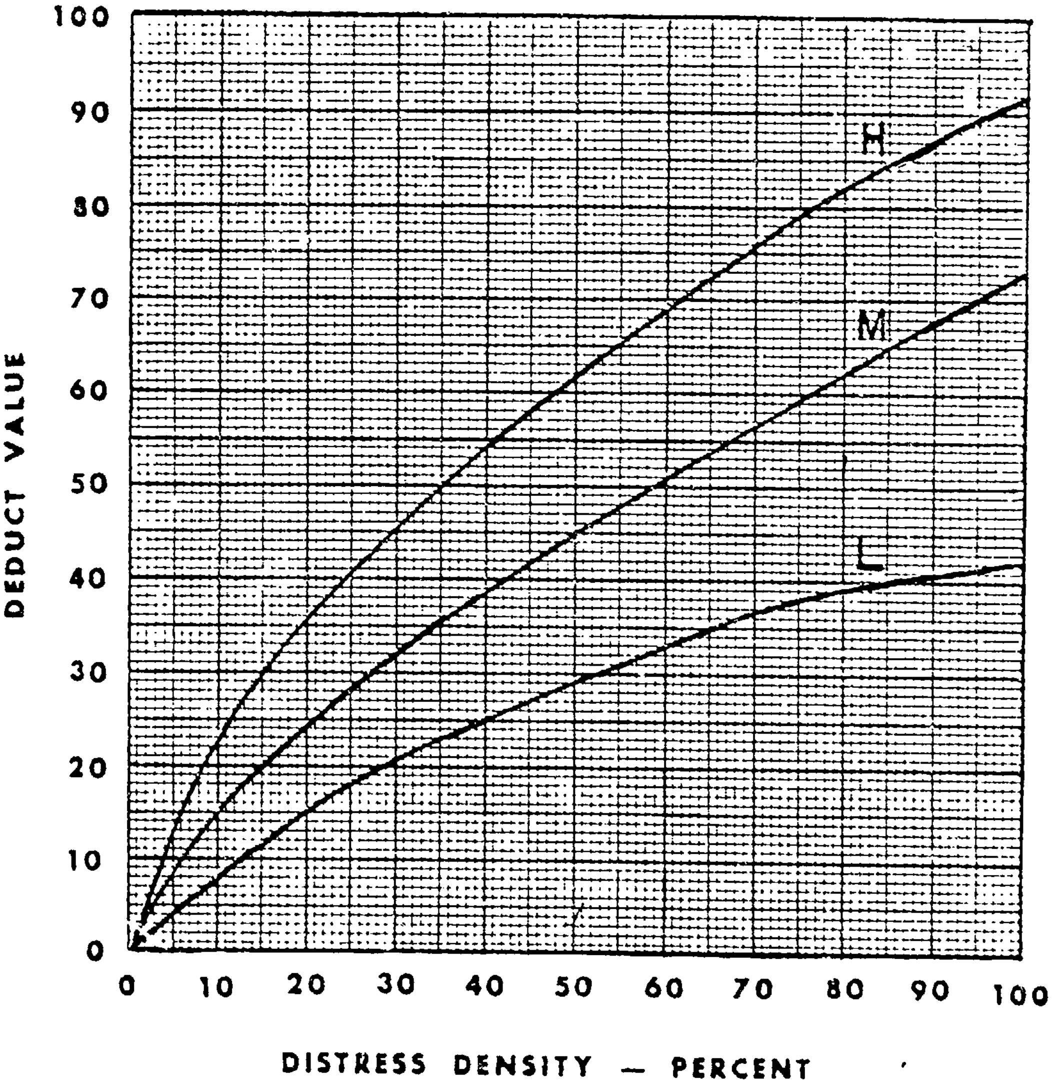
where: PCI = Pavement Condition Index at age and traffic since construction or overlay

P = total number of distress types

i = different distress types

M_i = number of severity levels of i type distress

j = different severity levels



Corner Break

Fig. 2-3. Jointed Concrete Pavement Deduct Values [17:4E]

TABLE 2-4

Descriptive Rating Scale [11:38]

Rating Scale	Descriptive Categories
100-86	Excellent
85-71	Very Good
70-56	Good
55-41	Fair
40-26	Poor
25-11	Very Poor
10- 0	Failure

$a(T_i, S_j, D_{ij})$ = deduct value for a given distress type T_i, at a severity level S_j, and density D_{ij}.

Based upon this expression, the PCI was determined by summing all the individual deduct values that existed in a pavement section, and subtracting them from 100 (11:40).

The first field test utilizing the above expression was conducted at Wright-Patterson AFB on five jointed concrete pavements. The types of distress, their levels of severity and overall density were recorded. From this information a PCI value was determined. In addition, four experienced pavement engineers subjectively rated and assigned a numerical rating to the pavement, consistent with the scale shown in Table 2-4. The apparent structural integrity and operational surface condition of the pavement constituted the major criteria for their evaluation. The results derived by the four engineers were combined to make up an average pavement condition rating, $\overline{PCR}$ (11:40).

When evaluating this initial field test, several major deficiencies were identified. First, a few of the definitions for distress types and severity levels did not adequately portray the actual conditions encountered in the field. To correct this, the definitions were revised based upon this new data. Second, when comparing the calculated PCI values with the $\overline{PCR}$, the PCI values were significantly lower than the $\overline{PCR}$ values. From information accumulated at Wright-Patterson AFB and Tinker AFB, the density versus deduct value curves were revised (11:40-42).

The second field test was conducted at Williams AFB and Craig AFB, on eleven jointed concrete pavement sections. The revisions resulting from the first field test were incorporated in this test. The second field test followed the same evaluation procedure as the first. Again, results from the test indicated that some of the definitions still did not clearly define existing conditions, and were, therefore, again revised. In addition, calculated PCI values for pavement sections containing several distress types were notably less than the determined $\overline{PCR}$ values. Further comparative analysis led to the conclusion that simply adding the individual deduct values for a pavement section having multiple distress types was not a valid procedure for arriving at a comparable $\overline{PCR}$ value. A correction factor applied to multiple distress sections was necessary to better predict the $\overline{PCR}$. By describing the relationship that existed between the sum of the individual deduct values and the corrected value (determined by subtracting the $\overline{PCR}$ from 100) a correction factor was obtained (11:44). Equation 2-1 was modified (11:31) to include this adjustment factor.

$$PCI = 100 - \sum_{i=1}^{P} \sum_{j=1}^{M_i} a(T_i, S_j, D_{ij}) F(t,d) \qquad [2\text{-}2]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

P = total number of distress types

i = different distress types

M_i = number of severity levels of i type distress

j = different severity levels

$a(T_i, S_j, D_{ij})$ = deduct value for a given distress type T_i, at a severity level S_j, and density D_{ij}

$F(t,d)$ = an adjustment factor for multiple distresses that varies with total summed deduct value (t) and number of deducts (d)

The third field test was conducted at Homestead AFB and Scott AFB. Fourteen pavement sections were surveyed and subjectively rated. The procedure for conducting the third field test was the same procedure followed for the previous two tests, with the revisions resulting from these tests incorporated in the third field test. This included calculating the PCI for concrete sections containing multiple distress types using an adjustment factor. An evaluation of the third field test revealed that all of the distress types and severity levels observed were adequately defined and the calculated PCI values corresponded closely with the $\overline{PCR}$ ratings (11:44).

Data collected from the first two field tests (i.e. Wright-Patterson AFB, Williams AFB and Craig AFB) was reevaluated using the rating procedure which included all the improvements. For the 30 sections of pavement at the five different airfields, the overall average $\overline{PCR}$ and PCI compared very closely, being within 2 points, and the mean absolute difference was relatively small, at 5.2 points (11:53).

Four additional airfields were selected for field validating the PCI rating system. These airfields included George AFB, Elmendorf AFB, Eielson AFB and Fort Wainwright. Ten concrete sections were surveyed. The $\overline{PCR}$ value was determined by four experienced pavement engineers, two from the Construction Engineering Research Laboratory and two major command pavement engineers. The test resulted in a mean absolute difference of 3.5 points between the $\overline{PCR}$ rating and the calculated PCI, a smaller difference than the 5.2 points determined from the previous 30 field tested pavement sections. The overall mean $\overline{PCR}$ differed from the mean PCI by 2 points (11:53).

Further analysis of the data collected on all 40 rigid pavement sections indicated a strong correlation between the calculated PCI and $\overline{PCR}$ rating, with a correlation coefficient of 0.97. Calculating the confidence interval, it was determined that there was 95 percent confidence the PCI value was within ± 5 points of the average pavement condition rating, and therefore, the final PCI procedure was determined to be a reliable pavement rating technique (11:56).

PCI Development/Flexible Pavement

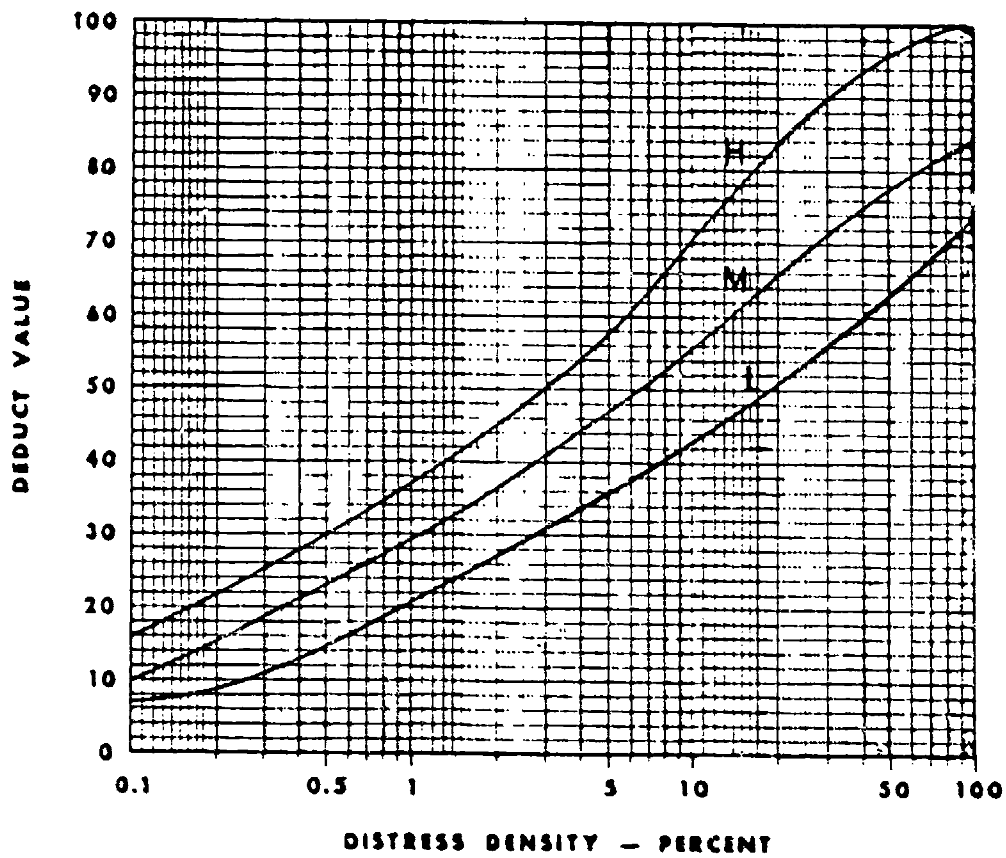
The development of the PCI for asphalt and tar-surfaced pavement followed very closely the methodology used to develop the PCI for concrete pavement. There were, however, several differences to be noted.

As with the rigid PCI, work to develop a flexible PCI procedure began at Tinker AFB. Background literature was reviewed concerning asphalt pavement distresses and initial descriptions of distress types and definitions of severity levels were developed. Pavement features were divided into 5000 square foot sample units, in a manner very similar to the 20 slab sample unit used for concrete PCI determination. Distress densities were determined by dividing the total surface area of the sample unit into the measured magnitude of the distress. Similar to the rigid PCI development, initial deduct values were determined. Deduct values were not matched with densities by continuous curves as was the case with rigid pavement.

Instead, a discrete method was used for density. Densities were grouped and deduct values assigned to each combination of severity level and density category according to the subjective scale in Table 2-4. PCI values were calculated using Equation 2-1 (11:62).

The first field test was conducted on four asphalt-surfaced pavements at Wright-Patterson AFB. The procedure for evaluating the calculated PCI was similar to that used for evaluating the rigid PCI. A subjective rating of the pavement, made by four experienced pavement engineers, resulted in a $\overline{PCR}$ value, based upon the rating scale depicted in Table 2-4. The evaluation concluded that only half of the calculated PCI values were reasonably close to the $\overline{PCR}$ values determined by the four engineers, and that the definitions of several distress types did not accurately describe the actual field conditions. Based upon this first test, deduct values and several distress definitions were revised. Additional analysis indicated that continuous density versus deduct value curves would provide a better result. Therefore, density versus deduct value curves were developed for all 16 distress types, at each level of severity (11:62-63). Figure 2-4 illustrates a sample density versus deduct value curve for alligator cracking in asphalt or tar-surfaced pavement.

The second field test was conducted on 17 asphalt and tar-surfaced pavement sections located at Williams AFB and Craig AFB.



Alligator Cracking

Fig. 2-4. Asphalt or Tar-Surfaced Pavement Deduct Values [17:40W]

The pavement sections were evaluated as before, including the revised procedure resulting from the first field test. The results indicated that several definitions for pavement distress types needed further revision and a few sections containing multiple distress types had PCI values significantly less than the $\overline{PCR}$ values determined by the engineering team. As with the rigid PCI, analysis of the data indicated that the sum of all the individual deduct values in a multiple distress pavement section must be adjusted to reflect the number of deducts and magnitude of the total deduct value. An adjustment factor was developed for flexible pavements, as was necessary for rigid pavements (11:63-65).

The third field test was conducted at Homestead AFB and Scott AFB. Seventeen pavement sections were evaluated using procedures previously employed, in addition to the revisions made thus far. The PCI values were calculated using Equation 2-2. The results indicated that all the distress types observed had been adequately described in existing definitions. Although several deduct value curves require some adjustments, the calculated PCI values generally corresponded closely with the $\overline{PCR}$ ratings for each pavement section (11:68).

New PCI values were calculated from the data collected during the first two field tests, using the improved procedure. The mean $\overline{PCR}$ and PCI for all 38 pavement sections compared very closely, having only a one point difference. The mean absolute difference between the $\overline{PCR}$ and PCI was relatively small, being 4.8 points (11:75).

A field validation of the PCI procedure was conducted at three additional bases: George AFB, Elmendorf AFB, and Eielson AFB. A total of 35 asphalt and tar-surfaced pavement sections were surveyed. The results indicated that the mean absolute difference between the $\overline{PCR}$ rating and the calculated PCI was 3.4 points, 1.4 points less than the value obtained from the 38 pavement sections previously field tested. The overall mean values compared very closely, with a total difference of only two points. Assuming that the difference between the PCI and $\overline{PCR}$ values was normally distributed, a confidence interval was determined. There was 95 percent confidence that the calculated PCI was within $\pm$ 4.75 points of the subjective $\overline{PCR}$ rating made by the group of experienced pavement engineers. The final PCI procedure was determined to be a reliable pavement condition rating technique for flexible airfield pavements (11:75-81).

<u>PCI Procedure</u>

Based upon the results obtained by the Construction Engineering Research Laboratory study, and the obvious usefulness of the PCI procedure for evaluating airfield pavements, the Air Force has chosen to adopt this system. It is currently the major command civil engineer's responsibility to ensure that each base within their jurisdiction accomplishes an airfield pavement condition survey on a recurring five year cycle, using the PCI procedure (17:8). The procedure followed, for both concrete and asphalt or tar-surfaced pavements, includes eight steps, as outlined in Figure 2-5. Similar to the earlier survey methods, before a condition survey can be accomplished, the airfield pavement must be separated into features, with each feature inspected as a separate entity.

Dividing each pavement feature into sample units is the first step in the PCI survey procedure. A sample unit for jointed concrete pavement is approximately 20 slabs, while a sample unit for asphalt or tar-surfaced pavement is approximately 5000 square feet. Each sample unit is then visually inspected, and a record maintained of the types of distress identified and their apparent levels of severity and densities. For each distress type and level of severity identified in a sample unit, deduct values are determined from the appropriate density versus deduct value curves. The Total Deduct Value (TDV) is obtained by summing the individual deduct values for a given sample unit. An adjustment factor is applied to the TDV for sample units containing multiple distresses, with individual deduct values greater than

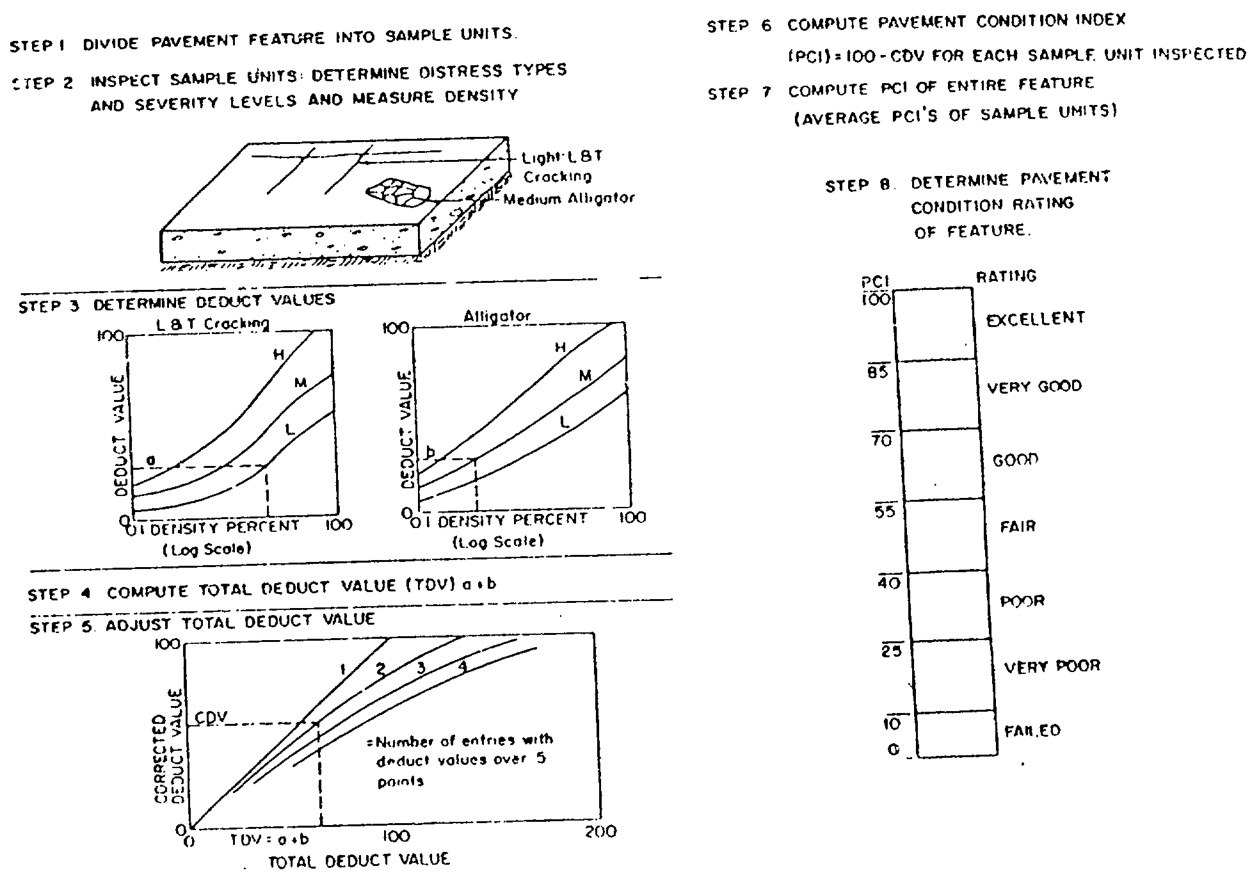


Fig. 2-5. Steps for Determining the PCI of a Pavement Feature [17:40A]

5 points, to obtain a Corrected Deduct Value (CDV). Corrected deduct value curves for rigid and flexible pavements are shown in Figures 2-6 and 2-7 respectively. The PCI for each sample unit is calculated using the following expression:

$$PCI = 100 - CDV \qquad [2\text{-}3]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

CDV = Corrected Deduct Value

However, should it happen that an individual deduct value exceeds the CDV for a given sample unit, then the greater value of the two will be used in Equation 2-3. The PCI for the entire feature is determined by averaging the individual sample unit PCI's. A descriptive appraisal of the condition of the pavement feature is assigned in accordance with the scale shown in Figure 2-5, Step 8 (17:23-24).

Since implementing the PCI rating system, the Air Force has adopted additional refinements designed to make the system even easier to use. In some cases, individual base pavement engineers have found that certain resource limitations (i.e. manpower, time or money) have prevented them from performing a PCI survey on an

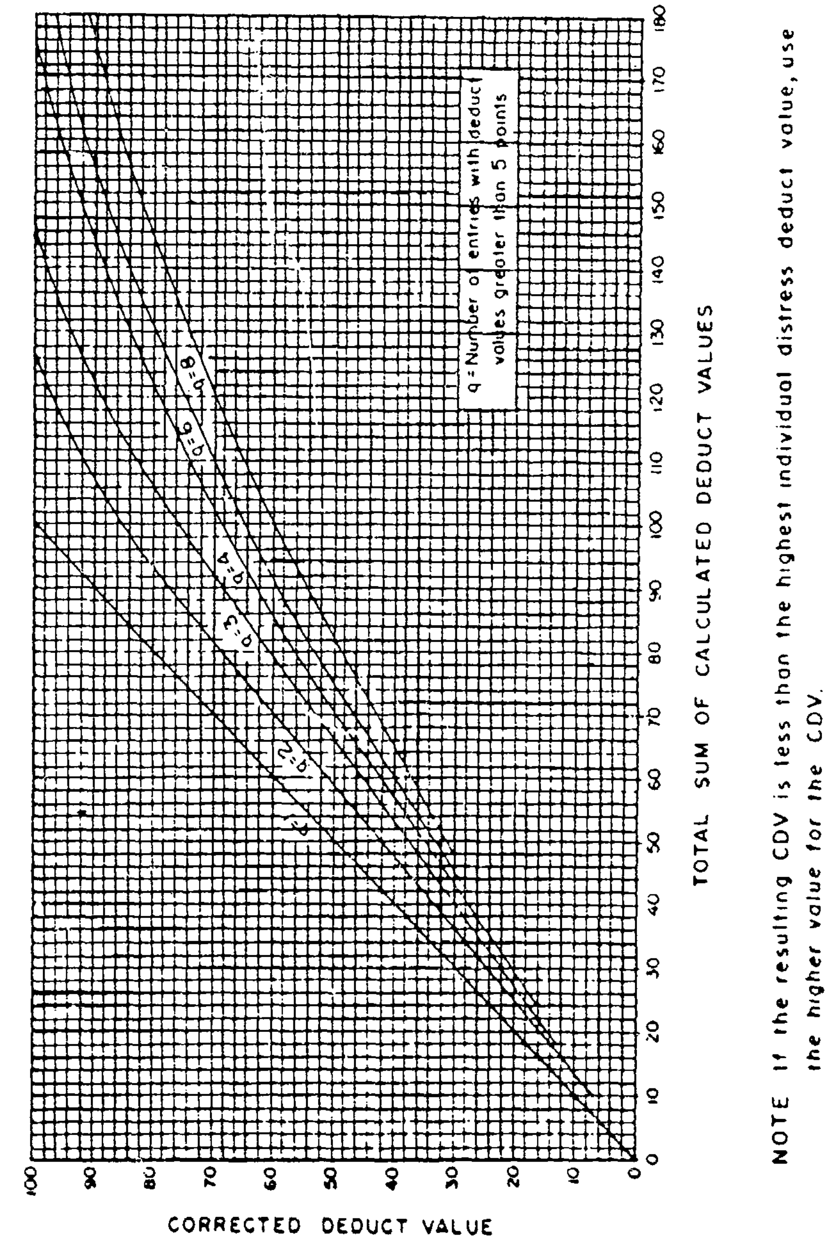


Fig. 2-6. Corrected Deduct Values for Jointed Concrete Pavements [17:40S]

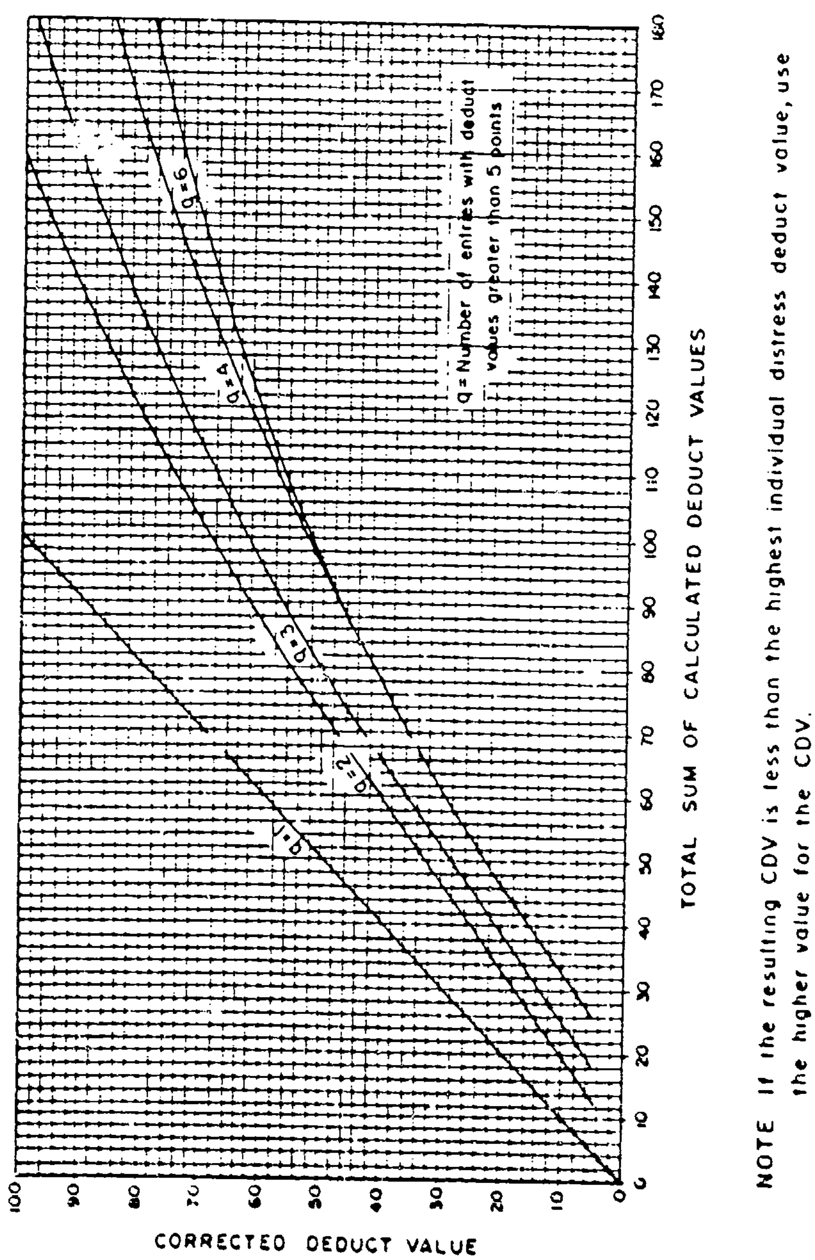


Fig. 2-7. Corrected Deduct Values for Asphalt or Tar-Surfaced Pavements [17:40mm]

exceptionally large pavement feature. In such circumstances, the pavement engineer has available to him, a method for inspecting only a portion of the sample units in a feature, while still generating a reliable estimate of the feature's condition. This method is known as the "Random Sampling Method for Condition Survey," and has been designed to reduce the time necessary to inspect a pavement feature, without adversely impacting upon the accuracy of the results (17:28-34).

A computer program for computing PCI values is also available in the Base Engineering Automated Management System (BEAMS). The program provides a means for rapidly computing PCI values for sample units and features, in addition to summarizing distress data (17:35).

Model Development

During fiscal year 1977, efforts were initiated to develop airfield pavement predictive models, designed to assist the pavement engineer in selecting the most economical maintenance and repair (M&R) alternative, among those available (13:1).

> The principle objectives of the prediction models are to forecast the PCI and key distresses of an existing pavement feature to predict the consequences of a variety of possible M&R alternatives. Such capability would aid greatly in deciding what M&R alternative to recommend for specific pavement features. Ideally, the models should be capable of forecasting

PCI and key distresses [separate models that are not addressed in this study] for the following actions: application of routine M&R, application of major M&R, placement of an overlay, and proposal of an aircraft mission change [13:40].

Since 1977, several models have been developed and tested for their ability to accurately forecast the condition of the airfield pavement, given various independent pavement related variables. The Pavement Condition Index is used as the basic determinate for evaluating the condition of the pavement and the single dependent variable in these models. This section of the review will include a brief discussion surrounding the development of the PCI predictive models and a look at the iterative process resulting in what appears to be the best predictor for PCI, currently available.

Prior to developing any sort of model, it was first necessary to obtain a reasonable data base from which to work. From field surveys conducted during fiscal years 1976 thru 1978, a project team from the Construction Engineering Research Laboratory (CERL) collected detailed distress data, including PCI and historical information from 19 Air Force bases. These bases are depicted on Figure 2-8. Most of the data was obtained from base pavement evaluation reports and direct discussions with base and major command pavement engineers. This information included data collected from concrete pavement sections having no overlay, concrete sections with a concrete overlay, concrete sections with an asphalt overlay, asphalt pavement

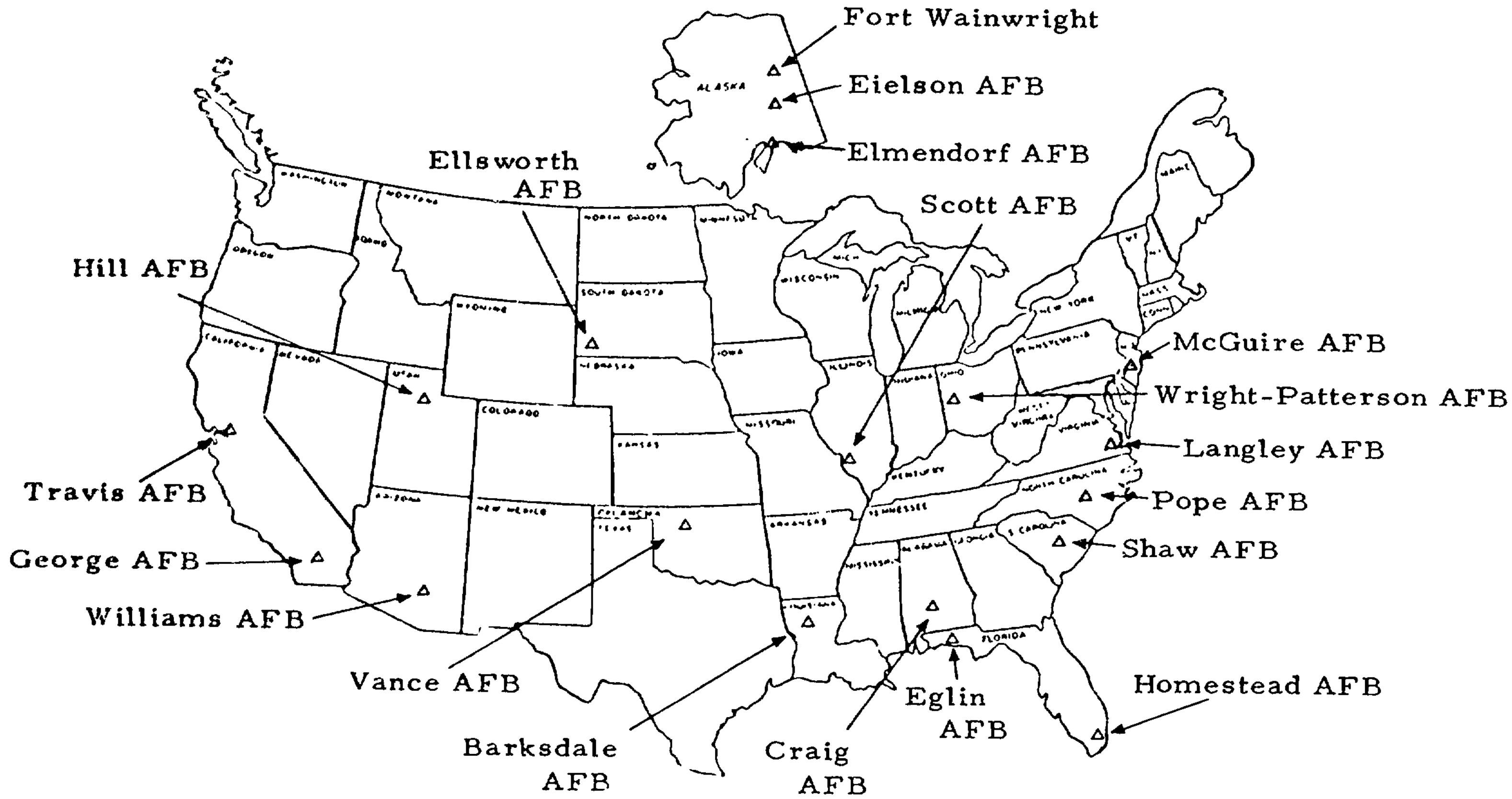


Fig. 2-8. Airfields Surveyed for Developing the Initial PCI Prediction Models [13:9]

with no overlay and asphalt pavement with an asphalt or tar-surfaced overlay (13:8). The data collected is summerized in Tables 2-5 and 2-6.

The data on concrete sections having no overlay came from surveys conducted at all 19 bases with the exception of Fort Wainwright, and Eielson, Craig, Eglin, and Pope Air Force Bases. A total of 76 concrete pavement features were surveyed, from which data was kept for analysis on 67 of the features. Nine of the features were deleted due to a lack of complete information (13:8). The pavement thicknesses ranged from 6 to 22 inches, with a mean of 12.3 inches. The average age was approximately 19 years, with some pavement features two years old and others older than 34 years (13:11). The PCI ranged from 36 to 97, with an overall mean of 70.6 (13:14).

Five pavement features were surveyed having concrete overlaid with concrete. The features inspected were located at Langley, Barksdale and Williams Air Force Bases. The overlays ranged in thickness from eight to ten inches, with a mean of 8.6 inches. The average age of the original slab was 33 years, while the overlays averaged 17 years. The mean PCI was 75 (13:20).

Data collected on concrete pavement overlayed with asphalt came from 19 pavement features located at Wright-Patterson, Scott, Williams, Barksdale, Shaw, Hill, Ellsworth, Elmendorf, and Langley

TABLE 2-5

Summary of Data for Concrete Pavement Features
With and Without an Overlay (13:8-21)

Factor	Concrete		Concrete/Concrete Overlay		Concrete/Asphalt Overlay	
	Mean	Range	Mean	Range	Mean	Range
PCI	70.6	36-97	75	60-90	70.5	48-87
Cracking (% Slabs)	16.6	0-71	24	0-56	---	---
Age Original Slab (Years)	19	2-34	33	22-37	28.7	17-37
Age of Overlay (Years)	---	---	17	12-23	9.5	4-21
Original Slab Thickness (Inches)	12.3	6-22	10.8	6-19	9.8	6-21
Subbase Thickness (Inches)	---	---	0	0	6.3	0-30
Overlay Thickness (Inches)	---	---	8.6	8-10	2.7	1.5-8.0
Modulus of Rupture (psi)	739	520-922	730	700-800	711	600-850
K-Value (pci)	163	30-500	98	60-130	197	60-500
Freezing Index (Degree Days Below 32°F)	99	0-678	0	0	392	0-2070
Average Annual Rainfall (Inches)	30.7	3.5-56	34.8	7-47	---	---
Average Annual Temperature (°F)	58.3	46-75	63.0	60-69	52.8	31-69
Tensile Stress/Flexible Strength	0.37	0.15-0.80	0.36	0.23-0.52	0.70	0.28-1.61

TABLE 2-6

Summary of Data for Asphalt Pavement Features With and Without an Overlay (13;23-39)

Factor	Asphalt		Asphalt/Asphalt Overlay	
	Mean	Range	Mean	Range
PCI	61	12-100	56.8	17-83
Alligator Cracking (Percent)	6.4	0-51	5.6	0.09-26.5
Patching (Percent)	0.135	0-0.6	0.85	0-4.7
Age of Original Construction (Years)	18	0.5-35	28	19-35
Age of Overlay (Years)	---	---	9.4	4-23
Original Thickness of ACC (Inches)	3.9	2-7.5	4.2	2.5-6.5
Thickness of ACC Overlay (Inches)	---	---	2.4	0.5-16.5
Base Thickness (Inches)	9.5	2-27	8.0	4-16.5
Subbase Thickness (Inches)	9.4	0-28	8.2	0-42
Base CBR (Percent)	71	24-100	56	24-100
Subbase CBR (Percent)	24.7	0-100	26	0-100
Subgrade CBR (Percent)	21.8	4-80	20	5-50
Freezing Index (Degree Days Below 32°F)	175	0-2070	1095	0-5320
Precipitation (Inches)	31.7	7-56	29.6	3.5-47
Average Annual Temperature (°F)	59.7	36-69	50.8	26-61
Average Annual Temperature Range (°F)	40.0	15-51	22	19-29
Average Daily Temperature Range (°F)	21.7	15-31	46	35.61
Load Repetition Factor at ACC/Base Interface	0.70	0.34-1.30	.83	0.43-1.43
Load Rep. Factor at Subgrade Level	1.48	0.72-2.83	1.25	0.59-3.0
Load Rep. Factor at Subgrade Level Based on Equivalent Thickness	1.89	0.818-3.06	1.50	0.73-3.42

Air Force Bases. The average age of the original pavement was 29 years, with a mean thickness of 9.8 inches. The average age of the asphalt overlays was 9.5 years, with a mean thickness of 2.7 inches (13:20). The PCI values ranged from 48 to 87, having a mean of 70.5 (13:21).

Reliable data on asphalt pavement without an overlay was collected at ten Air Force bases, including: Pope, McGuire, Williams, Vance, Homestead, Elmendorf, Ellsworth, Scott, Travis, and Hill. Overall, 26 features were surveyed, having thicknesses ranging from 2 to 7.5 inches, with a mean of 3.9 inches. The age of the pavements ranged from 0.5 to 35 years, averaging 18 years, with the mean PCI of 61 (13:23-32).

A total of eleven flexible pavement features having asphalt or tar-surfaced overlays were surveyed at Pope, George, McGuire, Eielson, Ellsworth, Scott, and Hill Air Force Bases. The original pavements averaged 28 years in age and 4.2 inches in thickness, while the average age and thickness of the overlays were 9.4 years and 2.4 inches respectively. The overall mean PCI was 56.8 (13:38-39).

In developing the initial PCI predictive models, the first step was to identify the principle independent variables thought to have an impact on the condition of the airfield pavement. This identification was based on a review of all applicable literature on the subject, discussions with base and major command pavement engineers, and the previous experience of the project staff (13:40). Table 2-7 lists those major independent variables considered important in developing the initial PCI predictive model for rigid pavement (i.e. concrete pavement with and without an overlay), and also includes variables thought to effect the condition of rigid pavement, but which were not included in the initial analysis due to resource and/or time constraints (13:40).

Variable measurements were obtained directly from the airfield pavement data base previously developed (Tables 2-5 and 2-6), or were derived based upon this data. The information was then coded and prepared for computer processing. The Statistical Package for the Social Sciences (SPSS) was used for all data analysis. A correlation matrix was developed to identify any significant relationships between the independent variables such as age, thickness, etc., and the dependent variable, PCI. A stepwise regression was then accomplished to formulate the prediction model (13:40).

Stepwise regression is a screening approach to model building, given a large number of independent variables having possible multivariable interactions (8:410). As a first step in this process, the computer fits all possible single-variable models of the form

TABLE 2-7

List of Independent Variables Considered in the Development of the Concrete Pavement PCI Prediction Models [13:41]

I. Variables used to develop models (data obtained from each feature):

AGE	(Time Since Original Construction of Slab) -- Years
SLAB	(Concrete Slab Thickness) -- Inches
BASE	(Granular Subbase Thickness) -- Inches
JSL	(Longest Joint Spacing) -- Feet
JSS	(Shortest Joint Spacing) -- Feet
MR	(Modulus of Rupture of Concrete) -- psi
K	(K-Value of Slab Foundation) -- Pounds/Cubic Inch
ACWGT	(Gross Maximum Weight of Critical Aircraft Using Feature) -- kips
FAT	(Ratio of Stress to Modulus of Rupture [Strength] x 100)
PEI	(Pavement Evaluation Index)
FEAT	(Type of Feature: Runway, Taxiway, Apron)
AREA	(Traffic Area: A, B, C)
PS	(Usage of Feature: Primary or Secondary)
FI	(Freezing Index) -- Degree Days Below 32°F
PPT	(Average Annual Precipitation) -- Inches
TEMP	(Average Annual Temperature) -- °F
SR	(Slab Replacement) -- Percent of Total Slabs
PATCH	(Large Patching) -- Percent of Total Slabs
ACOL	(Existence of AC Overlay)
PCOL	(Existence of Concrete Overlay)

II. Other variables considered which had important effects on PCI data, but were not obtained because of cost, time required, or lack of availability:

Number of Aircraft Passes Over Feature
Joint Design
Joint Load Transfer Efficiency
Several Additional Climatic Variables (Number of Freeze-Thaw Temperature Gradients Through Slab, Monthly Distribution of Precipitation, etc.)
Drainage Condition of Pavement Feature

$$Y = \beta_0 + \beta_1 X_1 \qquad [2\text{-}4]$$

to the data and then tests the hypothesis, $\beta_1 = 0$, against the alternative, $\beta_1 \neq 0$, using the F-test (or equivalent T-test). The independent variable, X_1, producing the largest F value is determined the best single-variable predictor of the dependent variable, Y. The computer then fits all possible two-variable combinations of the form

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \qquad [2\text{-}5]$$

and tests the hypothesis $\beta_2 = 0$, against the alternative $\beta_2 \neq 0$. The independent variable, X_2, producing the largest F value is retained. The computer then rechecks the F value for β_1, after $\beta_2 X_2$ is added to the model, to ensure that it remains significant for predicting the dependent variable Y, based upon a previously specified level of significance. This process is continued until all variables having a given level of significance have been included in the model. The result of the stepwise procedure is a model containing only variable coefficients with F values significant at a specified level (8:411-412).

In developing the concrete PCI prediction model, the criterion used for determining how many variables to retain in the regression model was to include only those variables whose estimated coefficients were significant at the 0.05 level, using the F-test (13:42). The following equation (13:52) was determined to be the best PCI predictor for rigid pavement, based upon the variables analyzed and criterion specified.

$$PCI = 100.0 - AGE\,[0.01967\,FAT - 0.02408\,SR + 0.001051\,JSL(JSS) + 0.94191\,ACOL + 0.03475\,PATCH + 2.91238 - 6.001775FI - 0.04066\,TEMP] \qquad [2\text{-}6]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

AGE = time since original construction or, if overlaid, time since overlay construction (years)

FAT = (ratio of interior slab stress to modulus of rupture) x 100

SR = slab replacement (percent total slab)

JSL = longest joint spacing (feet)

JSS = shortest joint spacing (feet)

ACOL = 1 if asphalt overlay and 0 if no asphalt overlay

PATCH = slabs containing large patches ($\geqq$ 5 square feet), percent of total slabs, or percent of total area patched if overlaid with asphalt

FI = freezing index (degree days below 32°F)

TEMP = average annual temperature (°F)

This equation was based on data collected from 91 features, and has a coefficient of determination of 0.37, with a standard deviation of 10.5 (13:52).

An evaluation of the predictive model for rigid pavement concluded that it meets the appropriate boundaries for predicting the PCI between 0 and 100, and that the coefficients present in the model appear to be reasonable (i.e. the PCI decreases as the pavement ages). The model also appears to be appropriate from the standpoint that it represents a realistic situation, and various sensitivity tests have indicated the model is usable (13:54-56).

The method used to develop the initial PCI prediction model for flexible pavement was very similar to that used for the rigid pavement. From a review of the appropriate literature, a discussion with base and major command pavement engineers, and based upon the previous experience of the project team, a list of major variables thought to affect the PCI value for flexible pavement was developed (13:71). The variables are listed in Table 2-8. A stepwise regression analysis was performed to identify those variables having a significant correlation with the dependent variable, PCI (13:71).

TABLE 2-8

List of Independent Variables of Asphalt Pavement [13:42]

AC (No overlay)	
AGEOR	(Ages of Pavement) -- Years
TAC THICK	(Total AC Thickness) -- Inches
B THICK	(Base Thickness) -- Inches
SB THICK	(Subbase Thickness) -- Inches
B CBR	(Base CBR) -- Percent
SB CBR	(Subbase CBR) -- Percent
SG CBR	(Subgrade CBR) -- Percent
ACWGT	(Aircraft Weight) -- kips
AREA	(Traffic Area, Type A=1, Type B=2, Type C=3)
P/S	(Primary=1, Secondary=2)
Feat	(Feature, Apron=1, Taxiway=2, Runway=3)
ZONE	(Environmental Zone: Wet, Freeze=1, Seasonally Wet, Freeze=2 Dry, Freeze=3, Wet, Freeze-Thaw=4, Seasonally Wet, Freeze-Thaw=5, Dry, Freeze-Thaw=6, Wet, No Freeze=7, Seasonally Wet, No Freeze=8, Dry, No Freeze=9)
FI	(Freezing Index, Degree Days (Below 32°F))
PPT	(Precipitation) -- Inches
AAT	(Annual Average Temperature) -- °F
ADTR	(Annual Daily Temperature Range) -- °F
AATR	(Annual Average Temperature Range) -- °F
α_{AC}	(Load Repetition Factor for AC Thickness/ Interface Base)
α_{SG}	(Load Repetition Factor for Subgrade)
T Equiv Thick	(Total Equivalent Thickness of Pavement) -- Inches
α Equip Thick	(Load Repetition Factor for Total Equivalent Thickness of Pavement)
TA	(Total Alligator Cracking) -- Percent of Sample Units
PATCH	(PATCHING) -- Percent of Sample Unit

TABLE 2-8--Continued

AC pavement with AC overlay

Variables for computing PCI prediction model were the same as the AC pavement variables with no overlay plus four more variables: AGEOL, AGECOL, ACOL Thick, and TAC Thick.

AGEOL	(Age after Overlay) -- Years
AGECOL	(Age between Original Construction and Overlay) -- Years
ACOL Thick	(AC Thickness for Overlay) -- Inches
TAC Thick	(Total AC Thickness) -- Inches
Age	(Age after Original Construction or Overlay)-- Years

Originally, two separate models were developed, one each for asphalt pavement and asphalt pavement having an overlay. The variables in Table 2-8 were then integrated to produce a single combined model for flexible pavements (13:96).

$$PCI = 100 - AGE\,[1.487/\alpha_{sg} + 0.143\,AGECOL + 6.56/TAC - 1.23\,\alpha_{ac}] \qquad [2\text{-}7]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

AGE = age since original construction or, if overlaid, time since overlay construction (years)

α_{sg} = load repetition factor determined at the subgrade level; α_{sg} is a function of total pavement thickness above the subgrade, subgrade CBR, and the tire contact area and tire pressure of an equivilant single wheel

AGECOL = age between the time the pavement was constructed and the time it received the last overlay; equals zero if no overlay

TAC = total asphalt thickness in inches, including overlay, if any

α_{ac} = load repetition factor determined at the asphalt/ base interface

This model was based on 37 pavement features, 26 from asphalt pavements without an overlay and 11 with an overlay. The coefficient of determination for the combined model was 0.62, with a standard deviation of 14.4 (13:91, 100).

An evaluation of the combined PCI predictive model for flexible pavements revealed that the model meets the parameters established for predicting PCI between 0 and 100. In addition, the variables incorporated in the equation appear to be appropriate and the signs for all the coefficients agree with engineering experience (13: 96).

Generally, both models (the rigid model and the combined flexible pavement model) reasonably predicted the PCI values given various independent factors, such as structural design, aircraft loading, the material properties of the pavement, the subgrade properties, and differing climate conditions. It was recommended by the Construction Engineering Research Laboratory's Project Staff that these only be considered as tentative models, based upon the fact that additional data is necessary before developing comprehensive and reliable PCI predictive models, useful for selecting various maintenance and repair alternatives (13:119). "However, the results did clearly show that more definitive models could be developed if a broader data base were available [15:2]."

Subsequently, a comprehensive data collection program began in fiscal year 1980 (15:2). Airfield pavement data was obtained from 12 Air Force bases, depicted in Figure 2-9. A total of 327 features from different major commands, having different climate and traffic conditions, and including both rigid and flexible pavement, were considered. The data was obtained from airfield evaluation reports, construction records, historical records, and observations made by long-time employees concerning the past and current aircraft traffic flow (15:4-5). In addition to the raw data collected, several "mechanistic variables" were computed. Edge stress for concrete slabs was computed by using the H-51 computer program (7). Radial strain, vertical stress on the base course, surface deflection and vertical strain on top of the subgrade was computed for asphalt pavements, using the Bitumen Structures Analysis in Roads (BISAR) computer program (4).

Initially, all of the variables that could possibly effect the condition of airfield pavements were considered in developing the next phase of predictive models. This list was later reduced to include only those variables which could be obtained with a reasonable

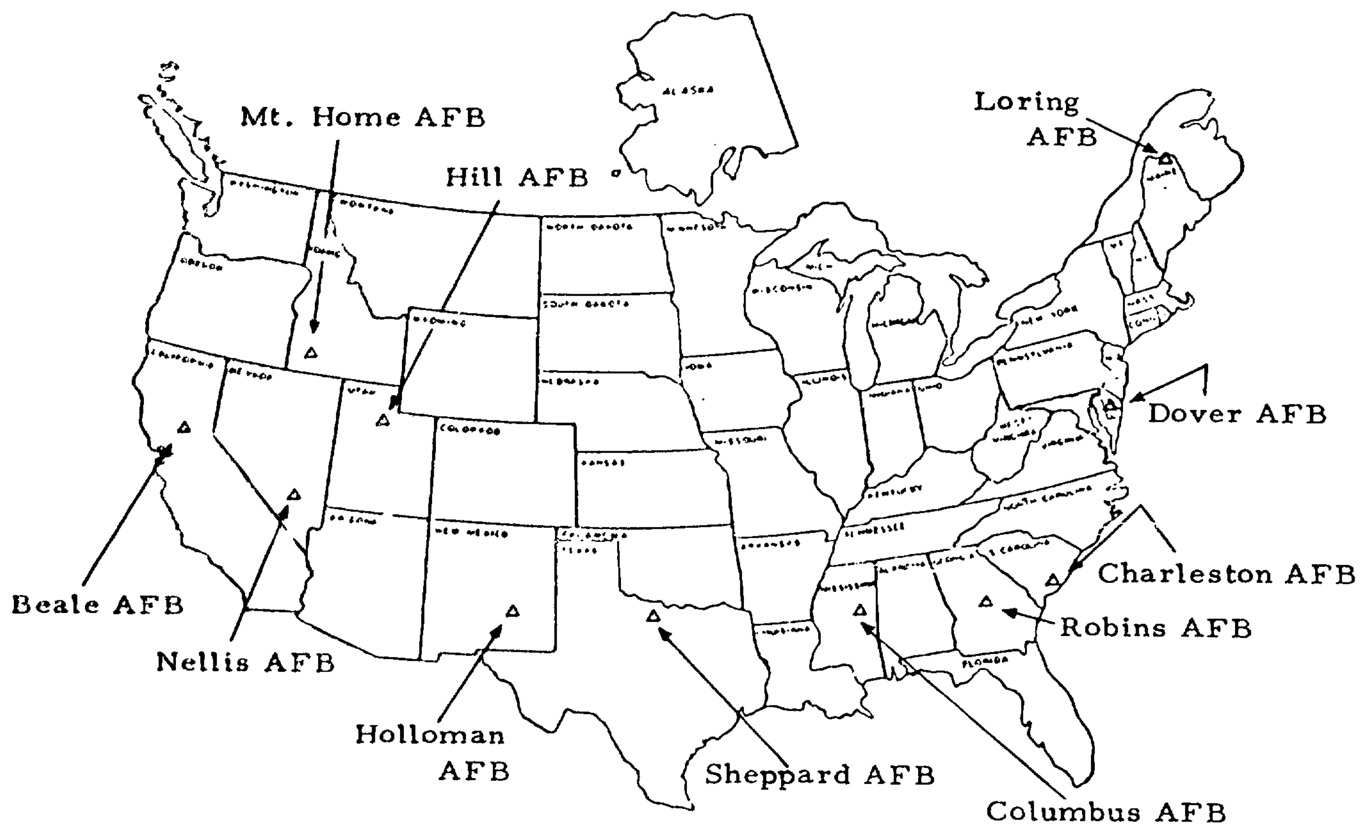


Fig. 2-9. Airfields Surveyed for Developing the Improved PCI Prediction Models [15:82]

degree of accuracy (15). Tables 2-9 and 2-10 list the raw data variables considered. For purposes of consistency and to reduce some of the difficulty in processing a large quantity of data, computer coded data sheets were used to collect the required information. A summary of the data collected is contained in Tables 2-11 and 2-12.

Prior to initiating the model building process, both the raw data variables and the computed mechanistic variables were examined to identify any obvious discrepancies. Based upon the engineering judgement of the Construction Engineering Research Laboratory's Project Staff, data collected from a number of pavement features was eliminated from the data base used in formulating the models. Any data which appeared exceptional, or where there was a question concerning its accuracy, was removed from the data base and not used in the model building process. As a result, many pavement features were not considered when developing this next phase of PCI prediction models. This included all pavement data collected at Wright-Patterson AFB (9).

The SPSS stepwise regression method was used in developing the PCI prediction model for concrete pavement (15:13). Originally, a single model was developed for concrete pavement without an asphalt overlay (15:14). This model was later refined to predict PCI values for concrete pavement with and without an overlay (9).

TABLE 2-9

List of Raw Data Variables Considered in the Development of the Concrete Pavement PCI Prediction Model [15:8]

FYTYPE	(Feature Type: Runway, Taxiway, Apron)
FWIDTH	(Feature Width) -- Feet
FLENGTH	(Feature Length) -- Feet
FAREA	(Feature Area) -- Square Feet
SURDATE	(Original Surface Placement Date) -- Year
SURTHICK	(Original Surface Thickness) -- Inches
SURMR	(Original Surface Modulus of Rupture) -- psi
BDATE	(Base Layer Placement Date) -- Year
BMATL	(Base Material) -- Coded
BTHICK	(Base Thickness) -- Inches
BK	(K-Value on Top of Base) -- Pounds per Cubic Inch
BMR	(Base Modulus of Rupture, Cement Stabilized Only) -- psi
JSL	(Slab Length) -- Feet
JSW	(Slab Width) -- Feet
LJDPL	(Joint Design, Longitudinal Paving Lane) -- Coded
TJD	(Joint Design, Transverse) -- Coded
JFILLER	(Joint Filler, Original) -- Coded
SGMOD	(Subgrade Modification, if any) -- Coded
SGMATL	(Subgrade Material) -- Coded
SGK	(K-Value on Top of Subgrade) -- psi
HZOTABLE	(Depth of Water Table) -- Feet
PMSTART	(Present Mission Starting Date) -- Year
PMSTOP	(Present Mission Ending Date) -- Year
PMCAT1	(Amount of Usage Category #1 Accounts for This Pavement Feature) -- Percentage
PMANOPS	(Number of Repetitions Per Year This Pavement Feature) -- Percentage
CRFILL	(Overall Maintenance Policy) -- Coded
JTCRFLI	(Joint/Crack Fill Interval) -- Years
SRAREA	(Slabs Replaced) -- Percentage of Total Area
SRAGE	(Average Age of Replaced Slabs) -- Years
FI	(Average Freezing Index) -- Degree Days Below 32°F

TABLE 2-9--Continued

FTC1	(Average Annual Number of Freeze-Thaw (F-T) Cycles at 1-Inch Depth)
FTC2	(Average Annual Number of F-T Cycles at 2-Inch Depth)
FTC3	(Average Annual Number of F-T Cycles at 3-Inch Depth)
AAPREC	(Average Annual Precipitation -- Inches
AATEMP	(Average Annual Temperature) -- °F
ADTR	(Average Daily Temperature Range) -- °F
AATR	(Average Annual Temperature Range) -- °F
THORMI	(Thornthwaite Moisture Index)
AASR	(Average Daily Solar Radiation) -- Langleys
JULSR	(July Daily Solar Radiation) -- Langleys
PEVAP	(Potential Evaporation) -- Inches
OPEVAP	(Open Water Evaporation Potential) -- Inches
AAWS	(Average Annual Wind Speed) -- mph

TABLE 2-10

List of Raw Data Variables Considered in the Development of the Asphalt Pavement PCI Prediction Model [15:9-10]

FTYPE	(Feature Type: Runway, Taxiway, Apron)
FWIDTH	(Feature Width) -- Feet
FLENGTH	(Feature Length) -- Feet
FAREA	(Feature Area) -- Square Feet
SURDATE	(Original Surface Placement Date) -- Year
SURPASPH	(Surface Layer Percent Asphalt)
SURAVOID	(Surface Layer Air Voids) -- Percent
SURFVOID	(Surface Layer Filler Voids) -- Percent
SURMS	(Surface Layer Marshall Stability) -- Pounds
SURFLOW	(Surface Layer Flow Measurement) -- 0.01 Inches
SURPEN	(Surface Layer Penetration) -- mm X 10^{-1}
BDATE	(Base Layer Placement Date) -- Year
BMATL	(Base Material) -- Coded
BTHICK	(Base Thickness) -- Inches
BCBR	(Base Layer California Bearing Ratio [CBR])
BMS	(Base Layer Marshall Stability) -- Pounds
BDENSE	(Base Layer Density) -- Percent of Optimum
BMOIST	(Base Layer Moisture Content) -- Percent
JSL	(Slab Length) -- Feet
JSW	(Slab Width) -- Feet
LJDPL	(Joint Design, Longitudinal Paving Lane) -- Coded
TJD	(Joint Design, Transverse) -- Coded
JFILLER	(Joint Filler, Original) -- Coded
SGMOD	(Subgrade Modification, if any) -- Coded
SGMATL	(Subgrade Material) -- Coded
SGCBR	(Subgrade CBR)
PI	(Plasticity Index for Subgrade)
LL	(Liquid Limit for Subgrade)
SGOPTMC	(Subgrade Optimum Moisture Content)
SGINSMC	(Insitu Subgrade Moisture Content)
SGDENSE	(Subgrade Density) -- Percent of Optimum
H2OTABLE	(Depth of Water Table) -- Feet
PMSTART	(Present Mission Starting Date) -- Year
PMSTOP	(Present Mission Ending Date) -- Year

TABLE 2-10--Continued

PMCAT1	(Amount of Usage Category #1 Accounts for on This Pavement Feature) -- Percentage
PMANOPS	(Number of Repetitions per Year This Pavement Feature) -- Percentage
CRFILL	(Overall Maintenance Policy) -- Coded
FI	(Freezing Index) -- Degree Days Below 32°F
FTC1	(Average Annual Number of Freeze-Thaw (F-T) Cycles at 1-Inch Depth)
FTC2	(Average Annual Number of F-T Cycles at 2-Inch Depth)
FTC3	(Average Annual Number of F-T Cycles at 3-Inch Depth)
AAPREC	(Average Annual Precipitation) -- Inches
AATEMP	(Average Annual Temperature) -- °F
ADTR	(Average Daily Temperature Range) -- °F
AATR	(Average Annual Temperature Range) -- °F
THORMI	(Thornthwaite Moisture Index)
AASR	(Average Daily Solar Radiation) -- Langleys
JULSR	(July Daily Solar Radiation) -- Langleys
PEVAP	(Potential Evaporation) -- Inches
OPEVAP	(Open Water Evaporation Potential) -- Inches
AAWS	(Average Annual Wind Speed) -- mph

TABLE 2-11

Means and Ranges of Key Concrete Pavement Variables [15:11]

	Mean Value	Range
Layer Information Variables		
Age -- years	18.0	2-37
PCC thickness -- inches	15.3	2-24
Modulus of rupture -- psi	701	480-992
Base material -- coded	---	---
Base thickness -- inches	12.7	2-55
Subgrade material -- coded	---	---
Modulus of subgrade reaction (k) -- pci	240	15-500
Environmental Variables		
Average annual temperature -- °F	60.0	38.8-65.8
Average annual precipitation -- inches	29.7	3.8-52.1
Freezing index -- degree days	127.4	0-1980
Freeze-thaw cyc[illegible] - 2-inch depth	25.8	0-111
Water table -- feet	100	4-500
Discrete Variables		
Feature type -- coded	---	---
Crack filling policy -- coded	---	---
Primary or secondary -- coded	---	---
Mechanistic Variables		
Fatigue	68.43	352-612,654
Damage	425.86	0-25,420

TABLE 2-12

Means and Ranges for Key Asphalt Pavement Variables [15:12]

	Mean Value	Range
<u>Layer Information Variables</u>		
Age -- years	10.58	0-27
Original AC thickness -- inches	3.80	2.0-7.0
Total AC thickness -- inches	5.85	2.0-14.0
Base material -- coded	---	---
Base CBR -- percent	85.13	20-100
Total select thickness -- inches	30.62	0.0-67.0
Subgrade material -- coded	---	---
Subgrade CBR -- percent	17.80	6-88
<u>Environmental Variables</u>		
Average annual temperature -- °F	54.2	38.0-65.8
Average annual temperature range -- °F	46.2	31.6-54.2
Average daily temperature range -- °F	23.4	19.1-28.5
Average annual precipitation -- inches	26.2	3.8-52.1
Average annual solar radiation -- langleys	407	325-520
Freezing index -- degree days	491	0-1980
Freeze-thaw cycles -- 2-inch depth	26.5	0-99
Water table -- feet	100	4-300
<u>Discrete Variables</u>		
Feature type -- coded	---	---
Crack filling policy -- coded	---	---
Primary or secondary -- coded	---	---
<u>Mechanistic Variables</u>		
Weighted average surface deflection (present period) -- (inches/equivalent single wheel load [ESWL])	0.001	0-.005
Weighted average surface deflection (first previous period) -- inches/ESWL)	0.001	0-.002

TABLE 2-12--Continued

Mechanistic Variables (cont)	Mean Value	Range
Weighted average vertical stress on base (present period) -- psi	86.2	0-175
Weighted average vertical stress on base (first previous period)	59.7	0-203
Cumulative vertical stress on base (present period) -- (psi, number of passes)	1.039×10^7	$0\text{-}1.414 \times 10^8$
Cumulative vertical stress on base -- (first previous period)	6.841×10^6	$0\text{-}1.163 \times 10^8$
Cumulative vertical strain on sub-grade (present period) -- (0.001 inches, number of passes)	6.067×10^5	$0\text{-}8.381 \times 10^6$
Cumulative vertical strain on sub-grade (first previous period) -- 0.001 inches, number of passes)	4.771×10^5	$0\text{-}1.274 \times 10^7$

Following the same stepwise procedure used to build the initial predictive models, the following equation (6) was developed for predicting the PCI in rigid pavement:

$$PCI = 97.4 - .25032960\,(I_1LDAM9) - .25323663 \times 10^{-2}\,(I_2FTCR) - .53386183 \times 10^{-3}\,(I_2PRECI) - .16042489\,(II_2AGECOL) - .40938352 \times 10^{-4}\,(I_2FATR) \qquad [2\text{-}8]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

I_1LDAM9 = AGE $[LOG_{10}\,(DAMAGE + 10)]$

AGE = time since original construction or, if overlaid, time since overlay construction (years)

DAMAGE = pavement damage factor

I_2FTCR = $AGE^2 \sqrt{\text{number of freeze - thaw cycles at a 2 inch depth}}$

I_2PRECI = AGE^2 (annual precipitation)

$II_2AGECOL$ = $\sqrt{AGE}$ (AGECOL)(LDAMCOL)/Thick

AGECOL = pavement age before overlay

LDAMCOL = pavement damage before overlay

THICK = most rec .. overlay thickness (in.)

I_2FATR = $AGE^2 \sqrt{FAT}$

FAT = pavement fatigue factor

This model was built based upon data collected from 168 rigid pavement features, both with and without an overlay (9). The model has a coefficient of determination of 0.65 and a standard deviation of 10.45 (6).

An evaluation of the concrete PCI prediction model was accomplished, from which it was determined that the model does not meet the appropriate boundary conditions. The calculated PCI at age zero is not 100 as it should be, but instead is 97.6. This could be corrected by forcing the model through the origin, however, this would also decrease the model's accuracy. Since 97.6 is close to 100, no action was taken. The coefficients appear to be reasonable in that they are all negative values (i.e. indicating an inverse relationship between the independent variables and the PCI). Most of the factors influencing the condition of the pavement, including: traffic, climate, materials, construction, foundation, and previous maintenance, are represented in the equation. Finally, a series of sensitivity analyses were accomplished to determine the degree of influence changes in each of the variables in the model had on the PCI. These tests led to the conclusion that the model is reasonable for predicting PCI values for concrete pavement (15:17-22).

From the same data base used to formulate the PCI prediction model for concrete pavement, the SPSS stepwise regression method was used to formulate a prediction model for asphalt pavement. Several models resulted from this analysis, however, the following model (15:23-24) was determined to be the best predictor of PCI for asphalt pavement:

$$PCI = 96.817 - 7.0733\,(ADAV)(AGE) - 0.00050865\,(\sqrt{VCR})\,(AGE) - 0.048290\left[\frac{(PRECI)(AGE)}{THICK}\right] \qquad [2\text{-}9]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

ADAV = AD x AV

AD = weighted average surface deflection divided by equivalent single wheel load

AV = weighted average vertical stress on top of the base course

AGE = time since original construction or, if overlaid, time since overlay construction (years)

$$VCR = \sum_{i=1}^{a} (USBC)(POL)$$

USBC = vertical stress on top of base course before most recent overlay

POL = number of passes before most recent overlay

PRECI = average annual precipitation, in.

THICK = thickness of asphalt concrete layer most recently constructed, in.

This model was built based on data collected from 70 flexible pavement features, including pavements with and without an overlay (9). The model has a coefficient of determination value of 0.71 and a standard deviation of 9.51 (15:23).

The procedures for evaluating the asphalt model very closely resembled those used in evaluating the concrete model. This process revealed that the appropriate boundary conditions for a PCI of 100 at age zero, were not met. In using this model to predict the PCI in flexible pavement, at age zero, the PCI equals 96.3. This is a result of the model not being forced through the origin, in an effort to maintain as much accuracy as possible in its predictive capability. The model does, however, agree with the basic assumption that the condition of the airfield pavement decreases with age (15:26).

The equation appears reasonable to the extent that all the coefficients are negative, and therefore are inversely related to the dependent variable, PCI. In addition, the model was determined to be plausible in that it represents a realistic situation. Most of the factors impacting the condition of the pavement are appropriately included in the equation. Using sensitivity analysis to determine the degree of influence that changes in the independent variables have on the PCI, the model was deemed appropriate for reasonably predicting the condition of asphalt pavements (15:27-31).

In summary, this latest phase of PCI prediction models (Equations 2-8 and 2-9) show considerable improvement over the initial models (Equations 2-6 and 2-7) developed in 1977. Much of this improvement is attributed to the fact that the data base used to build these latest models was considerably larger than the previous data base. In addition to a substantial increase in the number of pavement features surveyed, the number of independent variables considered more than doubled. Consequently, these latest models are currently the best tools available for predicting the condition of both rigid and flexible airfield pavements (6).

Conclusion

"Selecting the most economical maintenance and repair (M&R) alternative that satisfies all constraints is one of the major responsibilities of the airfield pavements engineer [13:1]." In light of the increasing difficulty of such a task, the Air Force found it necessary to develop a pavement maintenance management system that would assist the pavement engineer in effectively allocating limited maintenance and repair resources. The Air Force Engineering and Services Center has been assigned the responsibility of liaisoning and contracting with the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, to develop such a system.

Initial work began in the mid-1970's, to establish improved procedures for conducting condition surveys. This work eventually led to the development of the pavement condition index rating system, an analytical method used to determine "the pavement's structural integrity and operational surface condition [13:1]." The improved condition survey procedure, and the application of a Pavement Condition Index, led to the development of pavement condition prediction models, a principle element in the construction of a pavement maintenance management system. With the ability to predict the condition of the pavement, the consequence of applying various maintenance and repair strategies can be compared, and the selected alternatives justified.

Currently several phases of prediction models have been developed, based upon operational, construction, and environmental data collected from surveys on numerous airfield pavement features. The latest iteration of prediction models for concrete and asphalt pavements (i.e. Equations 2-8 and 2-9) apparently provide a reasonable representation of the actual condition of the pavement. Should the models continue to produce good predictions of the condition of the pavement, they will eventually be incorporated into the airfield pavement maintenance management system and used in selecting cost effective maintenance and repair strategies.

It should be noted that the prediction models identified in this review are not necessarily the final models to be developed. They do represent the best models available for predicting PCI values as of the time this study was conducted. Efforts will continue to improve upon these models as more data is collected and the causal relationships surrounding pavement distress are better defined.

Chapter III

RESEARCH METHODOLOGY

Scope and Delimitation

Since commencing in fiscal year 1976, the work to develop predictive condition index models for Air Force airfield pavements has primarily emphasized model development to cover two general categories of pavement design. As mentioned in previous chapters, the first model is applicable specifically to rigid airfield pavement. Rigid pavement includes concrete pavement, concrete pavement with a concrete overlay and concrete pavement with an asphalt or tar-surfaced overlay. The second model is applicable to flexible pavement. Flexible pavement includes pavement features containing only tar, asphalt or asphalt-concrete materials. Depending on the specific construction of a given pavement feature, the appropriate model can be utilized to predict the Pavement Condition Index (PCI) value.

To reduce the magnitude of this research to one that would provide the most comprehensive and meaningful results, it was determined that the scope of this study should be limited to the evaluation of only one prediction model. The final choice was to examine the airfield pavement condition prediction model for rigid pavement. However, this decision should in no way be interpreted as an evaluative judgement concerning the appropriateness of either model. The choice to evaluate the prediction model for rigid pavement is based primarily on the accessibility of relevant data.

This research entails an examination into, and an evaluation of, the validity of the PCI prediction model for rigid airfield pavement. In addition, this study investigates the possibility of improving the model's predictive capability, and examines the changes which occur to the model when combining additional data with the original data base used in developing the rigid pavement PCI prediction model. The scope of this research was designed to meet the specific objectives as stated in Chapter I. To satisfy these objectives, statistical analyses were accomplished using the Statistical Package for the Social Sciences (SPSS). A combination of the HARRIS 500 and CREATE computer systems was used to run all required programs.

Data Collection

One source of data, the original data base used in developing the rigid PCI prediction model, was obtained from the Construction Engineering Research Laboratory. As mentioned previously, this data base consists of pavement distress related information collected from 168 rigid pavement features. The data collection process took place during fiscal year 1980, and includes pavement feature information from Nellis, Mountain Home, Hill, Holloman, Sheppard, Columbus, Robins, Charleston, Dover and Loring Air Force Bases (15:4-12).

Wright-Patterson AFB serves as a second source of data used in this study. Aspects addressing the physical pavement design and construction history, the type and magnitude of aircraft operations and the actual pavement condition were measured for 12 rigid airfield pavement features, as identified in Figure 3-1. These particular features were chosen primarily due to their varying state of condition, construction, and loading, and therefore, they provided a good base from which to test the predictive capability of the rigid pavement PCI model. Additionally, climate data applicable to all 12 features was collected.

The types of data collected at Wright-Patterson AFB encompass only those which are pertinent to the PCI prediction model. The measured variables include: the actual condition of each pavement feature (i.e. the actual PCI value), the age of the feature, the Portland Cement Concrete (PCC) thickness and modulus of rupture, the modulus of subgrade reaction, the type and magnitude of aircraft operations over each feature and the climate conditions (including the

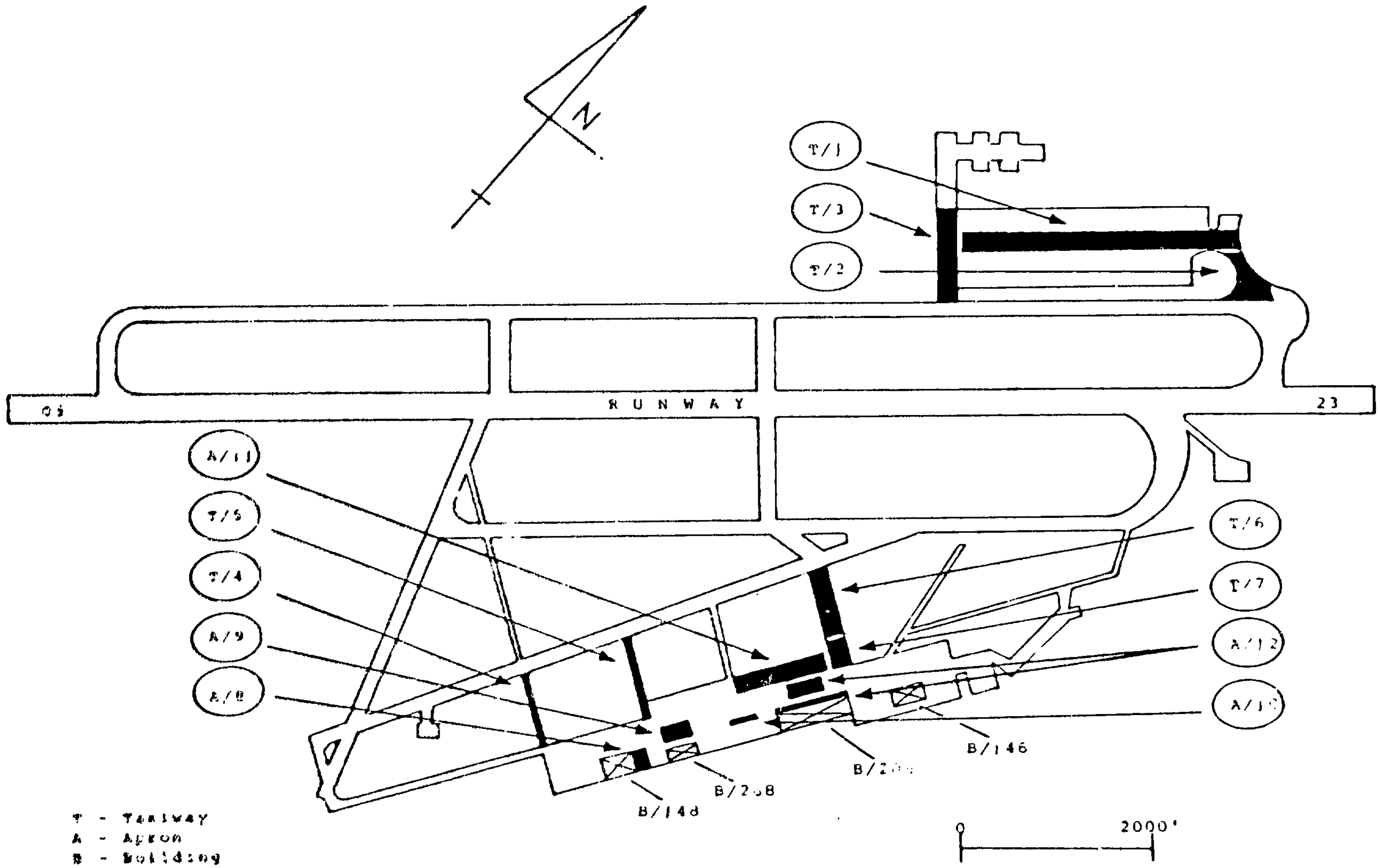


Fig. 3-1. Rigid Airfield Pavement Features Surveyed at Wright-Patterson AFB

average number of freeze-thaw cycles and annual precipitation).

Pavement Condition

The actual condition of each pavement feature was determined through the performance of an airfield pavement condition survey. This survey was conducted from 28 June thru 9 July 1982, and was accomplished in accordance with Air Force Regulation 93-5, Chapter 3. For concrete pavements with no overlay, each feature was divided into sample units of approximately 20 slabs. For pavements having an asphalt or tar-surfaced overlay, features were divided into sample units having an area of approximately 5000 square feet. The types of pavement distress, levels of severity, and densities were recorded for each sample unit in a given pavement feature. A Pavement Condition Index value for the sample unit was computed based upon the density versus deduct value relationships for each particular distress type and severity level. The PCI values for each sample unit in a pavement feature were averaged together to determine a Pavement Condition Index value for the entire feature.

To facilitate this operation, the Pavement Condition Index Program, available on the CREATE computer, was utilized in calculating PCI values for individual sample units and pavement features. This program was implemented by the Air Force Logistics Command (AFLC) for use by their base and command pavement engineers. The distress types, levels of severity, and density data obtained during the condition survey, for each sample unit, were input into the Pavement Condition Index Program, by which all necessary calculations were performed. An output of the program provides summary information concerning the percentage of distress per feature, in addition to providing the PCI value for each sample unit surveyed, and the overall PCI value for the corresponding pavement features.

Pavement Design/Construction

Data pertaining to the design and construction history for each pavement feature was obtained primarily from pavement construction drawings and specifications maintained by the 2750th Civil Engineering Squadron, the most recent Airfield Pavement Condition Report for Wright-Patterson AFB, and interviews with the base pavements engineer. In this manner, information concerning the age, PCC thickness and modulus of rupture, and the modulus of subgrade reaction, was obtained for each pavement feature surveyed.

Aircraft Traffic

Collecting accurate aircraft traffic data was one of the most difficult tasks in building the new data base for this study, and remains the least reliable variable in the model. However, as a necessary element in utilizing the PCI prediction model as it currently exists, information concerning the history of aircraft traffic across each feature must be obtained. The major difficulty encountered in researching this particular data element stems from the fact that a good historical record of past aircraft operations and specific traffic patterns is nonexistent.

In an effort to derive the best data possible concerning the number of passes a particular type of aircraft has made annually over a given feature, several research techniques were used. Interviews with personnel assigned to Base Operations, 2750th Air Base Wing, and with aircraft traffic controllers assigned to the 2046th Communications and Installations Group, provided valuable information concerning the primary traffic and parking patterns used under the current mission at Wright-Patterson AFB. Base Operations maintains a monthly traffic log for a period of one year, and an examination of this log provided necessary information concerning the different types of aircraft utilizing the Wright-Patterson airfield, in addition to the average number of monthly operations. A review of aircraft maintenance records, and a discussion with personnel currently performing aircraft maintenance, provided useful information on the loadings of features located adjacent to maintenance hangers.

Traffic data pertaining to previous missions was considerably more difficult to obtain. The primary source for this information was the office of the 2750th Air Base Wing historian. The number of different mission change-overs and effective dates, the types of aircraft used by each mission, and the approximate number of annual operations of the airfield were obtained from this office.

As a result of the large number of mission change-overs since the construction of the Wright-Patterson airfield (formerly the Patterson field), each specific mission identified in Table 3-1 was categorized into one of three major mission groups. The present mission entails the primary aircraft flown between 1975 and 1982. The first previous mission includes aircraft flown between 1959 and 1975 and the second previous mission includes those aircraft flown between 1943 and 1959. Based upon these three major mission groupings, the types of aircraft and the annual number of applications over a given pavement feature was determined.

Climate Conditions

The number of freeze-thaw cycles in concrete pavement is computed at a two inch depth. This variable is derived based upon the average air temperature, daily temperature range, annual temperature, wind speed, solar radiation in the month of July, and the annual solar radiation. In addition, the material density, specific

TABLE 3-1

Units Assigned to Patterson Field/
Wright-Patterson AFB

Organization and Dates of Assignment	Types of Aircraft
10th Transport Group 1937-1 April 1942	C-27, C-33, C-39
63rd Transport Group 17 Feb 1941-9 Sep 1941	C-33, C-34, C-39, C-50
316th Transport Group 14 Feb 1942-17 Jun 1942	C-47
97th Fighter Squadron 1 Dec 1950-18 Aug 1955	F-86
56th Fighter Squadron 18 Aug 1955-1 Mar 1960	F-86 (1955-1958); F-104 (1958-1960)
4043d Strategic Wing (SAC) 6 Feb 1959-1 Feb 1963	B-52E, KC-135A
17th Bombardment Wing (Heavy) 1 Feb 1963-1 Sep 1975	B-52E, B-52H, KC-135A
2750th Air Base Wing	
1948-1949	C-47, B-25, T-6, B-17, C-46, C-118
1950-1956	T-33, B-25, B-26, C-45, C-47, T-6, T-29, T-33, F-80, H-13
1957-1960	C-45, C-47, C-54, C-118, C-131, T-29, T-33, F-80, H-13, U-3A

TABLE 3-1--Continued

2750th Air Base Wing (cont)	
1961-1966	C-47, C-54, C-117, C-118, C-131, H-19B, T-29, T-33, T-34A, T-39A, U-3A, UH-19B
1967-1971	C-47, C-118, C-131, T-29, T-33, T-39A, U-3A
1972-27 Jun 1975	T-29/VT-29, T-33A, T-39A, C-118A, C-131D/E, C-135A
4950th Test Wing (ASD)	
1975	AC-130A, C-130A, C-130E, C-131B, C-135A, C-135B, C-141A, CH-3E, EC-135N, F-4C, F-4E, HH-53B, KC-135A, NC-141A, NKC-135A, RF-4C, T-37B, T-39A, XC-8

heat, conductivity, and absorbtivity are also taken into consideration (9). Following a survey conducted by the Construction Engineering Research Laboratory, during fiscal year 1980, the number of freeze-thaw cycles was calculated for Wright-Patterson AFB, and made available for use in this study.

The annual precipitation is an average figure applicable to all pavement features in a given region. The level of annual precipitation was obtained from Detachment 15, of the 15th Weather Squadron, currently assigned to Wright-Patterson AFB.

Calculated Variables

To supplement the raw data, several additional variables, pertinent to the magnitude of distress experienced in rigid airfield pavements, were calculated. These variables include edge stress, pavement fatigue and damage.

Edge Stress

In developing the PCI prediction model of Air Force airfield pavements, the maximum free edge stress at the bottom of a concrete slab was determined to be the "main response parameter" for concrete pavement analysis (15:69). The typical rigid pavement structure was modeled as a single slab, resting on an elastic foundation, having an elastic modulus of 4×10^6 pounds per square inch (psi) and a Poisson's ratio of 0.15 (15:69). Based upon these assumptions, a number of computations were performed using the computerized H-51 program (7), to determine the maximum free edge stress at the base of a concrete slab. From these computations, edge stress charts were developed for the main gear geometry, gear load, tire contact area, and tire pressure of each applicable aircraft (15:69-71). Using the stress chart, the maximum free edge stress is derived, knowing the PCC thickness of the feature, modulus of subgrade reaction, and type of aircraft loading. Edge stress charts that are applicable to this study are provided in Appendix A.

In a situation where the feature of concern is entirely concrete construction, the maximum free edge stress is obtained directly from the stress charts. However, if the feature has been overlaid with a flexible material (i.e. asphalt or tar) a modification to the edge stress values determined from the stress charts is appropriate, to account for the varying material characteristics and total pavement thickness (9). For pavement features having a flexible overlay, it becomes necessary to compute the actual edge stress based upon a transformed section. The maximum free edge stress, determined from the stress charts for the total section thickness, is incr.ased a proportional amount to accommodate material differences (13:20-23; 15:80-81).

$$\sigma' = \sigma y \qquad [3\text{-}1]$$

where: σ' = maximum free edge stress at the bottom of a concrete slab for a transformed section

σ = maximum free edge stress determined from the edge stress charts (i.e. based upon total thickness)

$y = 1.00 + 0.0143x$

x = percent asphalt or tar surface thickness of the total pavement thickness

Pavement Fatigue

The fatigue factor for rigid airfield pavement is a computational variable based upon the maximum free edge stress at the bottom of a concrete slab, the modulus of rupture of the pavement and the actual number of applications of each aircraft over a particular feature. The pavement fatigue factor (15:15) was calculated for each feature surveyed.

$$FAT = \sum_{i=1}^{a} \frac{0.75(\sigma)}{MR} n_i \qquad [3\text{-}2]$$

where: FAT = pavement fatigue factor

a = number of different aircraft using the feature

σ = maximum free edge stress, psi

(use σ' when applicable)

MR = modulus of rupture, psi

n_i = actual number of applications of aircraft i

Pavement Damage

The pavement damage factor is a rigid pavement variable contingent upon the sum of the ratios between the actual number of applications of a given aircraft and the maximum allowable number of aircraft applications before one unit value of damage occurs. The pavement damage factor (15:15) for each rigid pavement feature surveyed was determined.

$$\text{DAMAGE} = \sum_{i=1}^{a} n_i/N_i \qquad [3\text{-}3]$$

where: DAMAGE = pavement damage factor

a = number of different aircraft using the feature

n_i = actual number of applications of aircraft i

N_i = number of applications of aircraft i to cause failure to concrete

In calculating the number of applications, N_i of a particular aircraft over a given pavement feature required to cause structural failure, the maximum free edge stress at the bottom of the concrete slab must be obtained. The maximum edge free stress for concrete construction was found directly from the stress charts. For a concrete slab with a flexible overlay, the maximum free edge stress was determined by applying the transformed section correction factor, y, to the stress chart value. The value for N was calculated as follows (9):

$$LOG_{10}N_i = 17.61 - 17.61(0.75\sigma/MR) \qquad [3\text{-}4]$$

where: N_i = number of applications of aircraft i to cause failure to concrete

σ = maximum free edge stress, psi (use σ' when applicable)

MR = an assumed modulus of rupture of 750 psi

Under circumstances where the concrete feature had in fact been overlayed with a flexible material, it was also necessary to calculate the damage to the concrete pavement prior to the overlay (9).

$$LDAMCOL = LOG_{10}(DAMCOL + 10) \qquad [3\text{-}5]$$

where: I_1DAMCOL = damage to the pavement before the overlay

DAMCOL = DAMAGE

The distinguishing characteristic between DAMCOL and DAMAGE is that for a pavement feature having an asphalt or tar-surfaced overlay the value of the variable DAMCOL was derived using a maximum free edge stress, σ, taken directly from the stress charts, while the value of the variable DAMAGE was based upon the maximum free edge stress, σ', of a transformed section.

Predicted PCI Values

Pavement Condition Index values for each of the 12 pavement features surveyed at Wright-Patterson AFB were calculated using the PCI prediction model for rigid airfield pavements. A combination of the collected raw data, including pavement design characteristics, aircraft traffic information and climate conditions, together with the calculated variables of edge stress, pavement fatigue and damage, provided sufficient information to utilize the prediction model (9).

$$\begin{aligned} PCI = 97.4 &- 0.25032960\ (I_1LDAM9) \\ &- 0.25323663 \times 10^{-2}(I_2FTCR) \\ &- 0.53386183 \times 10^{-3}(I_2PRECI) \\ &- 0.16042489\ (II_2AGECOL) \\ &- 0.40938352 \times 10^{-4}(I_2FATR) \end{aligned} \qquad [2\text{-}8]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

I_1LDAM9 = AGE [LOG_{10}(DAMAGE + 10)]

AGE = time since original construction or, if overlaid, time since overlay construction

DAMAGE = pavement damage factor

I_2FTCR = $AGE^2 \sqrt{\text{number of freeze-thaw cycles at a 2 inch depth}}$

I_2PRECI = AGE^2 (annual precipitation)

$II_2AGECOL$ = $\sqrt{AGE}$ (AGECOL)(LDAMCOL)/THICK

AGECOL = pavement age before overlay

LDAMCOL = pavement damage before overlay

THICK = most recent overlay thickness (in.)

I_2FATR = $AGE^2 \sqrt{FAT}$

FAT = pavement fatigue factor

If the concrete is overlaid with flexible material, pavement distress as a result of freeze-thaw cycles at a 2 inch depth is considered negligable, and therefore, the variable I_2FTCR is equal to zero (9). Included in Table 3-2 is an example for calculating the PCI value using Equation 2-8.

TABLE 3-2

An Example Calculating the PCI Value for a Rigid Airfield Pavement Feature

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A. Information Available

Construction History:	1965, 15 Inches Portland Cement Concrete 1975, 2 Inches Asphalt Overlay
Design Characteristics:	Modulus of Rupture (MR) = 700 psi Modulus of Subgrade Reaction (K) = 300 pci
Climate Information:	Number of Freeze-Thaw Cycles at a 2 Inch Depth = 50 Average Annual Precipitation = 35 Inches
Traffic History:	1965-1970, B-52/11000 Coverages Per Year 1970-Present, KC-135/14000 Coverages Per Year

B. Solution

1965-1975	B-52:	σ = 850 psi
Original Construction	KC-135:	σ = 510 psi

(See Appendix A)

$$LOG_{10}N_i = 17.61 - 17.61\,(0.75\sigma/750)$$

B-52: $LOG_{10}N = 17.61 - 17.61\,(0.75(850)/750)$; $N = 438.03$

KC-135: $LOG_{10}N = 17.61 - 17.61\,(0.75(510)/750)$; $N = 4.26 \times 10^8$

$$DAMAGE = \sum_{i=1}^{a} n_i/N_i$$

$$\text{DAMAGE} = \frac{5(11000)}{438.03} + \frac{5(14000)}{4.26\times10^8} = 125.56$$

1975 - Present
Overlay Construction KC-135: σ = 440 psi

σ' σy

$$\sigma' = 440\,[1.0 + 0.0143(2/17)] = 440.74 \text{ psi}$$

KC-135: $LOG_{10}N = 17.61 - 17.61\,(0.75(440.74)/750)$; $N = 7.06\times10^9$

$$\text{DAMAGE} = \frac{7(14000)}{7.06\times10^9} = 0$$

$$\text{FAT} = \sum_{i=1}^{a} \frac{0.75(\sigma')}{MR} n_i$$

$$= \frac{0.75(440.74)(14000)(7)}{700} = 46277.70$$

$I_1LDAM9 = AGE\,[LOG_{10}\,(DAMAGE + 10)]$
$= 7[LOG_{10}\,(0 + 10)] = 7.0$

$I_2FTCR = AGE^2 \sqrt{\text{number of freeze-thaw cycles}}$
$= 0$ (flexible overlay)

$I_2PRECI = AGE^2$ (annual precipitation)
$= (7)^2\,(35) = 1715.0$

TABLE 3-2--Continued

$II_2AGECOL = \sqrt{AGE}\ (AGECOL)(LDAMCOL)/THICK$
$= \sqrt{7}\ (10)\ [LOG_{10}(125.56 + 10)]/2.0 = 28.21$

$I_2FATR = AGE^2 \sqrt{FAT}$
$= (7)^2 \sqrt{46277.70} = 10541.0$

$$PCI = 97.4 - 0.25032960\ (I_1LDAM9) - 0.25323663 \times 10^{-2}\ (I_2FTCR) - 0.53386183 \times 10^{-3}\ (I_2PRECI) - 0.16042489\ (II_2AGECOL) - 0.40938352 \times 10^{-4}\ (I_2FATR)$$

$$PCI = 97.4 - 1.75 - 0 - 0.92 - 4.52 - 0.43$$

$PCI = 89.78$ Excellent Condition

Analysis

In evaluating the predictive capability of the rigid airfield pavement condition index model, a comparative analysis between the actual PCI data, resulting from the condition survey, and the predicted PCI values was accomplished. The SPSS subprogram SCATTERGRAM was employed for this purpose. A graph was plotted of the data points based on two variables, one defining the x axis and the other the y axis (10:278). For this study the two variables included the actual PCI values and predicted PCI values for each of the 12 pavement features surveyed. The subprogram also computes the Pearson product-moment correlation coefficient, r. Pearson's r provides a measure of association indicating the strength of the linear relationship between two variables (10:279), in this case the actual and predicted PCI values. Based upon the degree of correlation for this sample, inferences can be made about the population as a whole, from which these values were taken.

> The correlation coefficient r measures the correlation between x values and y values in the sample, and that a similar linear coefficient of correlation exists for the population from which the data points were selected [8:313].

Statistics associated with bivariate regression, such as the regression coefficient and constant, were computed using the SCATTERGRAM subprogram (3:49).

In determining the influence that the collected data and computed variables have on the PCI prediction model, the new data was combined with the original data base used in building the prediction model, from which the construction of a modified model was accomplished. The SPSS REGRESSION subprogram was used for this purpose. Multiple regression is a general statistical technique through which the relationship between a dependent variable, such as the condition of the pavement (i.e. PCI value) and several independent variables can be quantitatively expressed. Multiple regression as a descriptive tool defines structural relationships and provides explanations for seemingly complex multivariate relationships (10:321). The primary means for determining the influence that the new data has on the model, is to compare the coefficients of determination for the original and modified prediction models. The coefficient of determination, R^2, is an index of the ability of independent variables to predict the value of a dependent variable (3:50). A partial F-test was used to evaluate the significance of each independent variable entering the modified model, based upon a significance level of 0.05.

The current prediction model is based upon the assumption that there exists a linear relationship between the dependent variable, PCI, and the independent variables I_1LDAM9, I_2FTCR, I_2PRECI, II_2AGECOL, and I_2FATR. In an effort to improve this model, multi-variable interactions and higher order polynomials for each of these independent variables were derived, and a stepwise regression analysis performed. The SPSS REGRESSION subprogram was again employed for this purpose. Through the use of multiple regression analysis, a new prediction model was hypothesized, unknown parameters estimated, the probability distribution of the random error specified and the utility of the model checked. The significance of each new variable entering the model was examined using the partial F-test at a significance level of 0.05.

Assumptions and Limitations

In developing the PCI prediction model for rigid Air Force airfield pavements, the Construction Engineering Research Laboratory began with over 40 raw data elements and three mechanistic variables (15:7-15). As a result of performing a stepwise regression analysis, this field of data was reduced to a few situational variables, pertinent to predicting the PCI values. A principle assumption and limitation of this study is that only pavement related variables of concern in using the model are addressed in this research (i.e. only those variables the Construction Engineering Research Laboratory found to be significant).

In obtaining the data base used to build the PCI prediction model, actual pavement condition surveys were accomplished to obtain existing PCI values, a necessary element in the model development process. In order to compare actual and predicted PCI values, a subsequent condition survey was performed to determine actual PCI values. Therefore, a second assumption of this research is that two separate condition surveys, performed by different evaluating engineers, having varying backgrounds, will result in little or no significant difference in their respective observations.

Chapter IV

FINDINGS AND ANALYSIS

This chapter contains a summary of the data collection effort conducted at Wright-Patterson AFB and the results from the statistical tests performed on this data and the data base provided by the Corps of Engineers, Construction Engineering Research Laboratory. The specific research questions stated in Chapter I are considered herein, and any additional significant statistical observations and test results noted as appropriate.

New Data Base

In addition to the pavement distress related information collected and compiled by the Construction Engineering Research Laboratory during fiscal year 1980, new data was obtained on 12 rigid airfield pavement features located at Wright-Patterson AFB. The actual condition of each pavement feature was determined through the performance of a pavement condition survey, in accordance with Air Force Regulation 93-5. A summary of the types, severity levels, and densities of the distresses observed in each feature is presented in Appendix B.

The magnitude of pavement loading was another primary element of information measured for each feature. Table 4-1 identifies the principle traffic by aircraft type and gives the approximate number of annual coverages, for each feature surveyed. Because of the large number of mission change-overs since the construction of the airfield, each specific mission has been grouped into one of three major categories. Segregating the specific missions in this manner accommodated a reasonable calculation of the mechanistic variables, pavement "fatigue" and "damage."

Other information obtained included the design and construction characteristics of each pavement feature and the typical climatic conditions of the area. Table 4-2 summarizes the collected raw data and the computed mechanistic variables for each of the 12 rigid pavement features surveyed at Wright-Patterson AFB. Complete listings of the data collected during the 1980 Corps of Engineers survey and this author's 1982 survey of Wright-Patterson AFB, are provided in Appendicies C and D respectively.

Prediction Model Evaluation

To determine the validity of the PCI prediction model for rigid airfield pavements (i.e. Equation 2-8), the actual PCI values obtained at Wright-Patterson AFB were compared with those PCI

TABLE 4-1

Wright-Patterson AFB Pavement Loading

Feature	Major Mission Group					
	1975 - Present		1959 - 1975		1943 - 1959	
	Aircraft Type	Annual Coverages	Aircraft Type	Annual Coverages	Aircraft Type	Annual Coverages
T/1	C-135	3150	B-52	2400		
	C-141	620	KC-135	2200		
	C-130	720				
T/2	C-135	760	B-52	840		
	C-141	160	KC-135	700		
	C-130	180				
T/3	C-135	2400	B-52	1850		
	C-141	320	KC-135	1600		
	C-130	400				
T/4	L 188	250	C-47	1920	C-47	2160
	T-39	360	C-54	1920	C-54	720
	T-38	120	T-29	3840	B-25	2160
	T-37	80	T-33	3840	B-17	2160
	T-33	30	T-39	3840	F-86	2770
	F-Series	890	C-131	1920	F-80	2770
T/5	L-188	250	C-47	1920	C-47	2160
	T-39	360	C-54	1920	C-54	720
	T-38	120	T-29	3840	B-25	2160
	T-37	80	T-33	3840	B-17	2160
	T-33	30	T-39	3840	F-86	2770
	F-Series	890	C-131	1920	F-80	2770
T/6	L-188	4540	C-47	1220	C-47	2160
	T-39	6460	C-54	1220	C-54	720
	C-135	150	T-29	2840	B-25	2160
	C-130	800	T-33	2840	B-17	2160

Table 4-1--Continued

Feature	Major Mission Group					
	1975 - Present		1959 - 1975		1943 - 1959	
	Aircraft Type	Annual Coverages	Aircraft Type	Annual Coverages	Aircraft Type	Annual Coverages
T/6	C-9	550	T-39	2840	F-86	2950
	T-38	2095	C-131	1220	F-80	3500
	T-37	1425				
	T-33	450				
	F-Series	16070				
T/7	L-188	4540	C-47	1220	C-47	2160
	T-39	6460	C-54	1220	C-54	720
	C-135	150	T-29	2840	C-25	2160
	C-130	800	T-33	2840	B-17	2160
	C-9	550	T-39	2840	F-86	2950
	T-38	2095	C-131	1220	F-80	3500
	T-37	1425				
	T-33	450				
	F-Series	16070				
A/8	T-39	4320	T-29	1020		
			T-39	1020		
			T-33	1020		
A/9	T-39	4320	T-29	1450		
			T-39	1450		
			T-33	1450		
A/10	T-39	360	T-39	290	C-47	280
	T-38	360	T-33	290	C-54	280
	T-37	360	T-29	290	B-25	280
	F-Series	360	C-47	140	B-17	160
			C-54	140	F-86	400
			C-131	140	F-80	430

Table 4-1--Continued

Feature	Major Mission Group					
	1975 - Present		1959 - 1975		1943 - 1959	
	Aircraft Type	Annual Coverages	Aircraft Type	Annual Coverages	Aircraft Type	Annual Coverages
A/11	T-39	6460	T-39	3840	C-47	2500
	T-38	2095	T-33	3840	C-54	2500
	T-37	1425	T-29	3840	B-25	2500
	T-33	450	C-47	1920	B-17	400
	F-Series	16070	C-54	1920	F-86	1500
	L-188	200	C-131	1920	F-80	1500
	C-9	150	C-135	50		
	C-130	500				
	C-135	100				
	C-141	150				
A/12	T-39	6460	T-39	3840		
	T-33	450	T-33	1840		
	L-188	200	T-29	1840		
	C-9	125	C-47	920		
	C-130	250	C-54	920		
	C-135	50	C-131	920		
			C-135	50		

TABLE 4-2

A Summary of Data Collected at
Wright-Patterson AFB

Variable	Mean	Range	Standard Deviation
AGE (Years)	18.25	1.0 - 23.0	6.06
AGECOL (Years)	8.25	0 - 22.0	10.28
Freeze-Thaw Cycles	93.0	---	---
Annual Precipitation (Inches)	34.36	---	---
FAT	66630.24	492.35 - 143885.72	50969.17
DAMAGE	64.74	0 - 625.0	181.63
DAMCOL	2.11	0 - 25.26	7.29
THICK (Inches)	0.81	0 - 2.50	1.04
I_1LDAM9	22.91	1.01 - 47.65	12.34
I_2FTCR	2361.09	0 - 5101.49	2261.68
I_2PRECI	12601.53	34.36 - 18176.44	5898.85
LDAMCOL	1.05	1.0 - 1.55	0.16
II_2AGECOL	15.68	0 - 45.36	20.15
I_2FATR	93916.72	22.189 - 183592.19	55223.05
Actual PCI	64.67	43.0 - 86.0	11.93

values predicted using the model. The scattergram in Figure 4-1 illustrates the relationship between these two variables. If the model was capable of predicting PCI values without error, then the actual PCI value would equal the predicted value, and all data points on this diagram would theoretically plot along the straight line a-a, defined as having an intercept of zero and a positive slope of one. The best fitting straight line to this data has an intercept of 34.75 and a slope of 0.59. Therefore, the prediction model is incapable of predicting the actual condition of the 12 pavement features at Wright-Patterson AFB.

To determine the strength of the linear relationship between the measured and calculated PCI values, Pearson's product-moment correlation coefficient, r, was utilized. The calculated values of the correlation coefficient rest between the limits of $\pm$ 1.0. Where there is a perfect fit of actual versus predicted PCI values, the value of the correlation coefficient will equal +1.0 or -1.0. A value of +1.0 indicates a positive relationship between actual and predicted PCI values, as in the case of line a-a in Figure 4-1. A value of -1.0 denotes an inverse relationship between the two variables, for example line b-b in Figure 4-1. For a correlation coefficient equal to zero, it is assumed that no linear relationship is present (10:279). For this study, a Pearson product-moment correlation coefficient of 0.80 was

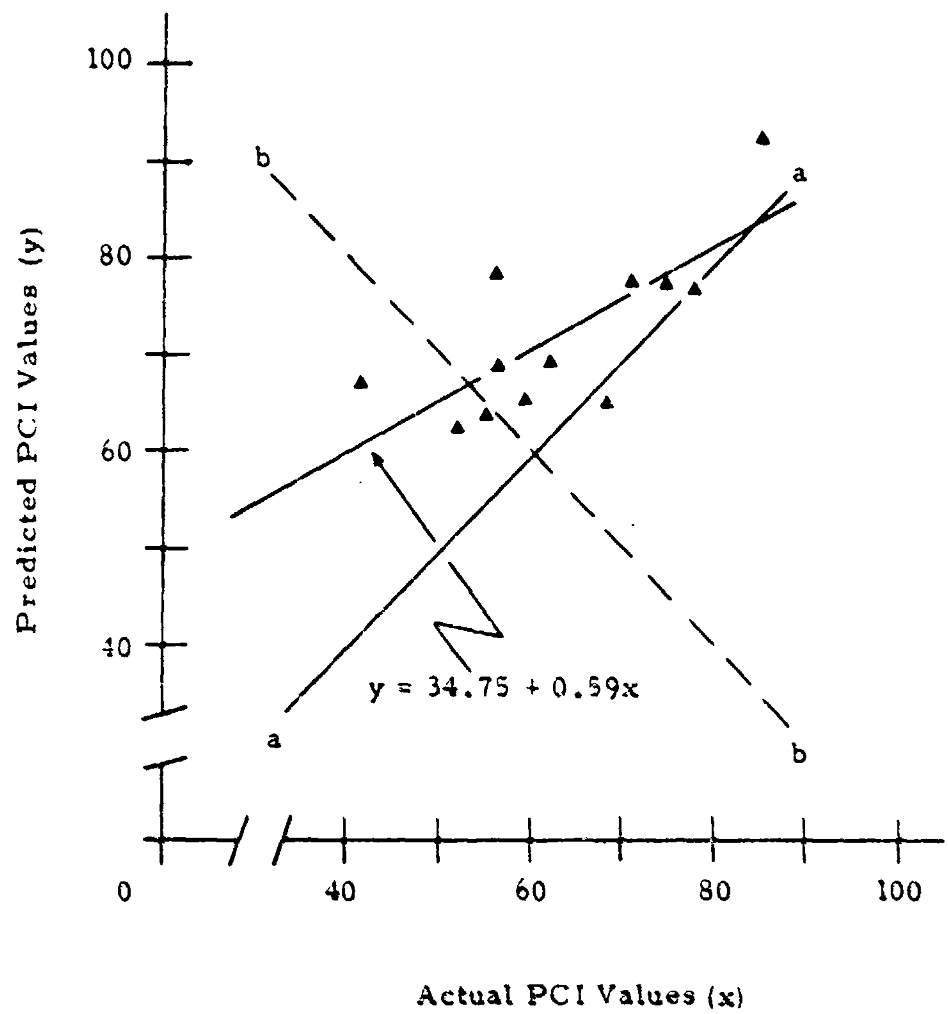


Fig. 4-1. Scattergram of Actual Versus Predicted PCI Values for the PCI Prediction Model

calculated, identifying the existence of positive linear relationship between the actual and predicted Pavement Condition Index values.

Modified Prediction Model

Having collected the pertinent data on the 12 Wright-Patterson AFB features, the new information was combined with the data base originally used in developing the PCI prediction model and a stepwise regression analysis performed (Ref. Appendix E). This process resulted in the creation of the following modified prediction model:

$$\begin{aligned} PCI = 97.4 &- 0.2206655\,(I_1LDAM9) \\ &- 0.2577991 \times 10^{-2}\,(I_2FTCR) \\ &- 0.5407277 \times 10^{-3}\,(I_2PRECI) \\ &- 0.1928937\,(II_2AGECOL) \\ &- 0.5609340 \times 10^{-4}\,(I_2FATR) \end{aligned} \qquad [4\text{-}1]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

I_1LDAM9 = AGE [LOG_{10} (DAMAGE + 10)]

AGE = time since original construction or, if overlaid, time since overlay construction

DAMAGE = pavement damage factor

$I_2FTCR = AGE^2 \sqrt{\text{number of freeze-thaw cycles at a 2 inch depth}}$

$I_2PRECI = AGE^2$ (annual precipitation)

$II_2AGECOL = \sqrt{AGE}$ (AGECOL)(LDAMCOL)/THICK

AGECOL = pavement age before overlay

LDAMCOL = pavement damage before overlay

THICK = most recent overlay thickness

$I_2FATR = AGE^2 \sqrt{FAT}$

FAT = pavement fatigue factor

Each variable entering the equation was tested using a partial F-test at a significance level of 0.05. All those variables present in the original model (i.e. Equation 2-8) remained significant in the modified prediction model (i.e. Equation 4-1). A summary of the data used in developing this modified PCI prediction model is included in Table 4-3.

When evaluating the change resulting from the addition of new data, several points are noted. First, though the constant remained virtually unchanged at 97.4, the regression coefficients for each independent variable in the equation significantly altered from the original model. The regression coefficient is the expected change in the dependent variable, PCI, as a result of a one unit change in any of the independent variables, assuming that all other

TABLE 4-3

A Summary of Data Used in Developing the Modified PCI Prediction Model

Variable	Mean	Range	Standard Deviation
AGE (Years)	17.63	1.0 - 37.0	7.08
AGECOL (Years)	3.08	0 - 30.0	7.03
Freeze-Thaw Cycles	23.34	0 - 105.0	40.52
Annual Precipitation (Inches)	30.51	3.80 - 52.10	16.77
FAT	81818.61	352.0 - 658325.0	122139.47
DAMAGE	8450.93	0 - 282780.0	38836.26
DAMCOL	13551.75	0 - 568460.0	73708.11
THICK (Inches)	0.74	0 - 8.0	1.82
I_1LDAM9	27.38	1.01 - 140.14	23.26
I_2FTCR	1064.91	0 - 5101.49	1867.98
I_2PRECI	10807.41	15.20 - 54512.50	9017.77
LDAMCOL	1.34	1.0 - 5.755	1.06
II_2AGECOL	11.39	0 - 197.97	35.17
I_2FATR	78747.19	22.19 - 709414.89	87631.48
Actual PCI	73.51	17.0 - 98.0	16.44

independent variables remain constant. The inclusion of the new data resulted in the variables I_2FTCR, I_2PRECI, II_2AGECOL and I_2FATR becoming more influencial in predicting the PCI value, while the variable I_1LDAM9, decreased slightly as a significant element in the prediction model.

More important is the fact that the modified model has a greater coefficient of determination, R^2, than the original prediction model. The coefficient of determination is a measure of variance in the dependent variable explained by the combined influence of the independent variables (8:350). When adding the new data, the value of the coefficient of determination increased from 0.65, calculated for the original prediction model, to 0.67. Therefore, given the data available, the utility of the modified model in predicting pavement condition indicies for rigid airfield pavements, improved 3% over the original model.

Improved Model

Limited to the types of pavement distress related information obtained from the Corps of Engineers, the original data base was manipulated several ways in an effort to improve upon the predictability of the condition of rigid airfield pavements. The possibilities of curviture in the relationships between dependent and independent variables, and interaction among the independent variables, were considered. Covering each possibility from all angles led to the creation of 14 new variables as described in Table 4-4. A multiple regression analysis was accomplished on the combination of these new independent variables and the original variables (Ref. Appendix F). At each step in the regression analysis, the variables present in the equation were checked for significance using the partial F-test at a significance level of 0.05. Those terms insignificant in predicting the PCI value were eliminated from the model. This analysis generated a new PCI prediction model, notably different from the original. The new model may be expressed as:

$$\begin{aligned} PCI = 98.2 &- 0.7351402\,(I_1LDAM9) \\ &+ 0.4368143 \times 10^{-2}\,(II_1LDAM9) \\ &- 0.6721296 \times 10^{-4}\,(I_2FATR) \\ &- 0.1543106 \times 10^{-2}\,(III_2AGECOL) \\ &- 0.5992802 \times 10^{-4}\,(DAMFT) \\ &- 0.3236294 \times 10^{-4}\,(PREAG) \\ &- 0.4666657 \times 10^{-2}\,(DAMAG) \end{aligned} \qquad [4\text{-}2]$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

I_1LDAM9 = AGE $[LOG_{10}$ (DAMAGE + 10)]

AGE = time since original construction or, if overlaid, time since overlay construction

TABLE 4-4

New Variables Created in Developing an Improved PCI Prediction Model

Variable	Description
II_1LDAM9	$I_1LDAM9 \times I_1LDAM9$
II_2FTCR	$I_2FTCR \times I_2FTCR$
II_2PRECI	$I_2PRECI \times I_2PRECI$
$III_2AGECOL$	$II_2AGECOL \times II_2AGECOL$
DAMFT	$I_1LDAM9 \times I_2FTCR$
DAMPR	$I_1LDAM9 \times I_2PRECI$
DAMAG	$I_1LDAM9 \times II_2AGECOL$
DAMFA	$I_1LDAM9 \times I_2FATR$
FTCPR	$I_2FTCR \times I_2PRECI$
FTCAG	$I_2FTCR \times II_2AGECOL$
FTCFA	$I_2FTCR \times I_2FATR$
PREAG	$I_2PRECI \times II_2AGECOL$
PREFA	$I_2PRECI \times I_2FATR$
AGEFA	$II_2AGECOL \times I_2FATR$

Note: I_1LDAM9, I_2FTCR, I_2PRECI, $II_2AGECOL$ and I_2FATR are defined in Equation 2-8.

$DAMAGE$ = pavement damage factor

$II_1LDAM9 = I_1LDAM9^2$

$I_2FATR = AGE^2 \sqrt{FAT}$

FAT = pavement fatigue factor

$III_2AGECOL = II_2AGECOL^2$

$II_2AGECOL = \sqrt{AGE}\,(AGECOL)(LDAMCOL)/THICK$

$AGECOL$ = pavement age before overlay

$LDAMCOL$ = pavement damage before overlay

$THICK$ = most recent overlay thickness (in.)

$DAMFT = I_1LDAM9 \times I_2FTCR$

$I_2FTCR = AGE^2 \sqrt{\text{number of freeze-thaw cycles at a 2 inch depth}}$

$PREAG = I_2PRECI \times II_2AGECOL$

$I_2PRECI = AGE^2$ (annual precipitation)

$DAMAG = I_1LDAM9 \times II_2AGECOL$

A summary of the data used in developing Equation 4-2 is presented in Table 4-5.

A major distinction between the new prediction model and the original model (i.e. Equation 2-8) is the fact that the new model

TABLE 4-5

A Summary of Data Used in Developing the Improved PCI Prediction Model

Variable	Mean	Range	Standard Deviation
AGE (Years)	17.59	2.0 - 37.0	7.16
AGECOL (Years)	2.71	0 - 30.0	6.23
Freeze-Thaw Cycles	21.31	0 - 105.0	39.184
Annual Precipitation (Inches)	30.23	3.80 - 52.10	17.33
FAT	82903.49	352.0 - 658325.0	125702.54
DAMAGE	9049.95	0 - 282780.0	40139.95
DAMCOL	14519.58	0 - 568460.0	76217.70
THICK (Inches)	0.73	0 - 8.0	1.86
I_1LDAM9	27.70	2.0 - 140.14	23.84
I_2FTCR	972.33	0 - 4959.52	1809.36
I_2PRECI	10679.25	15.20 - 54512.50	9219.32
II_2AGECOL	11.079	0 - 197.97	36.02
LDAMCOL	1.36	1.0 - 5.76	1.09
I_2FATR	77663.66	283.41 - 709414.89	89512.53
II_1LDAM9	1331.97	4.0 - 19638.84	2791.83
III_2AGECOL	1412.70	0 - 39192.74	5995.60
DAMFT	23200.32	0 - 250276.26	46035.10
PREAG	54125.18	---	196341.49
DAMAG	609.39	0 - 9855.58	2089.0
Actual PCI	74.14	17.0 - 98.0	16.56

no longer contains the original variables I_2FTCR, I_2PRECI and II_2AGECOL as independent terms. Instead, Equation 4-2 represents a second-order model, where the variables II_1LDAM9 and III_2AGECOL denote the presence of curvature in the response surface. It is interesting to note, however, that I_1LDAM9 also remains in the equation depicting a linear relationship with the PCI value, and is in fact the best single measurement for predicting PCI values. I_1LDAM9 was the first and most significant variable to enter the regression analysis.

The presence of the independent variables DAMFT, PREAG and DAMAG in the equation indicates that the PCI value is best predicted through the interaction of several terms (i.e. I_1LDAM9, I_2FTCR, I_2PRECI, and II_2AGECOL). "The presence of an interaction term implies that the effect [on the PCI value] of a one unit change in one independent variable will depend on the level of the other independent variable [8:384]."

Based upon the magnitude of the coefficient of determination, there is a marked improvement in the predictive capability of this model over the original PCI prediction model. Using an identical data base, this improved model has a coefficient of determination of 0.69, as compared to 0.65 for the original model, a 7% increase in the value of the coefficient of determination. From this, it can be inferred that the improved model is a better tool then the original model for predicting the condition of rigid airfield pavements.

Improved Model Evaluation

Similar to the analysis discussed earlier, the validity of the improved model (i.e. Equation 4-2) was checked by comparing the actual PCI values measured at Wright-Patterson AFB against the values predicted using the equation. The scattergram in Figure 4-2 illustrates the relationship between the two variables. If the model were a perfect fit, indicating a one to one correspondence between the actual and predicted PCI values, then all data points shown in the figure would plot on line a-a. Instead, the best fitting straight line to this data has an intercept of 9.09 and a slope of 0.89. Though not equivalant to the optimum response (i.e. line a-a) this is a considerable improvement over the relationship between actual and predicted PCI values as expressed by the original model (i.e. an intercept of 34.75 and a slope of 0.59). Therefore, it can be surmized, that although the improved model does not predict the actual PCI values without error, it is considerably more effective as a prediction instrument than the original.

In measuring the strength of the linear relationship between the actual PCI values and the predicted PCI values, employing this

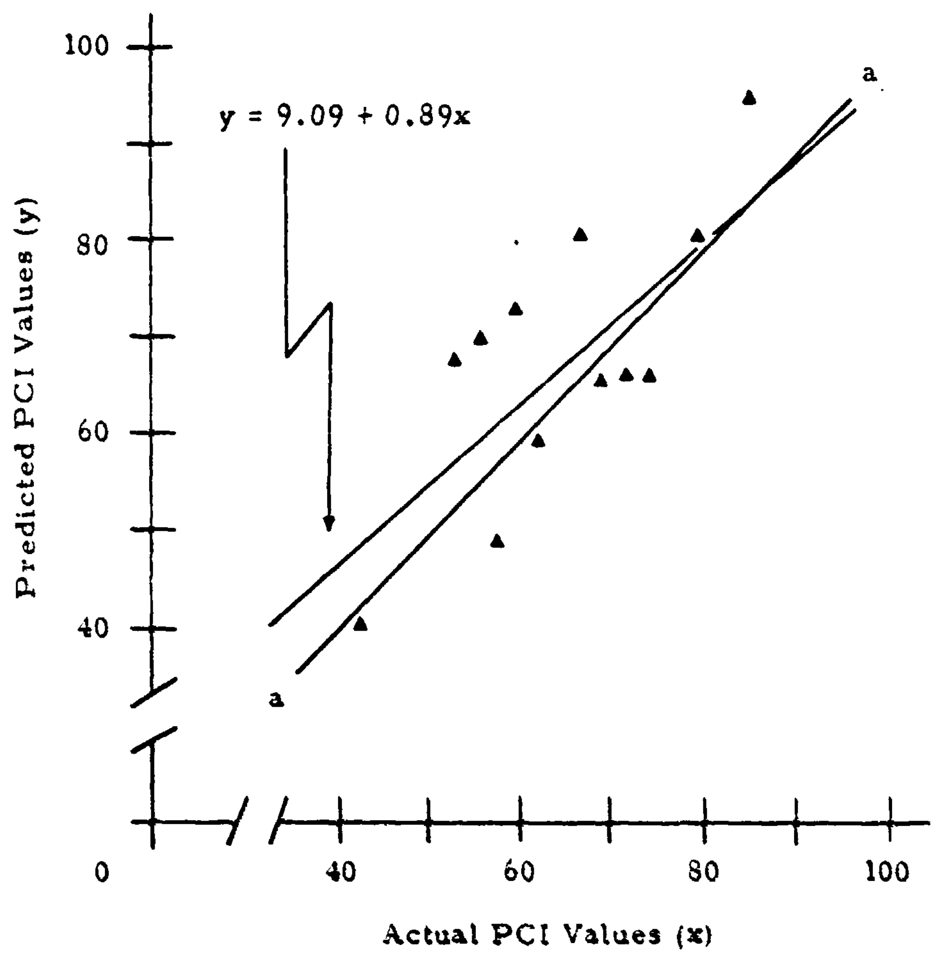


Fig. 4-2. Scattergram of Actual Versus Predicted PCI Values for the Improved PCI Prediction Model

improved model, it was discovered that the calculated Pearson product-moment correlation coefficient had decreased slightly from that value calculated using the original prediction model. Given the Wright-Patterson AFB data, the correlation coefficient was calculated at 0.80 for the original model, compared with 0.71 using the improved model. This change depicts a slight reduction in the overall strength of the linear relationship existing between the actual and predicted PCI values.

Modified Improved Model

Having developed an improved model for predicting the condition of rigid airfield pavements, based upon the Construction Engineering Research Laboratory data, the implications of enlarging this data base were then examined. Information collected on the 12 rigid pavement features surveys at Wright-Patterson AFB was added to the original data base. Again the new variables described in Table 4-4 were computed, and combining them with the original variables, a multiple regression analysis was accomplished (Ref. Appendix F). Those variables identified as insignificant in predicting the PCI value, using the partial F-test at a significance level of 0.05, were eliminated from the equation. This analysis resulted in a modification to the improved model, expressed as:

$$
\begin{aligned}
PCI = 98.2 &- 0.7467189\ (I_1LDAM9) \\
&+ 0.4456063 \times 10^{-2}\ (II_1LDAM9) \\
&- 0.6599812 \times 10^{-4}\ (I_2FATR) \\
&- 0.3101097 \times 10^{-4}\ (PREAG) \\
&- 0.6928678 \times 10^{-4}\ (DAMFT) \\
&- 0.1493424 \times 10^{-2}\ (II_2AGECOL) \\
&- 0.4455170 \times 10^{-2}\ (DAMAG) \qquad [4\text{-}3]
\end{aligned}
$$

where: PCI = Pavement Condition Index at age and traffic since construction or overlay

$I_1LDAM9 = AGE\ [LOG_{10}\ (DAMAGE + 10)]$

AGE = time since original construction or, if overlaid, time since overlay construction

DAMAGE = pavement damage factor

$II_1LDAM9 = I_1LDAM9^2$

$I_2FATR = AGE^2 \sqrt{FAT}$

FAT = pavement fatigue factor

$PREAG = I_2PRECI \times II_2AGECOL$

$I_2PRECI = AGE^2$ (annual precipitation)

$II_2AGECOL = \sqrt{AGE}\ (AGECOL)(LDAMCOL)/THICK$

AGECOL = pavement age before overlay

LDAMCOL = pavement damage before overlay

THICK = most recent overlay thickness

$$DAMFT = I_1LDAM9 \times I_2FTCR$$

$$I_2FTCR = AGE^2 \sqrt{\text{number of freeze-thaw cycles at a 2 inch depth}}$$

$$III_2AGECOL = II_2AGECOL^2$$

$$DAMAG = I_1LDAM9 \times II_2AGECOL$$

Contained in Table 4-6 is a summary of the data used in developing this expression.

Though the same independent variables remain significant for both the improved model (i.e. Equation 4-2) and the modified improved model (i.e. Equation 4-3), there appears to be some inequity surrounding each variable's relative influence on the predicted condition of rigid airfield pavements. When including the additional data in the regression analysis, the coefficients of the variables I_1LDAM9 and II_1LDAM9, increased in value, thereby indicating an increase in the strength that these two variables have in predicting the PCI value. On the other hand, the variables I_2FATR, PREAG, DAMFT, $III_2AGECOL$ and DAMAG slightly decreased in their predictive influence, while the constant, 98.2, remained virtually unchanged throughout this analysis.

Of primary importance here is the fact that this modified

TABLE 4-6

A Summary of Data Used in Developing the Modified Improved PCI Prediction Model

Variable	Mean	Range	Standard Deviation
AGE (Years)	17.63	1.0 - 37.0	7.08
AGECOL (Years)	3.08	0 - 30.0	7.03
Freeze-Thaw Cycles	23.34	0 - 105.0	40.52
Annual Precipitation (Inches)	30.51	3.8 - 52.1	16.77
FAT	81818.61	352.0 - 658325.0	122139.47
DAMAGE	8450.93	0 - 282780.0	38836.26
DAMCOL	15551.75	0 - 568460.0	73708.11
THICK (Inches)	0.74	0 - 8.0	1.82
I_1LDAM9	27.38	1.01 - 140.14	23.26
I_2FTCR	1064.91	0 - 5101.49	1867.98
I_2PRECI	10807.41	15.20 - 54512.50	9017.77
II_2AGECOL	11.39	0 - 197.97	35.17
LDAMCOL	1.34	1.0 - 5.76	1.06
I_2FATR	78747.19	22.19 - 709414.89	87631.48
II_1LDAM9	1287.48	1.02 - 19638.84	2707.28
III_2AGECOL	1359.70	0 - 39192.74	5798.44
DAMFT	25465.50	0 - 250276.26	47405.39
PREAG	61805.41	---	202030.69
DAMAG	590.71	0 - 9855.58	2023.02
Actual PCI	73.51	17.0 - 98.0	16.44

improved PCI prediction model has a coefficient of determination of greater value than the improved model. For the improved model the coefficient of determination was computed at 0.69 while the modified improved model has a computed value of 0.71. Subsequently, the coefficient of determination for the modified model is also greater then that computed for the original prediction model (i.e. Equation 2-8); almost a 10% increase in value. The fact that the coefficient of determination for this modified improved model is greater than that for either the original or improved model implies that the modified improved model is a better predictor of PCI values. Therefore, based upon these results, it is suggested the modified improved model is the most appropriate instrument thus far available for predicting the condition of rigid airfield pavements.

Modified Improved Model Evaluation

Actual PCI values measured at Wright-Patterson AFB were once again compared with predicted PCI values, this time using the modified improved PCI prediction model. Figure 4-3 depicts the actual versus predicted PCI value relationship. Though the values do not plot along line a-a, the best fitting straight line to this data is noticeably closer to line a-a than observed using any of the previous prediction models. The best fitting straight line to this data is

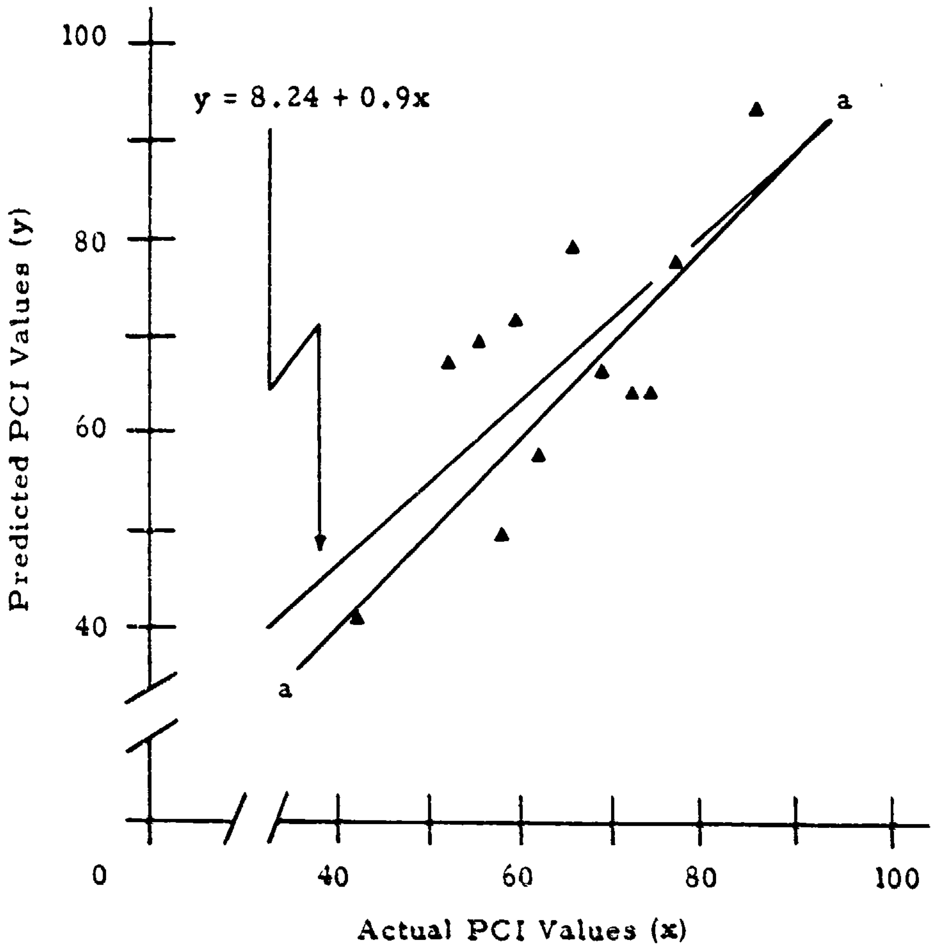


Fig. 4-3. Scattergram of Actual Versus Predicted PCI Values for the Modified Improved PCI Prediction Model

defined as having a slope of 0.90 and an intercept of 8.24. The strength of the linear relationship between the actual and predicted PCI values, as measured by the Pearson product-moment correlation coefficient, was calculated at 0.73, a slight increase over the improved PCI prediction model. From this it can be concluded, the modified improved PCI prediction model provides the best possible estimate of the actual condition of the 12 rigid airfield pavement features located at Wright-Patterson AFB.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

This research effort addressed the need to evaluate the most current Air Force PCI prediction models for airfield pavements. Upon these models, hinges an even greater requirement, that being the development of an airfield pavement maintenance management system. While most of the airfields owned by the Air Force are in need of some degree of repair or restoration, as discussed in Chapter I, considerable monetary restrictions exist. In light of this fact, a comprehensive airfield pavement maintenance management system is necessary to ensure the optimum use of limited resources. Because the forecasting models for pavement condition indicies form an integral element in the development of a pavement maintenance management system, it is essential to ensure their appropriateness.

This thesis evaluated the validity of the PCI prediction model for rigid airfield pavements. While formulating the research objective, a series of three questions were developed. Each of the research questions will be restated and the conclusions discussed separately.

Research Question #1: When applying a new data base, does the forecasting model reasonably predict actual pavement condition indicies?

Actual PCI values obtained on 12 rigid pavement features located at Wright-Patterson AFB were compared with values calculated employing the current Air Force PCI prediction model. The results indicated that the predicted values were reasonably close to their corresponding actual PCI values. However, the model was incapable of estimating PCI values completely free of error. The data demonstrated definite signs of linearity, yet the prediction model typically provided PCI values greater than the actual values. Computing the intersection between the best fitting straight line to the comparative data, and the optimum relationship of a predicted PCI equal to an actual PCI, it was observed that the predicted values were frequently greater than the actual values, up to a PCI value of 85. For rigid pavements having an actual PCI value greater than 85, the model would generally predict values less than the actual. A comparison between the actual (i.e. best fitting straight line to the data) and optimum response is illustrated in Figure 5-1. This illustration depicts a significant shortcoming to the prediction model. As identified in Figure 5-1, the major discrepancies between the actual and predicted values occur at the lower level PCI values. Because the lower values of PCI signify pavements of unsatisfactory condition, the majority of maintenance and repair work is devoted to pavements

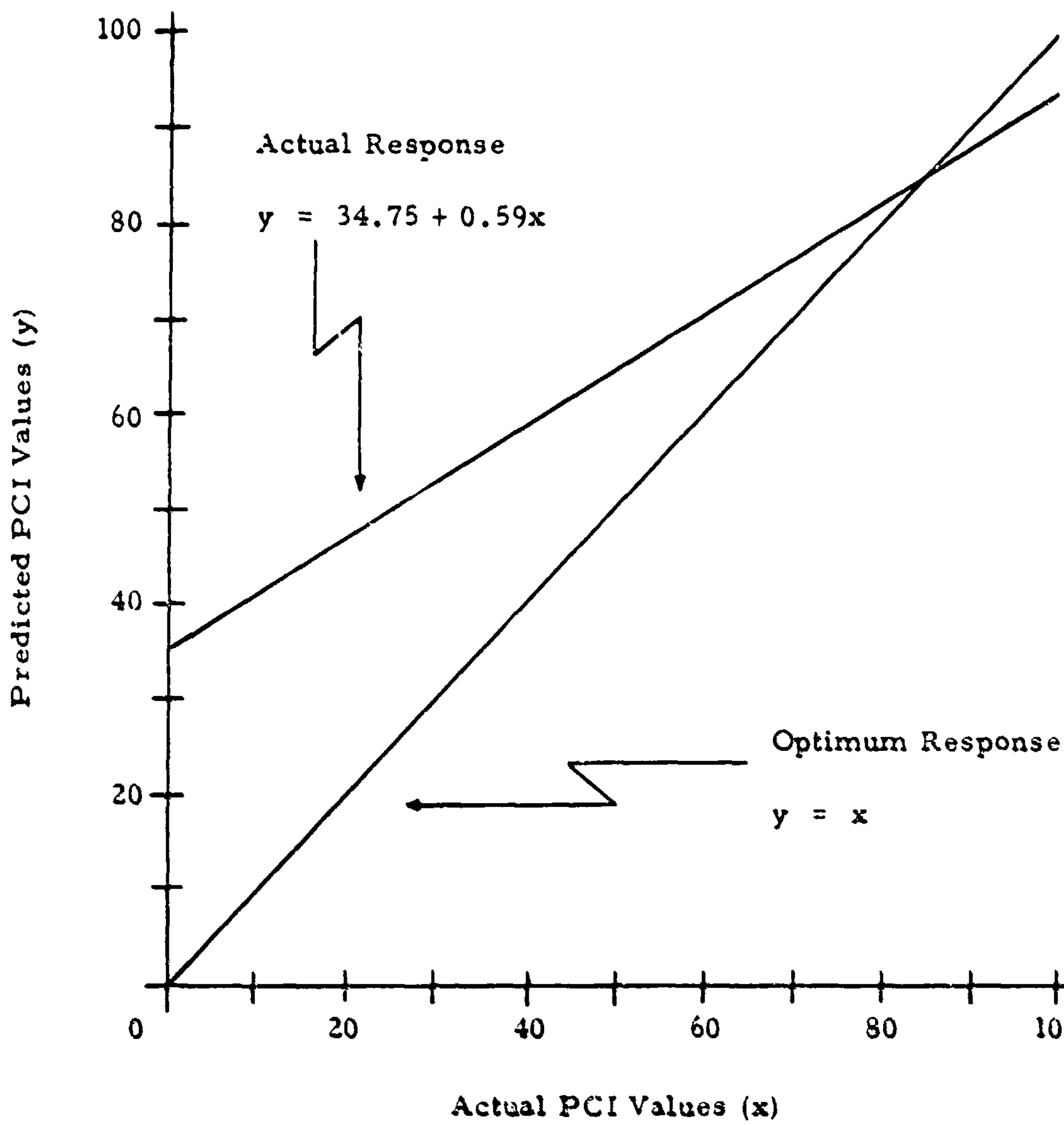


Fig. 5-1. A Comparison of Actual and Predicted PCI Values

having low PCI values. Therefore, in using this forecasting model, the error of prediction is greatest at PCI levels where accurate estimates of the pavement condition are most critical.

Research Question #2: What effect does adding the new field data to the original data base have on the PCI prediction model?

New field data collected at Wright-Patterson AFB was combined with the data base used in developing the PCI prediction model, resulting in several changes to the model. Although all of the original independent variables in the equation remained significant in predicting PCI values, their relative degrees of influence on the PCI value changed somewhat. Secondly, the utility of the prediction model before including the Wright-Patterson AFB data was compared against that measured after the additional data was included. The results confirmed that there was an increase in the predictive capability of the model, subsequent to enlarging the data base. This improvement was identified by an increase in the model's coefficient of determination, from 0.65 to 0.67.

Research Question #3: Given the data available, can this prediction model be improved upon?

Speculation on improvements in the model were studied by introducing interaction among the independent variables and curvature in the independent/dependent variable response surface. This led to the development of a prediction model, containing several new terms, in addition to variables present in the original model. Comparing the utility of the new model (i.e. Equation 4-2) with that of the original model (i.e. Equation 2-8), the new model was observed to be a better predictor of the condition of rigid airfield pavements. The coefficient of determination had increased from 0.65, calculated for the original model, to 0.69.

Enlarging the data base with information collected at Wright-Patterson AFB resulted in a slight modification to the new, improved PCI prediction model. However, there were no significant alterations in the variables present in the model. The additional data did increase the predictive capability of the model by increasing the coefficient of determination, from 0.69 to 0.71.

Overall, this thesis achieved its purpose of examining the validity of the PCI prediction model for rigid airfield pavements. Based upon the research effort presented, it can be concluded that the original prediction model, developed by the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, is incapable of providing prediction values with complete accuracy. For example, a pavement feature having an actual PCI value of 10 would have a predicted value of 41, when employing the original model. This equates to a 300 percent error, and the difference between a "failed" condition pavement and a "fair" condition pavement.

Furthermore, the improved model developed during this study, perhaps to be modified by an enlarged data base, may prove a better predictor of the condition of rigid airfield pavements. A pavement feature having an actual PCI value of 10 has a corresponding predicted PCI value of 18, when applying the improved PCI prediction model.

Recommendations

Developing airfield PCI prediction models is a fairly new endeavor for the Air Force, and therefore requires considerably more research. Currently, the field is extremely dynamic, with work continuing to improve upon existing equations and models. This, coupled with the fact that this thesis was accomplished under fairly strict assumptions and limitations, as discussed in Chapter III, provides vast opportunities for additional study. Below are areas recommended for further research, either in conjunction with, or independent of this thesis.

1. Efforts should continue examining the U.S. Army Corps of Engineers' PCI prediction model for rigid airfield pavements. Collecting and applying additional data from airfields not yet tested with the model would provide valuable insight concerning the behavior of the model when exposed to large quantities of new information. As this thesis compared actual and predicted PCI values located

solely at Wright-Patterson AFB, new data collected from different airfields would confirm the results of this study, or identify any unknown peculiarities concerning the prediction model or the Wright-Patterson AFB data.

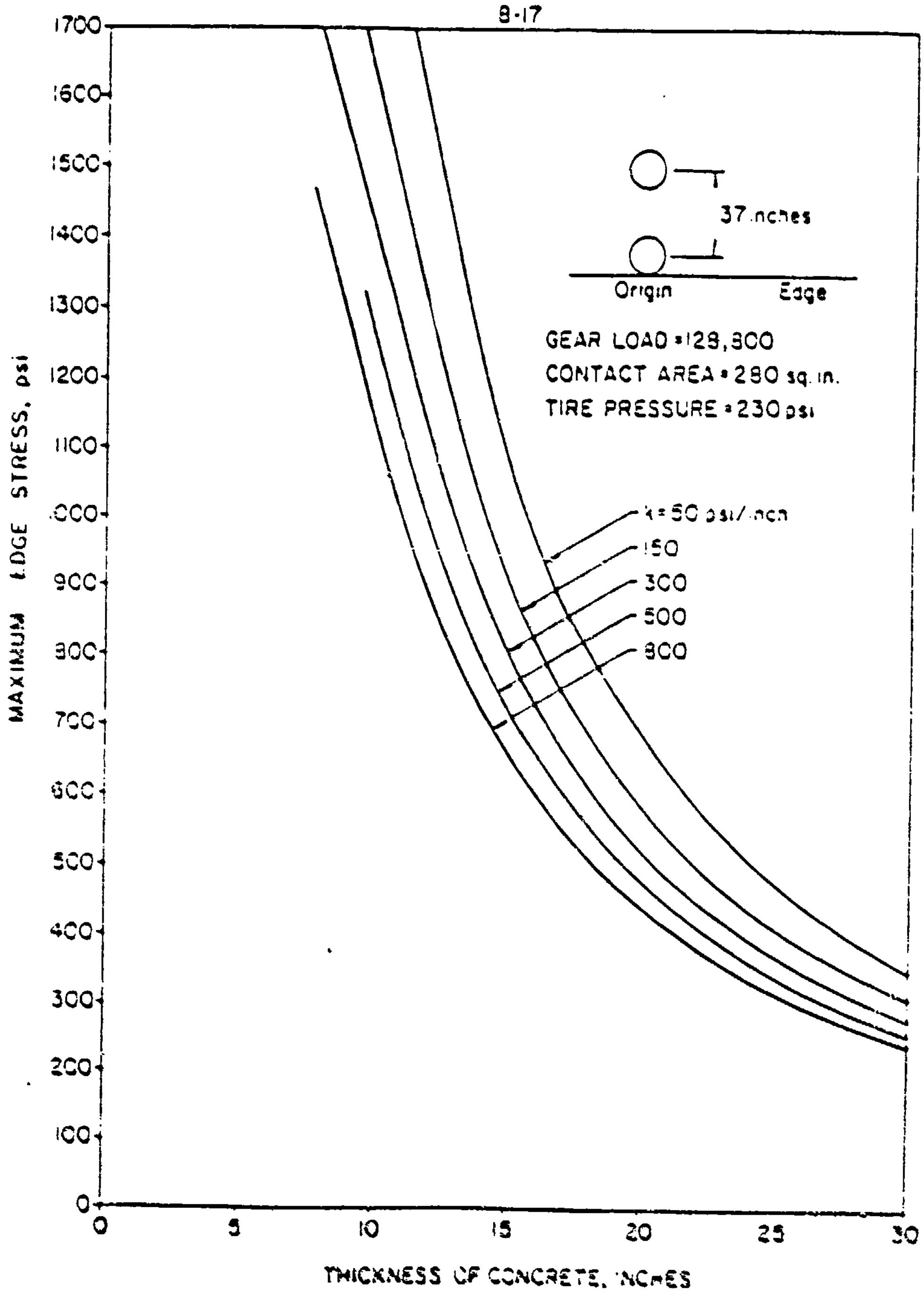
2. As a result of this study, an improved PCI prediction model was developed, based upon the original data combined with new data collected at Wright-Patterson AFB. No attempt has yet been made to either prove or denounce the reliability of the improved prediction model, by using a new and separate data base. The need exists to evaluate the effectiveness of this model in predicting PCI values, in much the same manner that this research examined the original PCI prediction model.

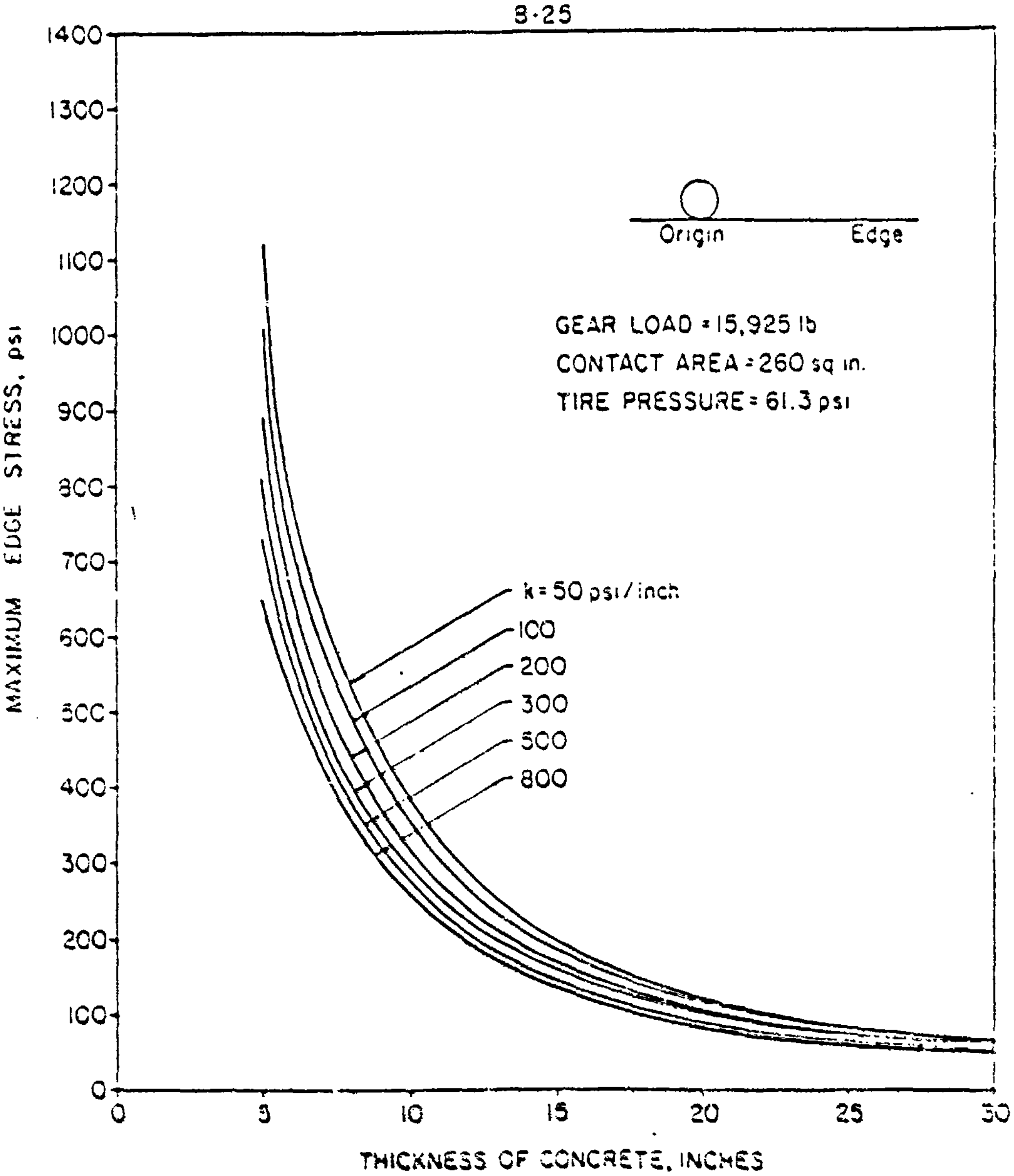
3. In developing pavement condition forecasting models, the Construction Engineering Research Laboratory designed rigid and flexible prediction models. This thesis specifically examined the rigid pavement prediction model. Of equal importance is the requirement to validate the PCI prediction model for flexible airfield pavements.

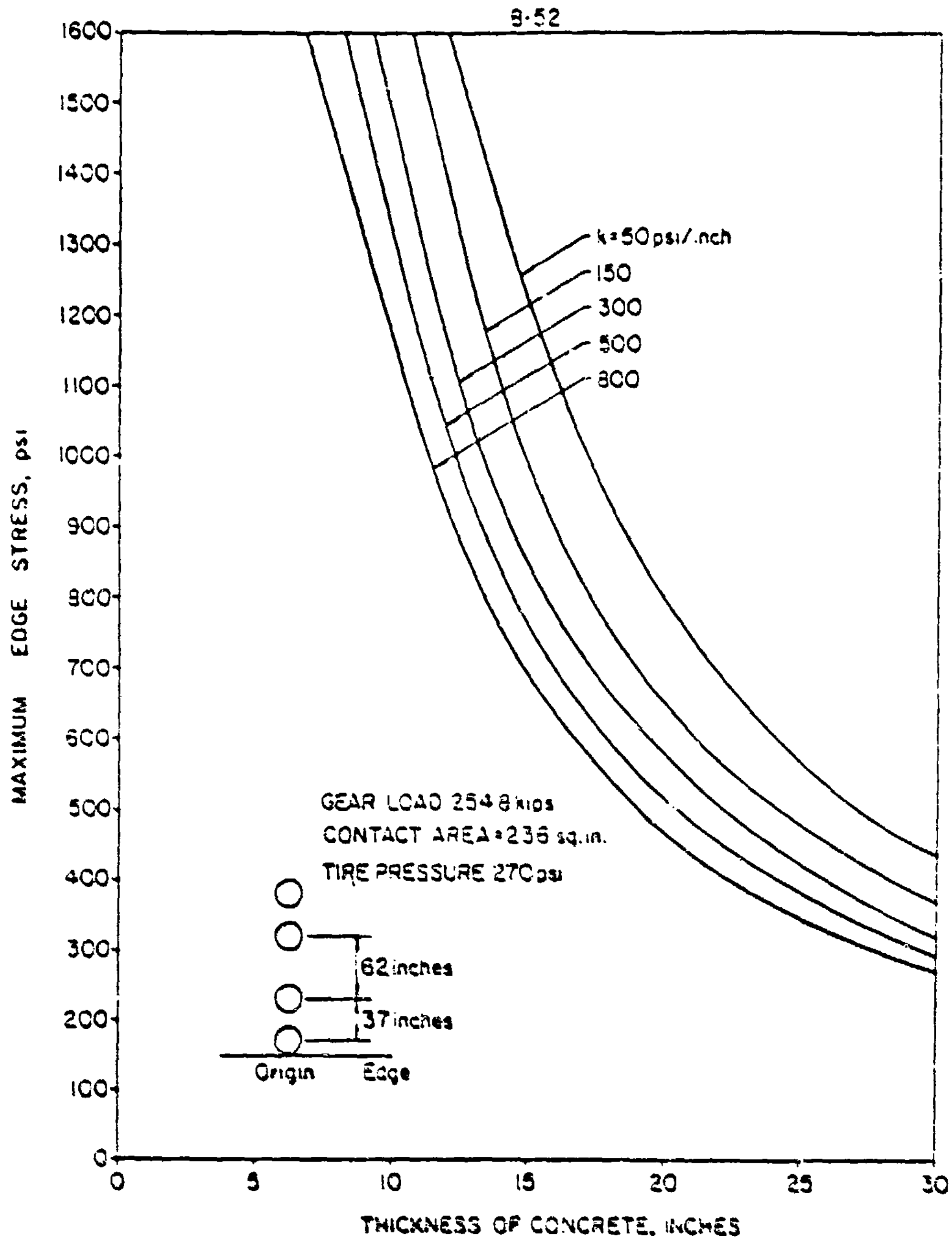
APPENDICIES

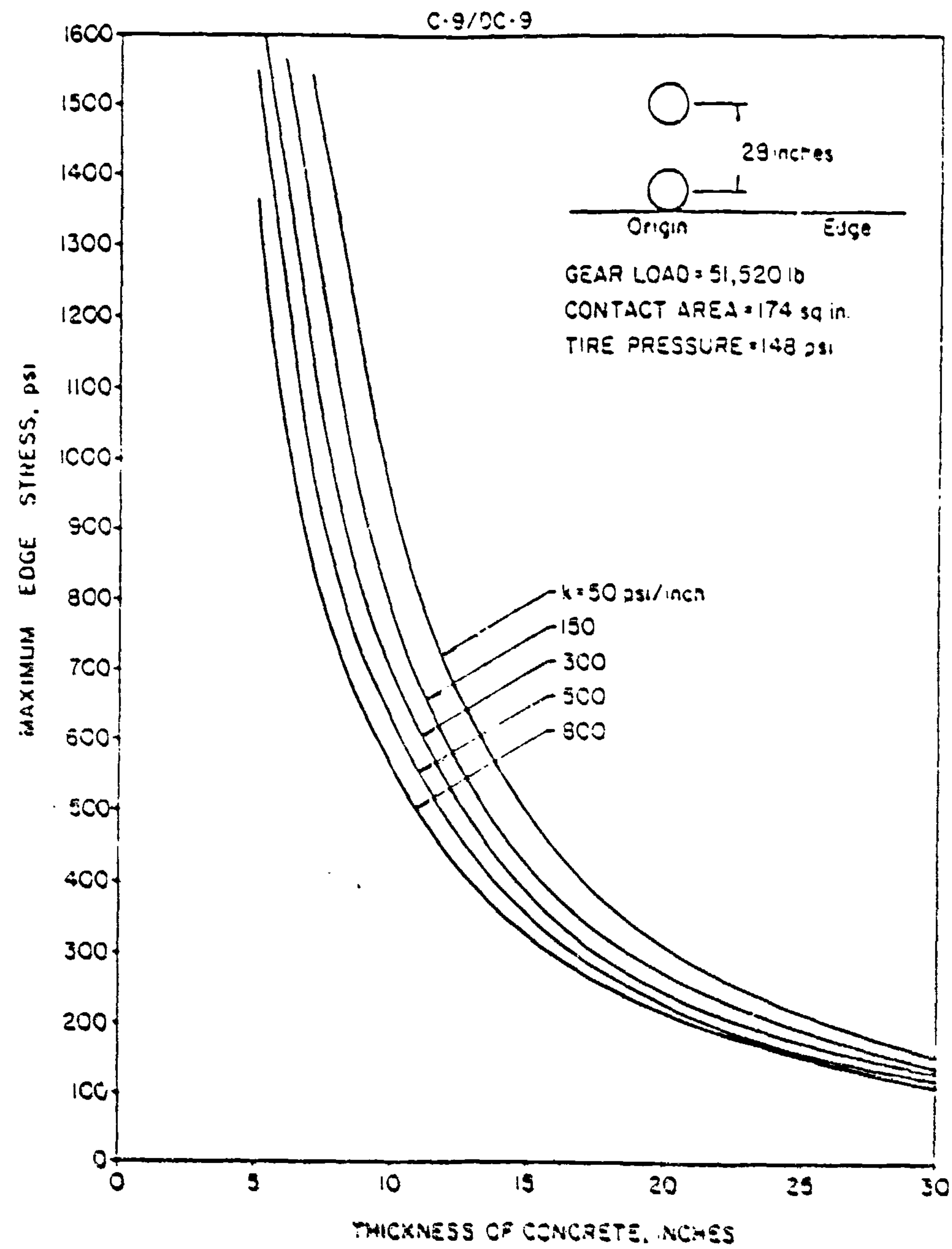
APPENDIX A

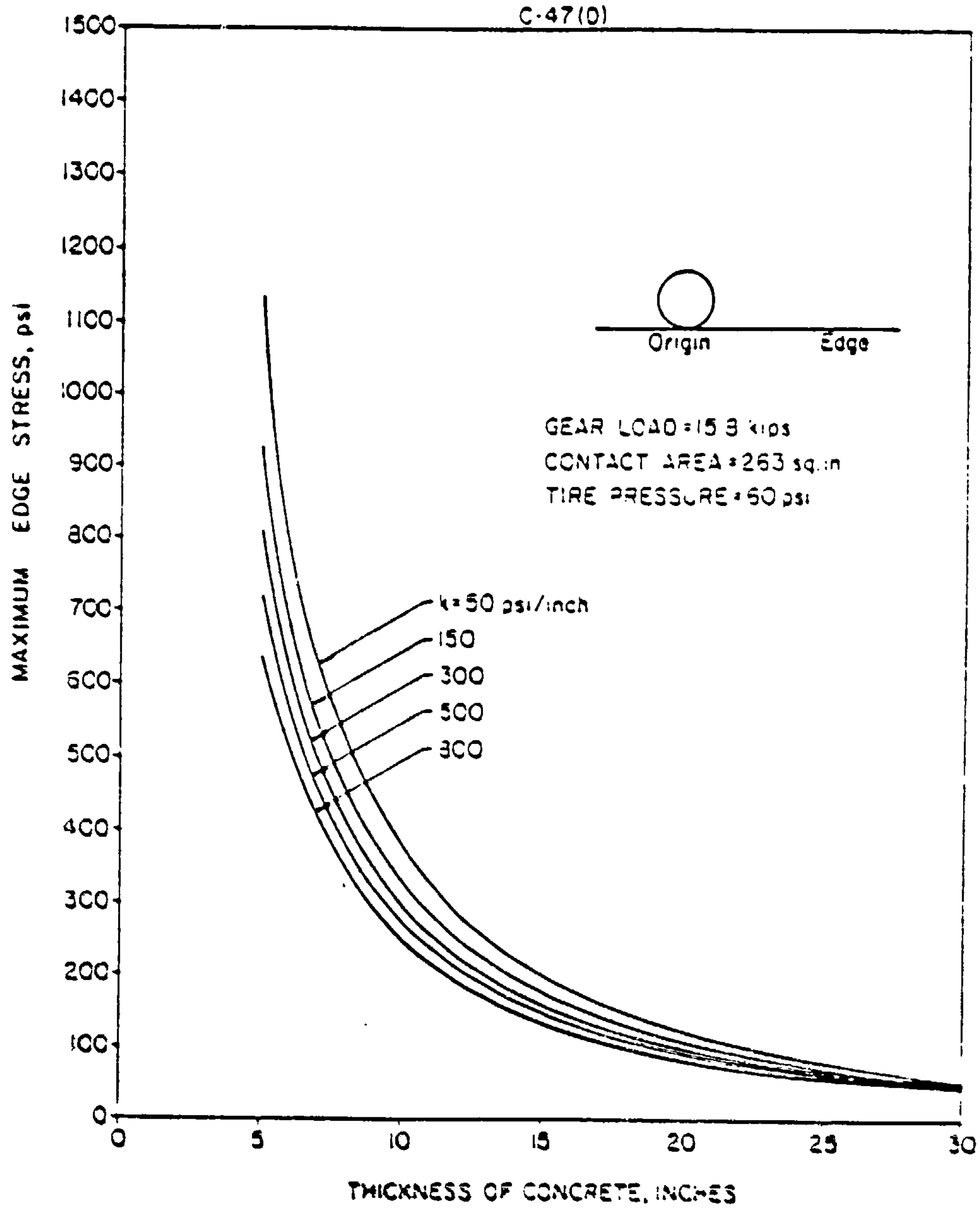
RIGID PAVEMENT EDGE STRESS CHARTS


8-17
37 inches
Origin
Edge
GEAR LOAD = 128,300
CONTACT AREA = 280 sq. in.
TIRE PRESSURE = 230 psi
k = 50 psi/inch
150
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES

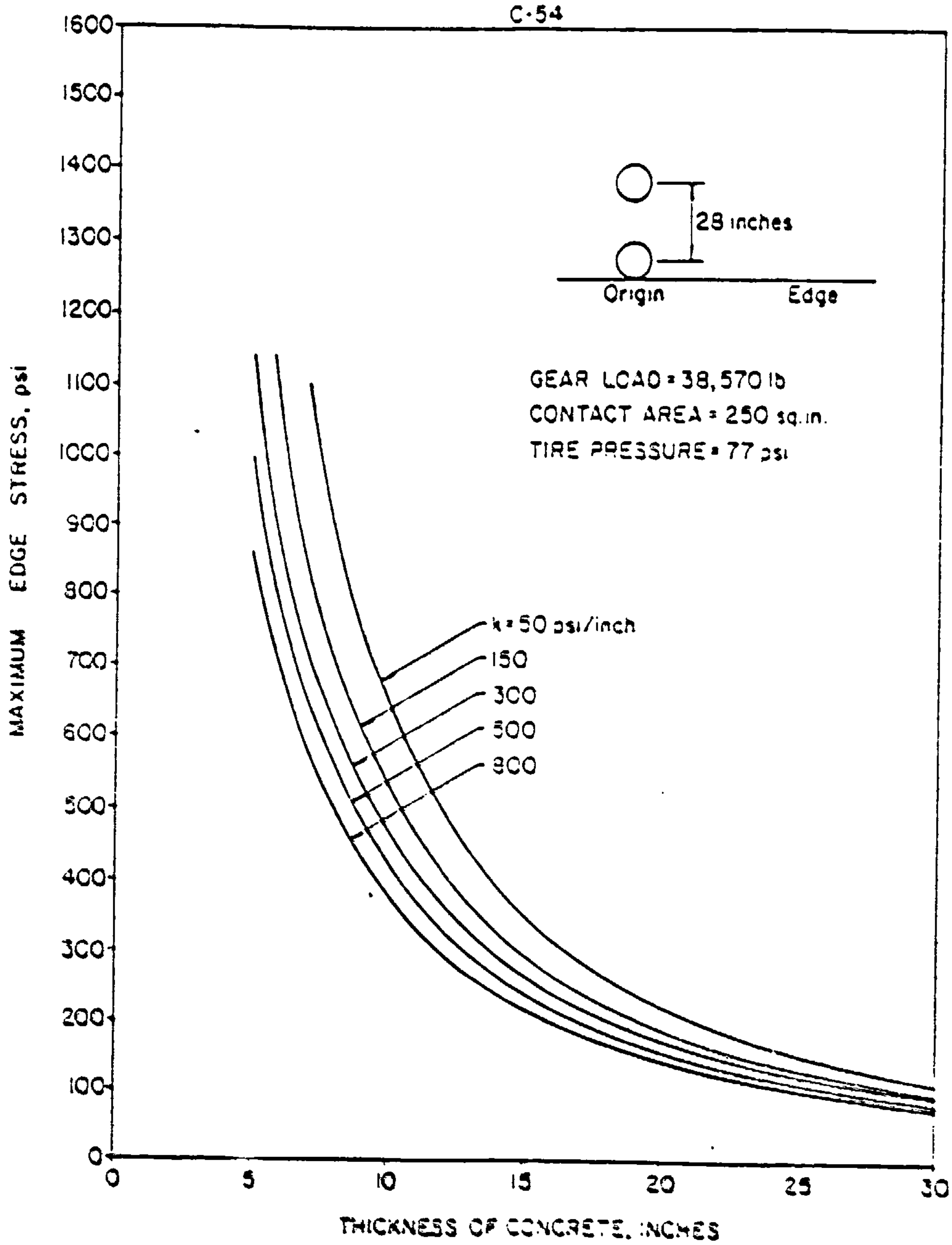

B-25
GEAR LOAD = 15,925 lb
CONTACT AREA = 260 sq in.
TIRE PRESSURE = 61.3 psi
Origin
Edge
k = 50 psi/inch
100
200
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
0
5
10
15
20
25
30

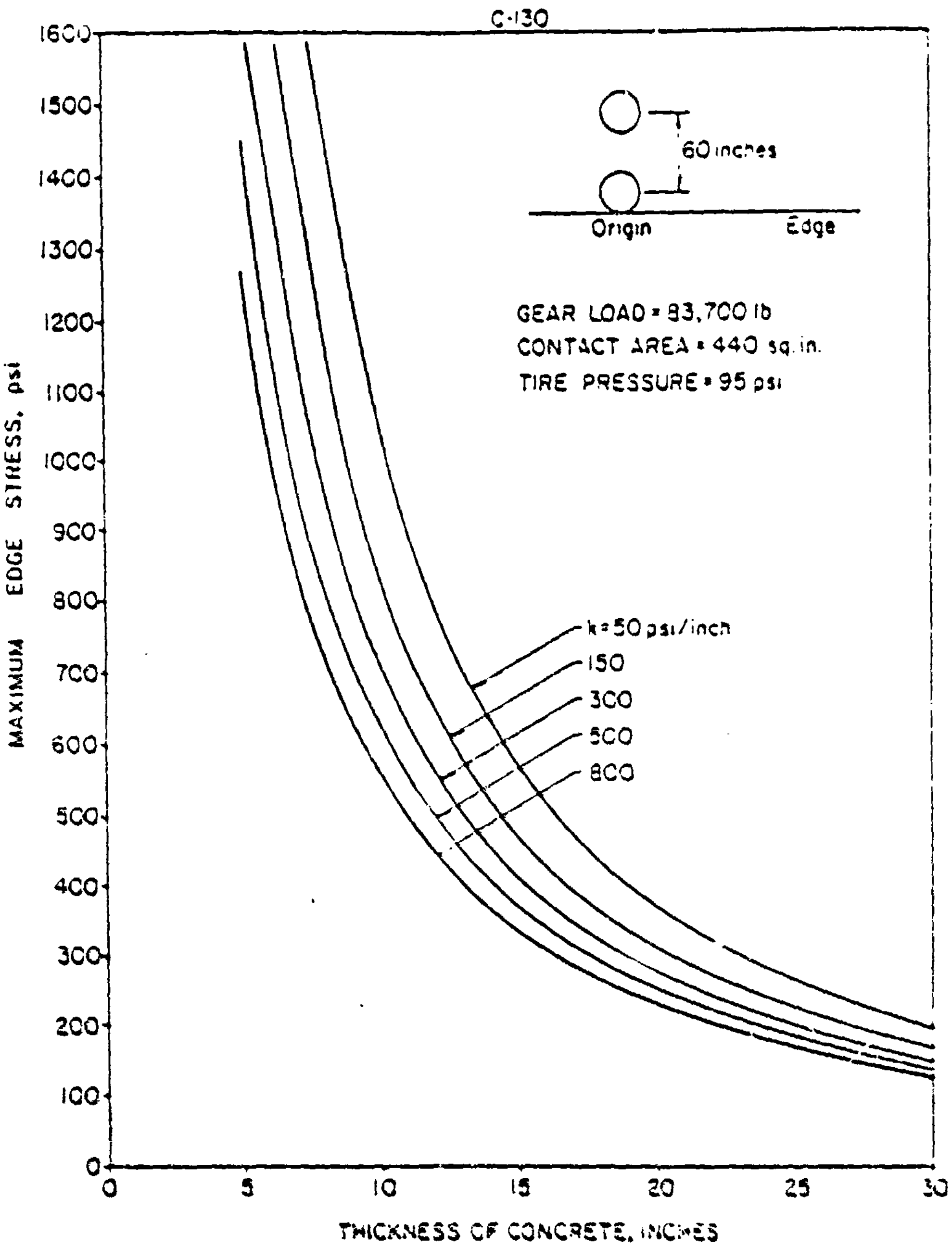

B-52
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
MAXIMUM EDGE STRESS, psi
0
5
10
15
20
25
30
THICKNESS OF CONCRETE, INCHES
k=50psi/inch
150
300
500
800
GEAR LOAD 254.8 kips
CONTACT AREA=236 sq.in.
TIRE PRESSURE 270psi
62 inches
37 inches
Origin
Edge

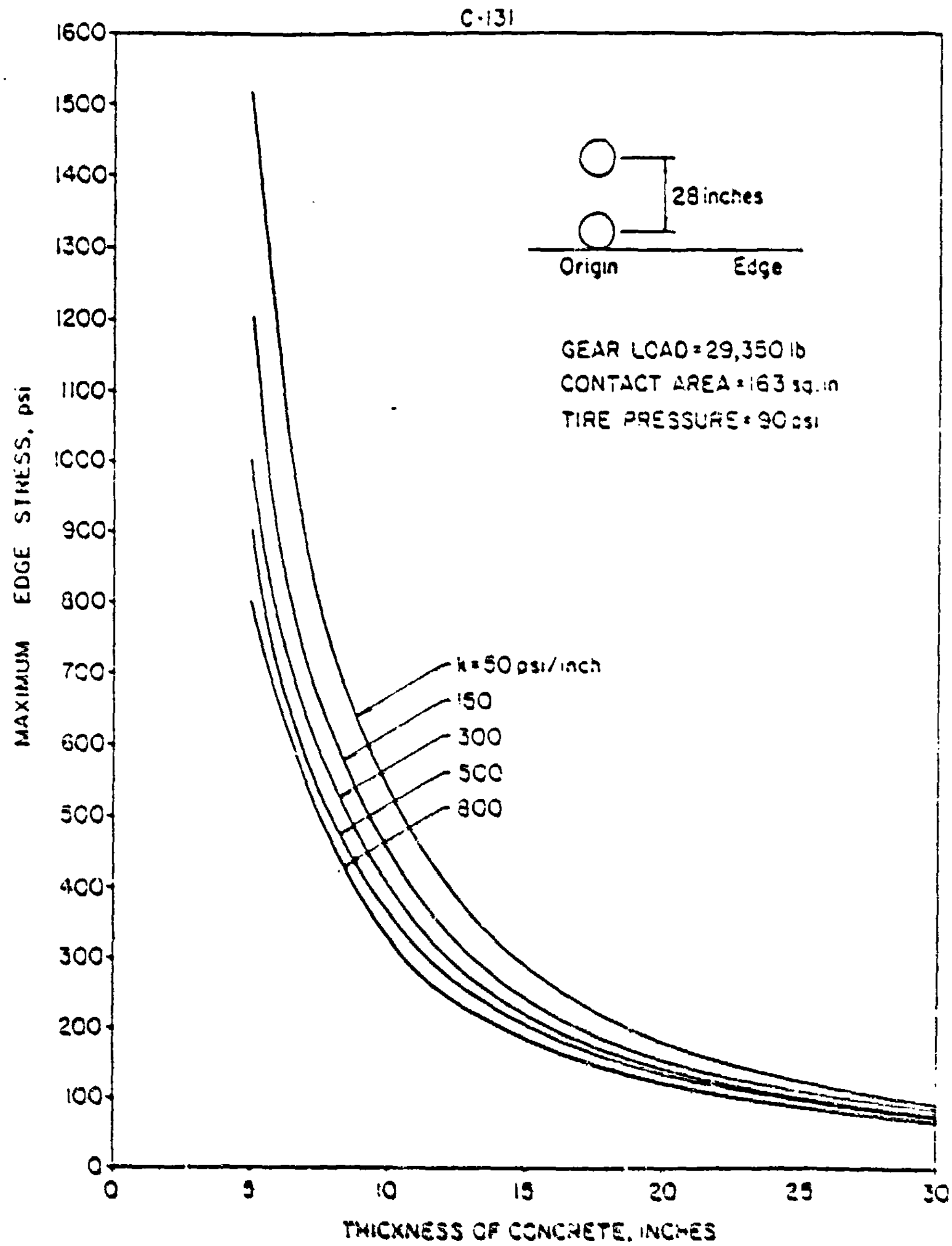

C-9/DC-9
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
MAXIMUM EDGE STRESS, psi
29 inches
Origin
Edge
GEAR LOAD = 51,520 lb
CONTACT AREA = 174 sq in.
TIRE PRESSURE = 148 psi
k = 50 psi/inch
150
300
500
800
0
5
10
15
20
25
30
THICKNESS OF CONCRETE, INCHES



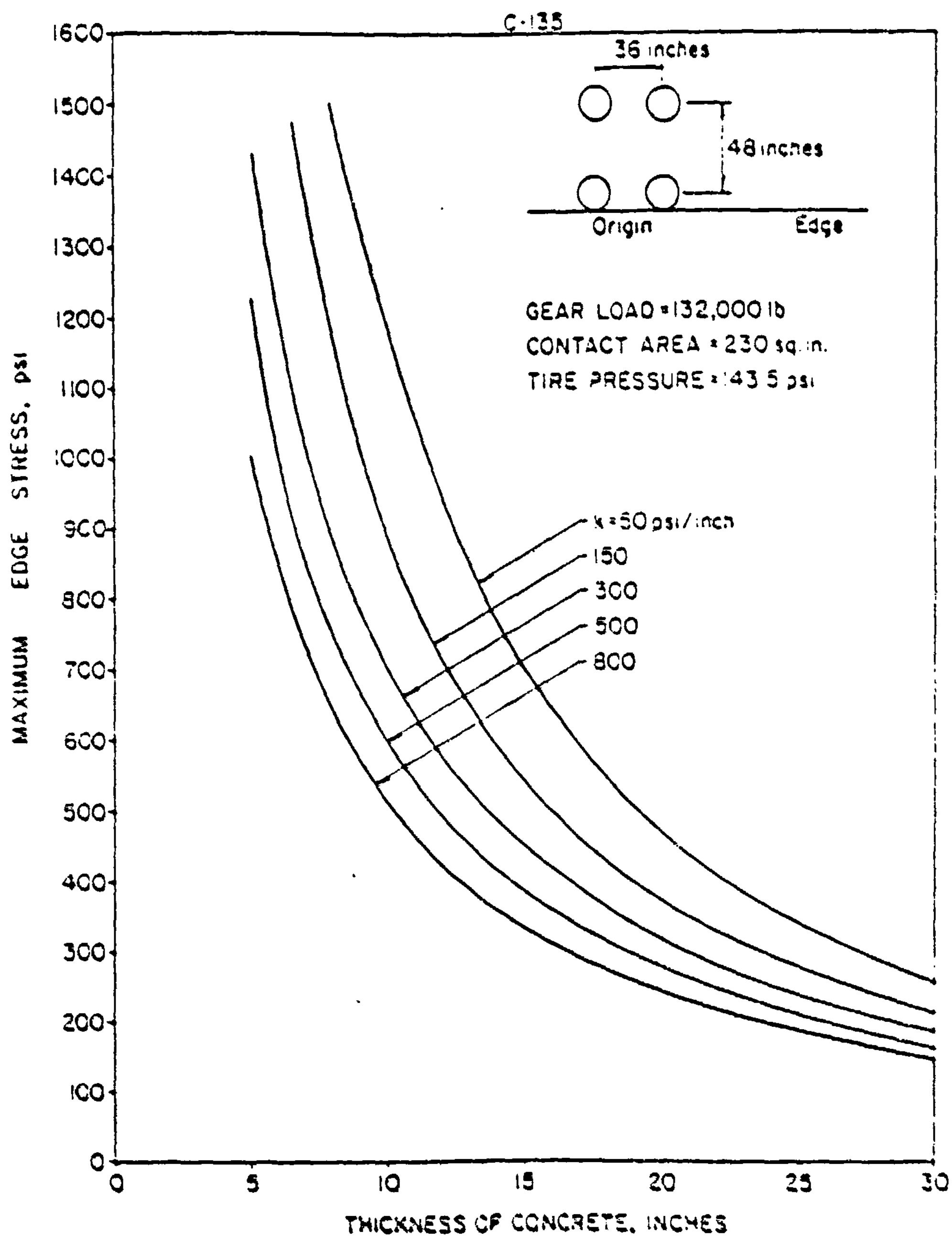
C-47(D)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
MAXIMUM EDGE STRESS, psi
Origin
Edge
GEAR LOAD = 15.8 kips
CONTACT AREA = 263 sq. in
TIRE PRESSURE = 60 psi
k = 50 psi/inch
150
300
500
800
0
5
10
15
20
25
30
THICKNESS OF CONCRETE, INCHES


1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
MAXIMUM EDGE STRESS, psi
28 inches
Origin
Edge
GEAR LOAD = 38,570 lb
CONTACT AREA = 250 sq.in.
TIRE PRESSURE = 77 psi
k = 50 psi/inch
150
300
500
800
0
5
10
15
20
25
30
THICKNESS OF CONCRETE, INCHES

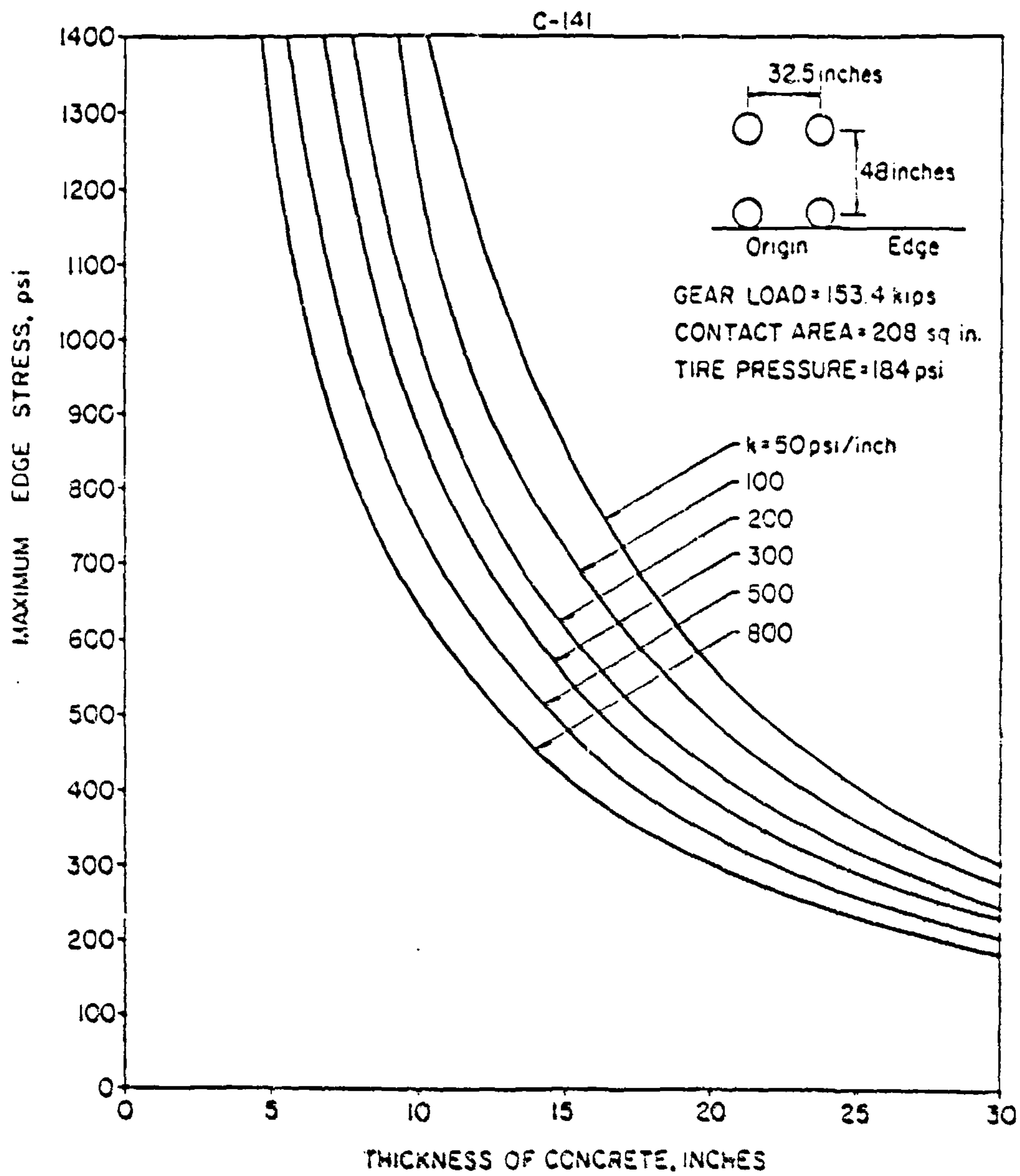

C-130
60 inches
Origin
Edge
GEAR LOAD = 83,700 lb
CONTACT AREA = 440 sq. in.
TIRE PRESSURE = 95 psi
k = 50 psi/inch
150
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES

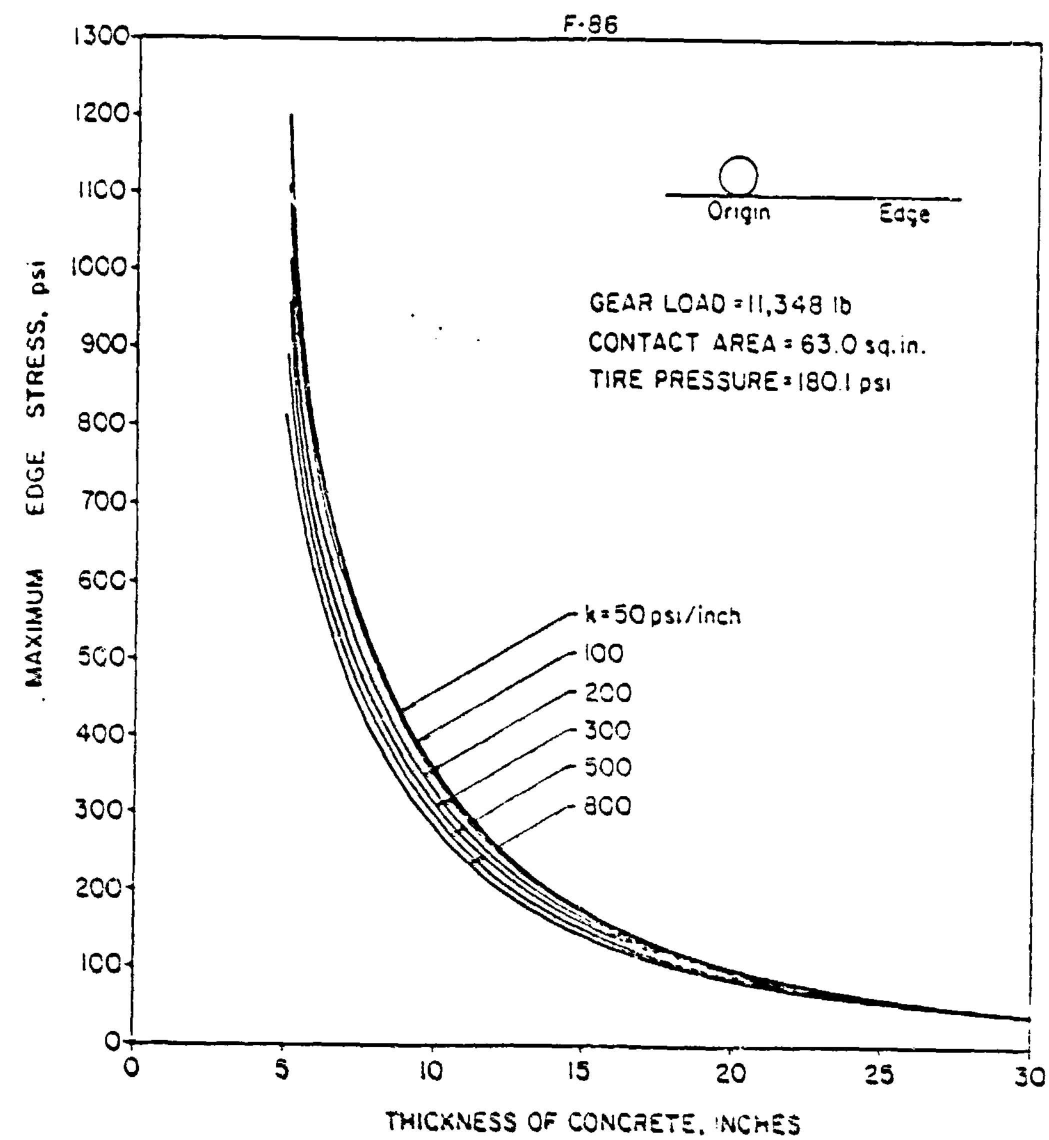


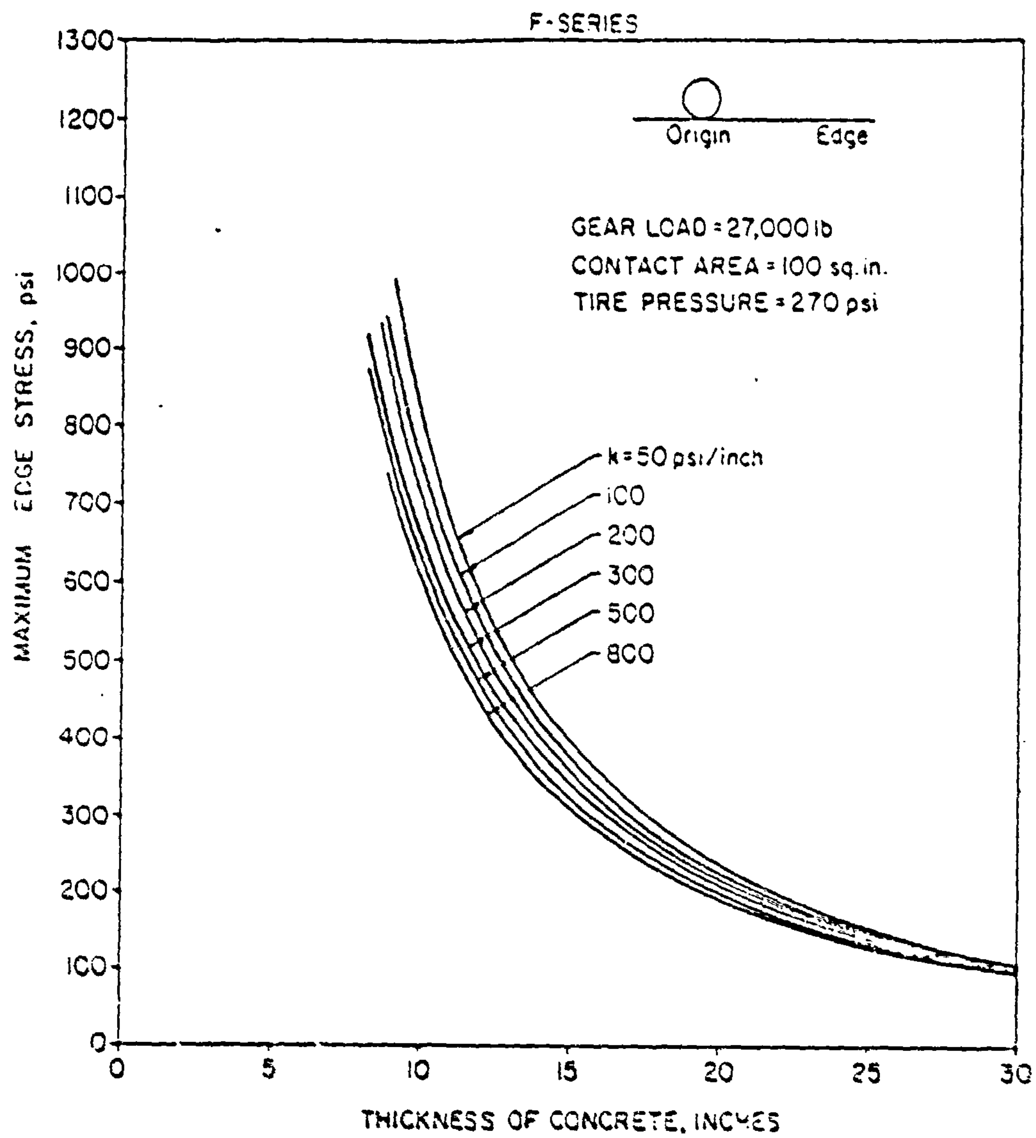
C-131
28 inches
Origin
Edge
GEAR LOAD = 29,350 lb
CONTACT AREA = 163 sq. in
TIRE PRESSURE = 90 psi
k = 50 psi/inch
150
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES
0
5
10
15
20
25
30
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600



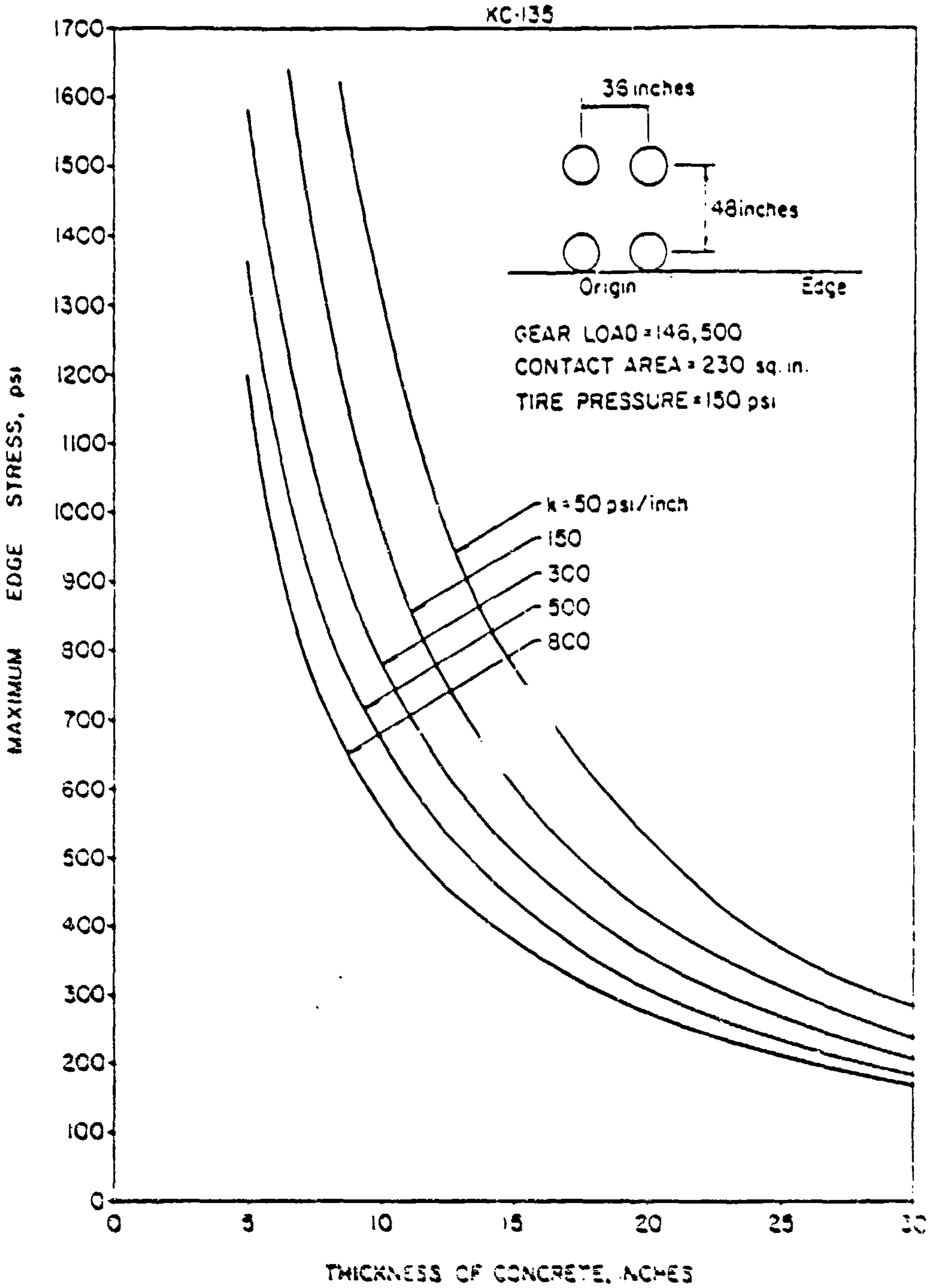
C-135
36 inches
48 inches
Origin
Edge
GEAR LOAD = 132,000 lb
CONTACT AREA = 230 sq. in.
TIRE PRESSURE = 143.5 psi
k = 50 psi/inch
150
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES

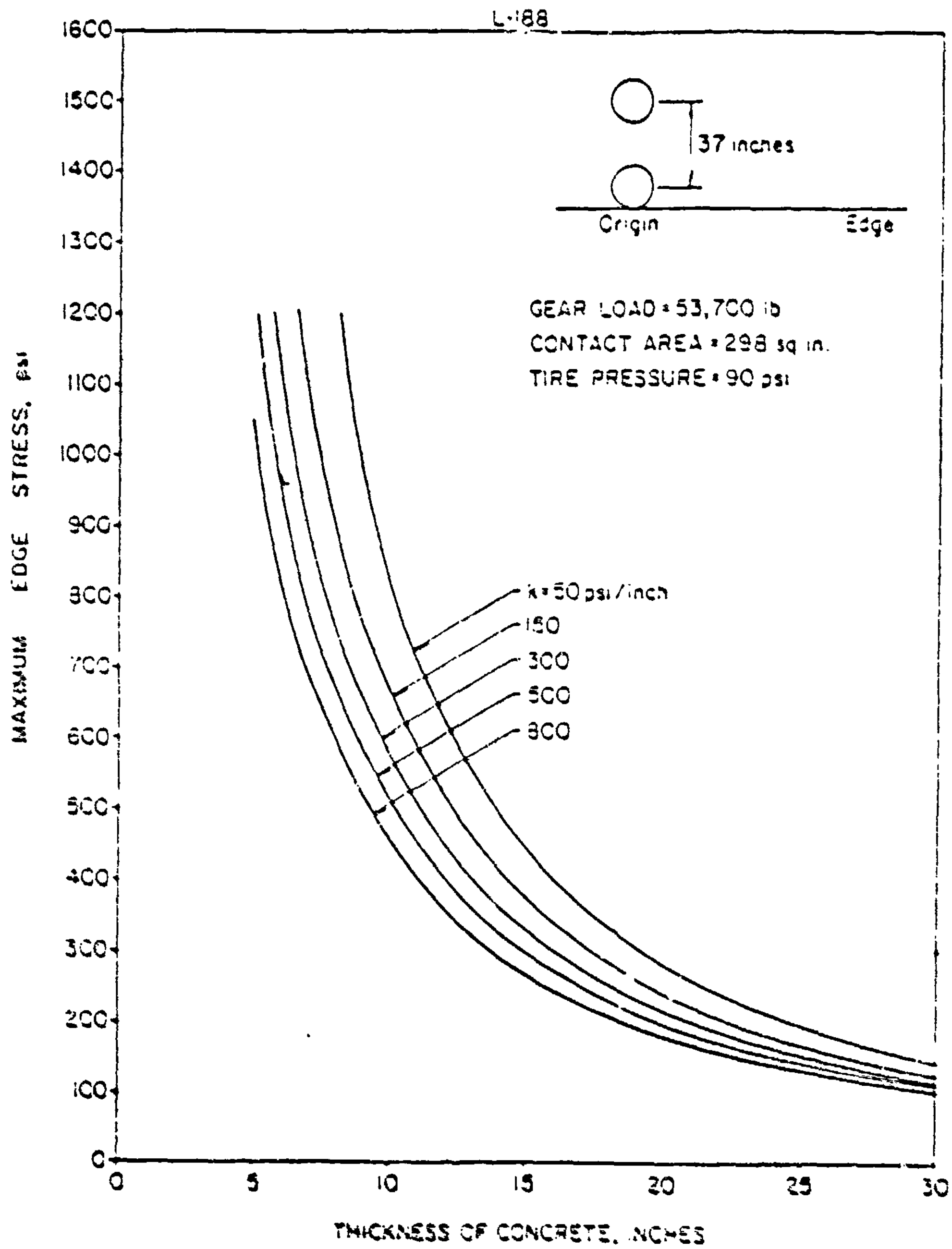

C-141
32.5 inches
48 inches
Origin
Edge
GEAR LOAD = 153.4 kips
CONTACT AREA = 208 sq in.
TIRE PRESSURE = 184 psi
k = 50 psi/inch
100
200
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
5
10
15
20
25
30

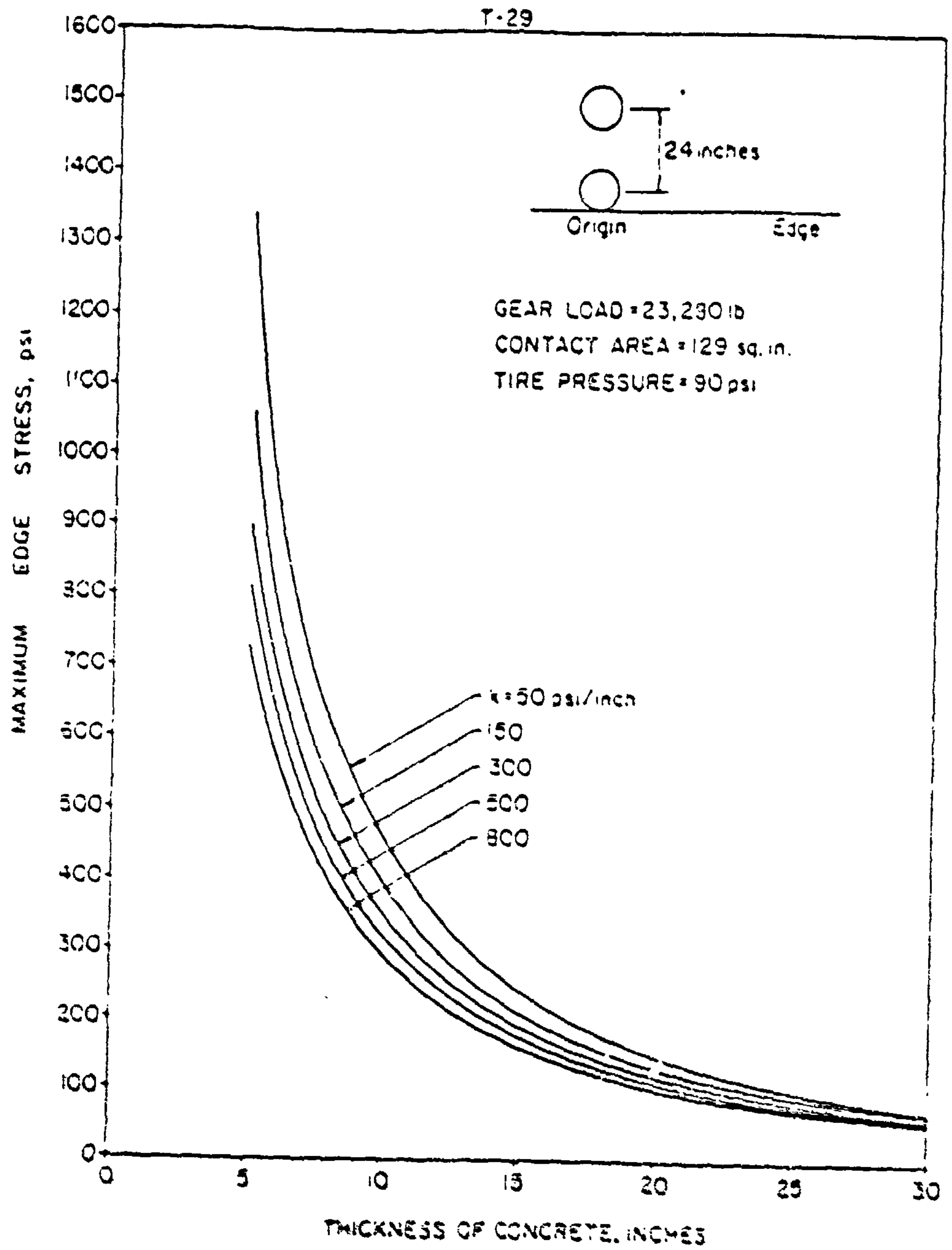

F-86
Origin
Edge
GEAR LOAD = 11,348 lb
CONTACT AREA = 63.0 sq. in.
TIRE PRESSURE = 180.1 psi
k = 50 psi/inch
100
200
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES

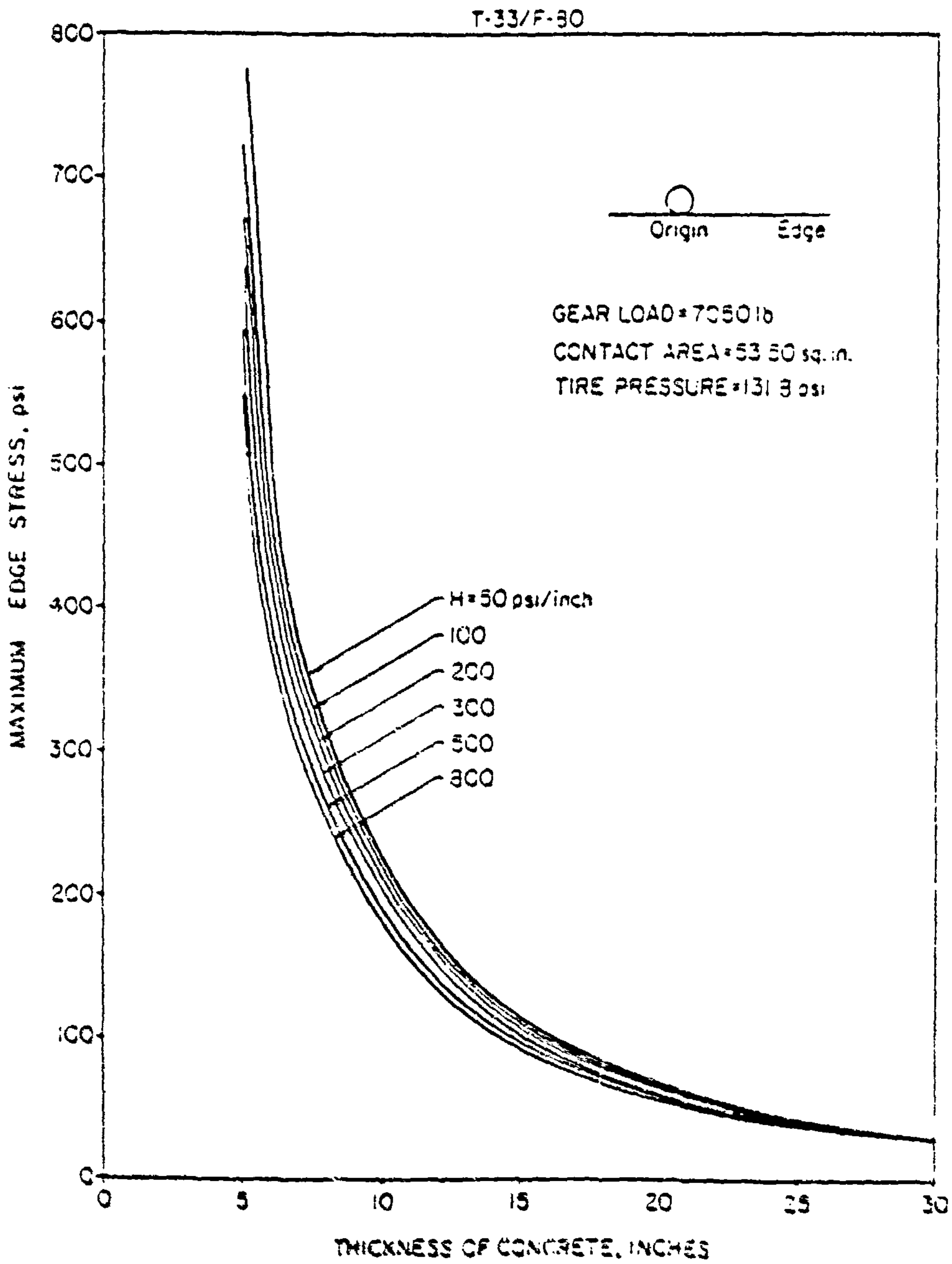


F-SERIES
Origin
Edge
GEAR LOAD = 27,000 lb
CONTACT AREA = 100 sq. in.
TIRE PRESSURE = 270 psi
k = 50 psi/inch
100
200
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
5
10
15
20
25
30

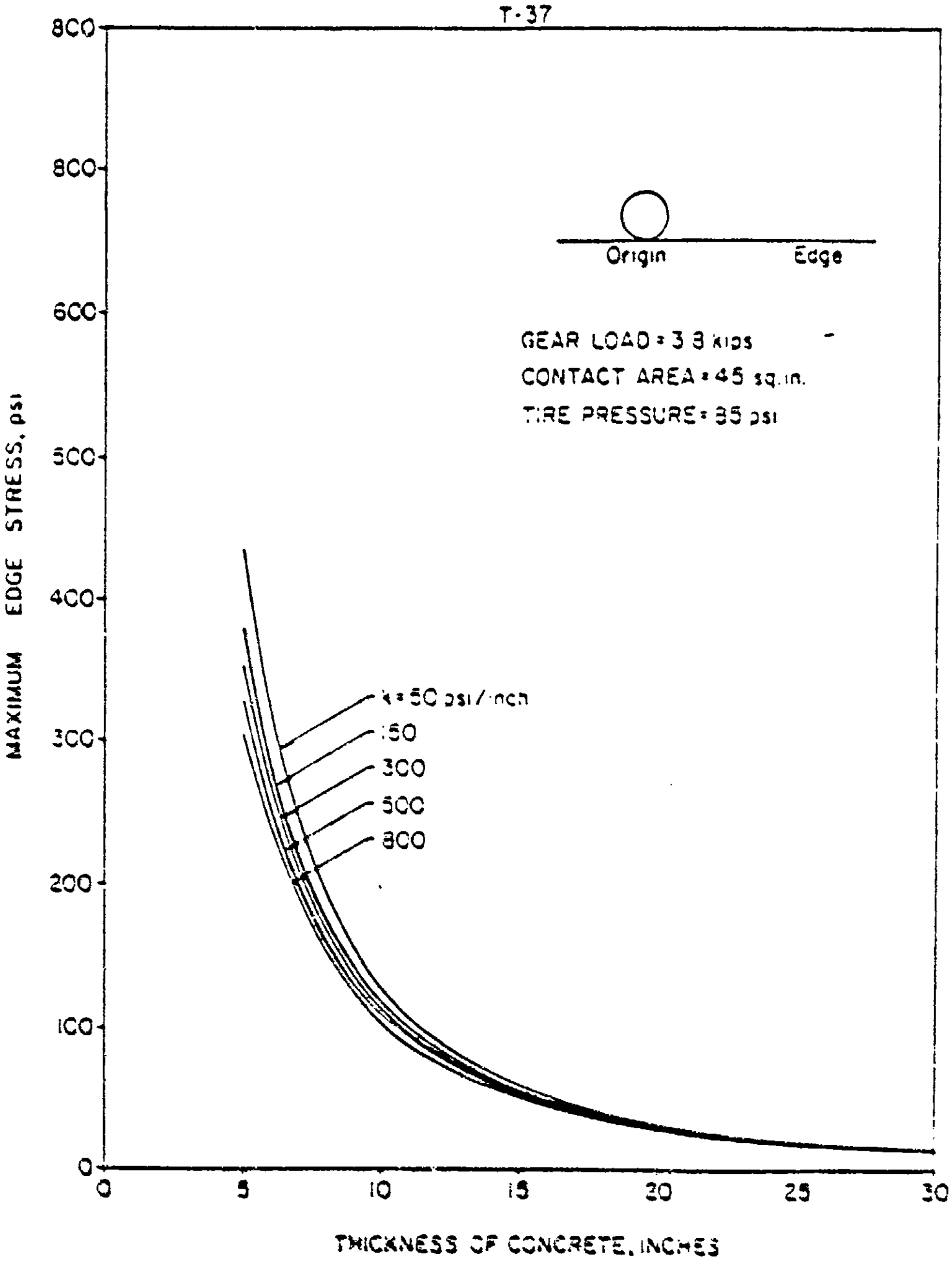

KC-135
36 inches
48inches
Origin
Edge
GEAR LOAD = 146,500
CONTACT AREA = 230 sq. in.
TIRE PRESSURE = 150 psi
k = 50 psi/inch
150
300
500
800
MAXIMUM EDGE STRESS, psi
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
0
5
10
15
20
25
30
THICKNESS OF CONCRETE, INCHES

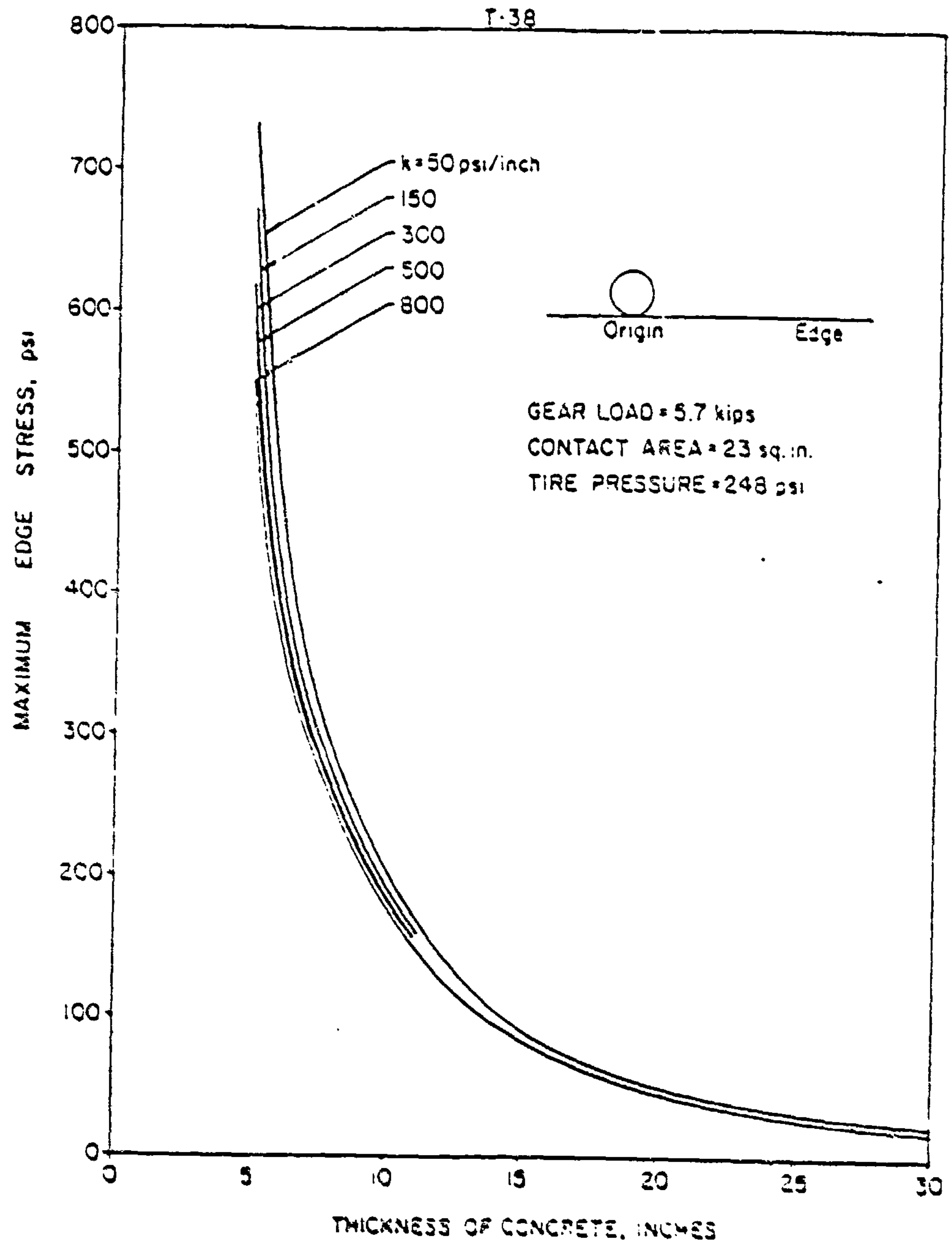

L-188
37 inches
Origin
Edge
GEAR LOAD = 53,700 lb
CONTACT AREA = 298 sq in.
TIRE PRESSURE = 90 psi
k = 50 psi/inch
150
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES

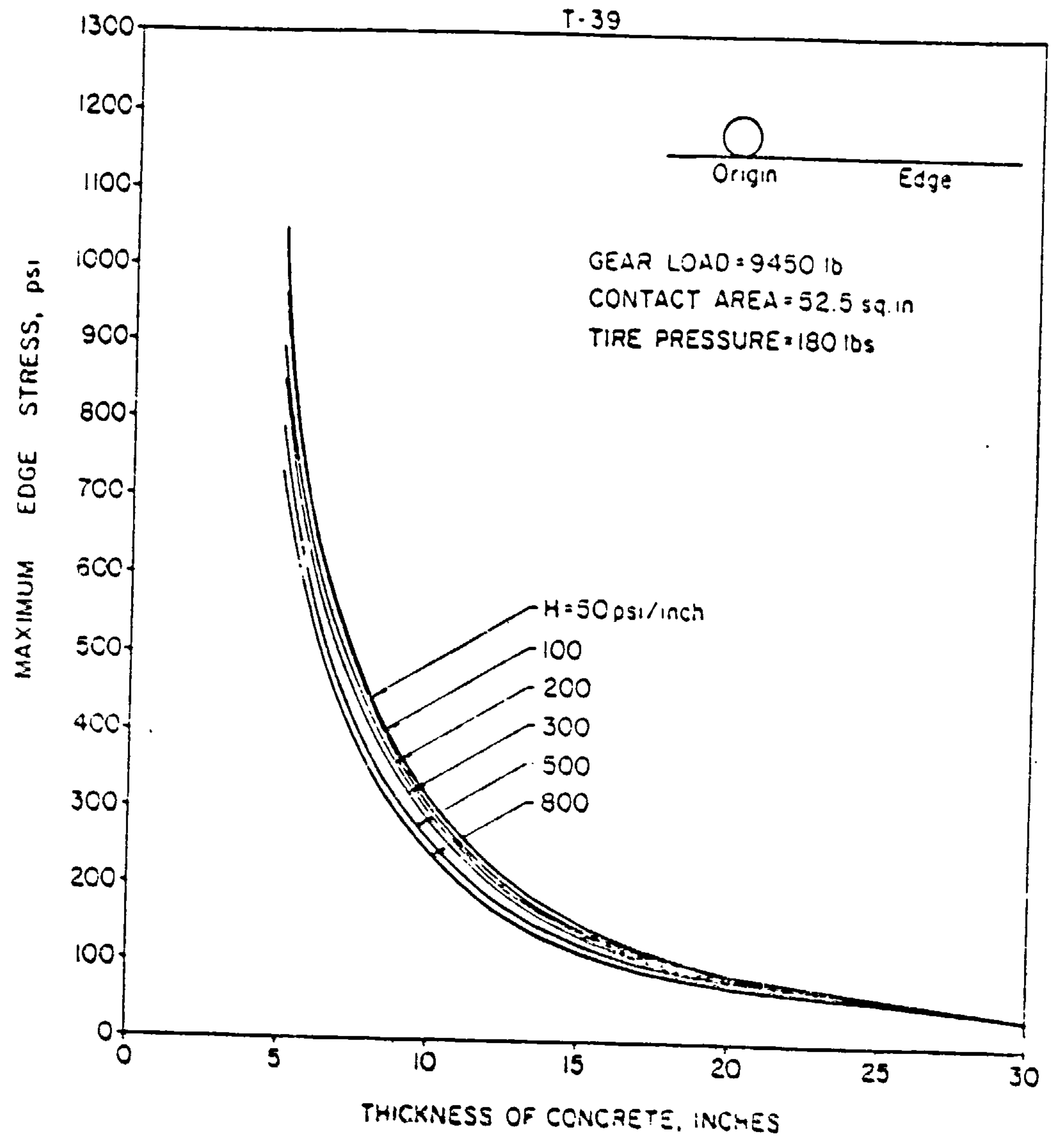

T-29
24 inches
Origin
Edge
GEAR LOAD = 23,230 lb
CONTACT AREA = 129 sq. in.
TIRE PRESSURE = 90 psi
k = 50 psi/inch
150
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES
0
5
10
15
20
25
30
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600



T-33/F-80
GEAR LOAD = 7050 lb
CONTACT AREA = 53.50 sq.in.
TIRE PRESSURE = 131.8 psi
Origin
Edge
H = 50 psi/inch
100
200
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES


T-37
Origin
Edge
GEAR LOAD = 3.8 kips
CONTACT AREA = 45 sq.in.
TIRE PRESSURE = 85 psi
k = 50 psi/inch
150
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES


T-38
k = 50 psi/inch
150
300
500
800
Origin
Edge
GEAR LOAD = 5.7 kips
CONTACT AREA = 23 sq.in.
TIRE PRESSURE = 248 psi
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES
0
100
200
300
400
500
600
700
800
5
10
15
20
25
30


T-39
Origin
Edge
GEAR LOAD = 9450 lb
CONTACT AREA = 52.5 sq. in
TIRE PRESSURE = 180 lbs
H = 50 psi/inch
100
200
300
500
800
MAXIMUM EDGE STRESS, psi
THICKNESS OF CONCRETE, INCHES
0
5
10
15
20
25
30
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300

APPENDIX B

SUMMARY OF THE PAVEMENT CONDITION
SURVEYS PERFORMED AT
WRIGHT-PATTERSON AFB

PCI OF FEATURE - T/1 = 53 RATING = FAIR

RECOMMENDED MINIMUM OF 6 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED= 7.3

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02 CORNER BREAK	LOW	32	9.87	7.9
02 CORNER BREAK	MEDIUM	8	2.46	4.1
03 STRUC CRKS	LOW	37	11.41	9.3
03 STRUC CRKS	MEDIUM	17	5.24	11.9
03 STRUC CRKS	HIGH	3	0.92	3.6
04 'D' CRK	LOW	176	54.32	14.4
04 'D' CRK	MEDIUM	4	1.23	0.9
04 'D' CRK	HIGH	1	0.30	0.5
05 JT SEAL DAM	LOW	0	0.00	2.0
06 PATCH < 5 SF	LOW	139	42.90	6.0
06 PATCH < 5 SF	MEDIUM	4	1.23	0.6
08 POPOUTS		24	7.40	5.4
10 SCALING	LOW	3	0.92	0.4
10 SCALING	MEDIUM	4	1.23	1.8
14 JT SPALL	LOW	6	1.85	1.2
14 JT SPALL	HIGH	1	0.30	0.9
15 COR SPALL	LOW	21	6.48	2.4
15 COR SPALL	MEDIUM	16	4.93	3.2
15 COR SPALL	HIGH	1	0.30	0.3

LOAD RELATED DISTRESSES = 52.21 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 47.78 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - T/2 = 60 RATING = GOOD

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02 CORNER BREAK	LOW	10	10.00	8.0
02 CORNER BREAK	MEDIUM	5	5.00	8.2
04 'D' CRK	LOW	5	5.00	1.8
04 'D' CRK	MEDIUM	27	27.00	16.5
04 'D' CRK	HIGH	2	2.00	3.8
05 JT SEAL DAM	LOW	0	0.00	2.0
06 PATCH < 5 SF	LOW	15	15.00	1.6
10 SCALING	LOW	5	5.00	2.1
14 JT SPALL	LOW	37	37.00	9.0
15 COR SPALL	MEDIUM	5	5.00	3.3

LOAD RELATED DISTRESSES = 30.19 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 69.80 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - T/3 = 55 RATING = FAIR

RECOMMENDED MINIMUM OF 5 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED= 5.3

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02 CORNER BREAK	LOW	5	4.06	3.0
03 STRUC CRKS	LOW	19	15.44	11.5
03 STRUC CRKS	MEDIUM	6	4.87	11.3
04 'D' CRK	LOW	34	27.64	8.7
04 'D' CRK	MEDIUM	42	34.14	19.9
04 'D' CRK	HIGH	1	0.81	1.5
05 JT SEAL DAM	LOW	0	0.00	2.0
06 PATCH < 5 SF	LOW	75	60.97	8.0
06 PATCH < 5 SF	MEDIUM	1	0.81	0.4
10 SCALING	LOW	2	1.62	0.8
13 SHRINK CRK		3	2.43	0.8

LOAD RELATED DISTRESSES = 44.18 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 55.81 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - T/4 = 72 RATING = VERY GOOD

RECOMMENDED MINIMUM OF 5 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED= 4.1

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
01 ALLIG CRK	LOW	99	0.24	9.5
03 BLOCK CRK	LOW	1000	2.50	10.5
07 JT REFLECT	LOW	4900	12.25	17.0
07 JT REFLECT	MEDIUM	180	0.45	3.7
08 LONG & TRAN CRK	LOW	3150	7.87	19.5
10 PATCH	LOW	40	0.10	2.0
10 PATCH	MEDIUM	100	0.25	7.2

LOAD RELATED DISTRESSES = 20.31 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 79.68 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - T/5 = 74 RATING = VERY GOOD

RECOMMENDED MINIMUM OF 5 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED= 1.7

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
01 ALLIG CRK	LOW	460	1.02	20.6
07 JT REFLECT	LOW	5850	13.00	17.5
08 LONG & TRAN CRK	LOW	360	0.80	4.7
10 PATCH	LOW	500	1.11	4.0
12 RAV/WEATH	MEDIUM	3	0.00	0.0
16 SWELL	LOW	4	0.00	0.0

LOAD RELATED DISTRESSES = 48.29 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 51.70 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - T/6 = 58 RATING = GOOD

RECOMMENDED MINIMUM OF 11 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED= 13.0

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
01 ALLIG CRK	LOW	630	1.05	20.9
03 BLOCK CRK	LOW	8300	13.83	18.9
07 JT REFLECT	LOW	3000	5.00	10.5
07 JT REFLECT	MEDIUM	1800	3.00	20.5
10 PATCH	LOW	400	0.66	2.9
10 PATCH	MEDIUM	160	0.26	7.2
12 RAV/WEATH	MEDIUM	94	0.15	4.0
13 RUTTING	LOW	4800	8.00	26.7

LOAD RELATED DISTRESSES = 47.13 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 52.77 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - T/7 = 69 RATING = GOOD

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02 CORNER BREAK	MEDIUM	1	1.38	2.4
03 STRUC CRKS	MEDIUM	9	12.50	21.5
05 JT SEAL DAM	HIGH	0	0.00	12.0
13 SHRINK CRK		4	5.55	1.0
14 JT SPALL	LOW	1	1.38	0.8
14 JT SPALL	MEDIUM	4	5.55	4.8

LOAD RELATED DISTRESSES = 56.23 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 43.76 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - A/8 = 60 RATING = GOOD

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
03 STRUC CRKS	LOW	4	9.52	8.1
04 'D' CRK	LOW	23	54.76	14.4
04 'D' CRK	MEDIUM	1	2.38	1.7
05 JT SEAL DAM	LOW	0	0.00	2.0
06 PATCH < 5 SF	LOW	24	57 14	7.7
07 PATCH > 5 SF	LOW	12	28.57	12.9
10 SCALING	LOW	1	2.33	1.1
13 SHRINK CRK		1	2.38	0.8
14 JT SPALL	LOW	4	9.52	3.3

LOAD RELATED DISTRESSES = 35.19 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 64.42 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - A/9 = 78 RATING = VERY GOOD

RECOMMENDED MINIMUM OF 5 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED= 5.7

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02 CORNER BREAK	LOW	2	1.51	1.1
02 CORNER BREAK	MEDIUM	1	0.75	1.3
03 STRUC CRACK	MEDIUM	3	2.27	5.6
04 'D' CRK	LOW	2	1.51	0.7
05 JT SEAL DAM	HIGH	0	0.00	12.0
07 PATCH > 5 SF	LOW	1	0.75	0.5
10 SCALING	MEDIUM	2	1.51	2.2
13 SHRINK CRK		4	3.03	0.9
14 JT SPALL	LOW	6	4.54	2.1
14 JT SPALL	MEDIUM	3	2.27	2.3
15 COR SPALL	MEDIUM	1	0.75	0.6

LOAD RELATED DISTRESSES = 27.78 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 71.67 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

PCI OF FEATURE - A/10 = 86 RATING = EXCELLENT

RECOMMEND ALL SAMPLE UNITS BE SURVEYED.

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
06 JET BLAST		4	0.04	0.0
07 JT REFLECT	LOW	520	5.20	10.7
08 LONG & TRAN CRK	LOW	90	0.90	5.1
09 OIL SPILL		22	0.22	2.0
11 POL AGG		4	0.04	0.6
13 RUTTING	LOW	3	0.03	2.5

LOAD RELATED DISTRESSES = 11.96 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 75.59 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 12.44 PERCENT DEDUCT VALUES.

PCI OF FEATURE - A/11 = 43 RATING = FAIR

RECOMMENDED MINIMUM OF 7 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED= 7.3

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
01 ALLIG CRK	LOW	1802	1.12	21.4
03 BLOCK CRK	MEDIUM	87466	54.66	41.3
07 JT REFLECT	MEDIUM	8320	5.20	28.5
07 JT REFLECT	HIGH	1066	0.66	10.1
10 PATCH	LOW	533	0.33	2.0
10 PATCH	MEDIUM	2005	1.25	10.4
11 POL AGG		2560	1.60	4.4

LOAD RELATED DISTRESSES = 23.31 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 72.97 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 3.71 PERCENT DEDUCT VALUES.

PCI OF FEATURE - A/12 = 62 RATING = GOOD

RECOMMENDED MINIMUM OF 9 RANDOM SAMPLE UNITS BE SURVEYED.

STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED= 14.8

ESTIMATED DISTRESS FOR FEATURE

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
02 CORNER BREAK	LOW	3	1.64	1.2
03 STRUC CRKS	LOW	6	3.29	3.2
03 STRUC CRKS	MEDIUM	1	0.54	1.3
03 STRUC CRKS	HIGH	0	0.00	0.0
04 'D' CRK	LOW	29	15.93	5.2
04 'D' CRK	MEDIUM	4	2.19	1.6
05 JT SEAL DAM	MEDIUM	0	0.00	7.0
06 PATCH < 5 SF	LOW	41	22.52	2.7
06 PATCH < 5 SF	MEDIUM	22	12.08	6.4
07 PATCH > 5 SF	LOW	5	2.74	1.8
08 POPOUTS		3	1.64	1.4
13 SHRINK CRK		5	2.74	0.8
14 JT SPALL	LOW	2	1.09	0.7
14 JT SPALL	MEDIUM	3	1.64	1.7
14 JT SPALL	HIGH	1	0.54	1.7
15 COR SPALL	LOW	9	4.94	1.8
15 COR SPALL	MEDIUM	1	0.54	0.4

LOAD RELATED DISTRESSES = 28.53 PERCENT DEDUCT VALUES.

CLIMATE/DURABILITY RELATED DISTRESSES = 71.20 PERCENT DEDUCT VALUES.

OTHER RELATED DISTRESSES = 0.00 PERCENT DEDUCT VALUES.

APPENDIX C

DATA OBTAINED FROM THE CONSTRUCTION ENGINEERING RESEARCH LABORATORY

CONSTRUCTION ENGINEERING RESEARCH LABORATORY DATA

ACTUAL PCI VALUE	AGE	AGECOL	NUMBER OF FREEZE-THAW CYCLES AT A TWO INCH DEPTH	AVERAGE ANNUAL PRECIPITATION	PAVEMENT FATIGUE FACTOR	PAVEMENT DAMAGE FACTOR	DAMCOL	OVERLAY THICKNESS
32	11	0	0	52.1	339960	0.0039893	0	0
38	11	0	0	52.1	389390	0.0092243	0	0
48	11	0	0	52.1	462092	0.1433	0	0
85	11	0	0	52.1	243802	0.092277	0	0
75	11	0	0	52.1	205246	0.00018868	0	0
33	14	0	0	52.1	438538	0.0015716	0	0
70	12	0	0	52.1	266574	0	0	0
81	12	0	0	52.1	81300	0.1164	0	0
42	20	0	0	52.1	179412	0.00940179	0	0
94	9	0	0	52.1	101587	0.0020832	0	0
55	20	0	0	49.6	20950	0.019602	0	0
90	9	0	0	49.6	30294	0	0	0

```
94 9 0 0 49.6 31104 0 0 0
97 10 0 0 49.6 33660 0 0 0
92 10 0 0 49.6 35440 0 0 0
89 20 0 0 49.6 16580 0.019579 0 0
88 20 0 0 49.6 15830 0.000151 0 0
78 20 0 0 49.6 21510 0.0038707 0 0
91 20 0 0 49.6 16170 0.010667 0 0
81 20 0 0 49.6 14230 3.584 0 0
87 12 9 0 52.1 339934 8276 405 5
17 12 30 0 52.1 112300 40912 100000 3
31 19 17 0 52.1 153875 94711 144500 4
91 20 0 0 49.6 11840 0.0087094 0 0
94 9 0 0 49.6 111564 344.454 0 0
90 20 0 0 49.6 13560 0.0025805 0 0
87 20 0 0 49.6 990 0.6766 0 0
68 20 0 0 49.6 990 0.6766 0 0
93 20 0 0 49.6 24970 1.13 0 0
89 20 0 0 49.6 4420 0 0 0
78 20 0 0 49.6 4840 0 0 0
75 20 0 0 49.6 24610 2.544 0 0
81 20 0 0 49.6 10920 0.7535 0 0
63 20 0 0 49.6 29690 0.0087094 0 0
70 20 0 0 49.6 960 0.2 0 0
87 20 0 0 49.6 17310 0.61519 0 0
97 9 0 0 49.6 21330 0 0 0
83 24 0 49 40.3 74549 0.002544 0 0
94 24 0 49 40.3 39183 0 0 0
88 24 0 49 40.3 39286 0 0 0
82 9 15 0 40.3 26567 17588.4 26535 7
79 24 0 49 40.3 14079 0 0 0
87 24 0 49 40.3 15139 0 0 0
54 9 13 0 40.3 9142 1.3211 14.4547 3
64 9 13 0 40.3 15234 131.305 15.08 3
71 9 13 0 40.3 17323 1.4732 11831.3 4
62 9 13 0 40.3 3209 2562 1794 4
77 9 15 0 40.3 3149 2562 2055.3 4
97 2 0 49 40.3 5920 0 0 0
97 4 0 49 40.3 4083 0.000091812 0 0
85 10 15 0 40.3 5949 3570 2300 2.5
65 24 11 0 40.3 13472 3884.51 0 4
68 24 11 0 40.3 13422 2595 0 4
58 20 0 49 40.3 7670 0 0 0
53 21 0 105 15.2 571551 0.0081602 0 0
34 21 0 105 15.2 67368 0.0000273189 0 0
82 21 0 105 15.2 66940 0.0000273189 0 0
66 22 0 105 15.2 61264 0.000875 0 0
93 3 0 105 15.2 9546 0.000617 0 0
69 15 0 105 15.2 28065 0.00257 0 0
79 19 0 105 15.2 320321 0 0 0
39 21 0 105 15.2 66927 0.000027 0 0
38 21 0 105 15.2 12453 0.000015 0 0
```

```
53 21 0 105 15.2 612591 0.00107 0 0
67 21 0 105 15.2 42550 0.000051 0 0
63 8 29 0 15.2 372338 251360 568460 2.5
70 8 29 0 15.2 397656 251360 568460 2.5
83 12 25 0 15.2 39343 24000 10000 2.5
65 21 16 0 15.2 8421 2787 800 2
54 12 25 0 15.2 370212 180000 175000 3
18 9 29 0 15.2 424107 282780 488460 2.5
32 19 18 0 15.2 6289 0.30704 1100 3
28 34 0 0 10.6 376604 0.4275 0 0
59 14 0 0 10.6 50519 0.004966 0 0
72 10 0 0 10.6 45046 0.006013 0 0
76 22 0 0 10.6 7282 0 0 0
65 13 0 0 10.6 79225 1014 0 0
24 37 0 0 10.6 58219 6121 0 0
76 20 0 0 10.6 27356 351 0 0
80 22 0 0 10.6 12728 0.09471 0 0
59 24 0 0 10.6 7134 0.000001692 0 0
97 21 0 0 10.6 1086 0.01849 0 0
80 24 0 0 10.6 84362 1932 0 0
44 20 0 42 35.8 53104 0.001469 0 0
60 20 0 42 35.8 57128 0.007462 0 0
55 24 0 42 35.8 971 0.1244 0 0
62 24 0 42 35.8 971 0.1244 0 0
50 24 0 42 35.8 616 0.05272 0 0
76 24 0 42 35.8 616 0.05272 0 0
66 22 0 103 11.5 189336 8.7282 0 0
72 22 0 103 11.5 189324 8.7282 0 0
81 6 7 0 11.5 145230 86700 5338.3 1.5
81 22 0 103 11.5 103026 1.188 0 0
81 22 0 103 11.5 104004 2.183 0 0
54 22 0 103 11.5 211168 8.7282 0 0
65 16 0 103 11.5 114862 0.2111 0 0
74 22 0 103 11.5 95692 0.02059 0 0
71 22 0 103 11.5 118546 0.028017 0 0
94 19 0 103 11.5 611 0 0 0
70 22 13 0 11.5 273160 57602 109213 4
42 22 0 103 11.5 5004 197 0 0
93 19 0 103 11.5 1839 0 0 0
59 22 0 103 11.5 58452 6.1317 0 0
48 23 13 0 11.5 658325 143400 214500 4
49 22 0 103 11.5 64769 2.968 0 0
73 22 0 103 11.5 1080 0.059672 0 0
71 22 0 103 11.5 14616 0.2423 0 0
42 22 0 103 11.5 1583 43 0 0
92 19 0 103 11.5 704 0 0 0
98 2 0 0 3.8 35050 0.0002176 0 0
98 2 0 0 3.8 35050 0.0002176 0 0
98 2 0 0 3.8 35050 0.0002176 0 0
98 2 0 0 3.8 35050 0.0002176 0 0
95 3 0 0 3.8 39737 16501 0 0
```

94 2 0 0 3.8 29072 0.00006258 0 0
78 37 0 0 3.8 4790 210.67 0 0
76 6 0 0 3.8 141493 16.01 0 0
92 2 0 0 3.8 15817 0.0001088 0 0
35 6 0 0 3.8 24456 0.02731 0 0
88 9 0 0 3.8 98933 0.004337 0 0
55 22 0 0 3.8 878 0.00002124 0 0
65 36 0 0 3.8 5184 1800 0 0
71 22 0 0 3.8 44042 42.571 0 0
66 26 0 0 3.8 65222 26420 0 0
97 6 0 0 3.8 2417 0.71081 0 0
91 4 0 0 3.8 11829 0.0014245 0 0
75 20 0 0 44.5 61670 0.0024578 0 0
78 20 0 0 44.5 65170 0.0124438 0 0
72 20 0 0 44.5 80650 8.186 0 0
88 11 0 0 44.5 110264 0.2633 0 0
84 16 0 0 44.5 151679 0.106 0 0
77 23 0 0 44.5 28760 77.65 0 0
77 23 0 0 44.5 28760 77.65 0 0
65 23 0 0 44.5 154503 0.00023078 0 0
70 23 12 0 44.5 358031 5747.7 0.37796 8
69 22 12 0 44.5 37768 580.614 0.37992 8
64 22 12 0 44.5 41523 168.16 0.0030258 8
59 22 12 0 44.5 31468 1.988 0.00009638 8
79 23 0 0 44.5 17158 0.000025648 0 0
72 20 0 0 44.5 49600 0.000092812 0 0
77 20 0 0 44.5 49600 0.000092812 0 0
77 20 0 0 44.5 49600 0.000092812 0 0
74 20 0 0 44.5 4960 0.000092812 0 0
76 20 0 0 44.5 58600 0.0010281 0 0
78 13 0 0 44.5 82965 0.0039966 0 0
79 22 14 0 44.5 243342 0.2141 0.4925 8
79 23 14 0 44.5 107414 1724.404 6.559 8
69 35 0 0 44.5 32786 3.8522 0 0
79 23 0 0 44.5 77522 0.00011541 0 0
77 20 0 0 44.5 77900 3.42 0 0
74 20 0 0 44.5 116790 0 0 0
81 23 0 0 44.5 8579 0.000012824 0 0
78 20 0 0 44.5 9820 0.0017708 0 0
49 35 0 0 44.5 9345 23.7665 0 0
84 11 0 0 27.2 12826 0 0 0
30 19 0 0 27.2 37460 84.76 0 0
87 19 0 0 27.2 41929 0 0 0
76 19 0 0 27.2 125771 0 0 0
87 11 0 0 27.2 12829 0 0 0
87 19 0 0 27.2 4707 0 0 0
90 19 0 0 27.2 806 0 0 0
90 11 0 0 27.2 29940 0 0 0
91 19 0 0 27.2 32620 0 0 0
92 19 0 0 27.2 352 0.00001366 0 0
73 19 0 0 27.2 352 0.00001366 0 0

78 19 0 0 27.2 11596 0.004583 0 0
79 19 0 0 27.2 5364 0.0002083 0 0
69 15 0 0 27.2 9144 0.03972 0 0

APPENDIX D

DATA COLLECTED AT WRIGHT-PATTERSON AFB

WRIGHT-PATTERSON AFB DATA

ACTUAL PCI VALUE	AGE	AGECOL	NUMBER OF FREEZE-THAW CYCLES AT A TWO INCH DEPTH	AVERAGE ANNUAL PRECIPITATION	PAVEMENT FATIGUE FACTOR	PAVEMENT DAMAGE FACTOR	DAMCOL	OVERLAY THICKNESS
69	22	0	93	34.36	141354.8318	0.6241	0	0
78	17	0	93	34.36	45901.188	0.579	0	0
62	17	0	93	34.36	91555.0	625	0	0
60	23	0	93	34.36	14680.75	0.0012145	0	0
53	23	0	93	34.36	46223.88	0.00347	0	0
55	23	0	93	34.36	34254.33	0.0026736	0	0
46	17	0	93	34.36	33202.772	0	0	0
43	20	19	0	34.36	143478.7853	150.1509	0.0093158	2.5
74	17	22	0	34.36	52266.6635	0.0097656	0.0007945	2
72	17	22	0	34.36	52266.6635	0.0097656	0.0007945	2
58	22	17	0	34.36	143885.7147	0.2052	0.00071392	2
86	1	19	0	34.36	492.3504	0.24	25.2602	1.25

APPENDIX E

DEVELOPMENT OF A MODIFIED PCI PREDICTION MODEL

```
 1 RUN NAME        MODIFIED PCI PREDICTION MODEL
 2 PRINT BACK      CONTROL
 3 VARIABLE LIST   ACTPCI,AGE,AGECOL,FRETHAW,ANNPREC,FAT,DAMAGE,DAMCOL,THICK
 4 INPUT FORMAT    FREEFIELD
 5 N OF CASES      UNKNOWN
 6 COMPUTE         I1LDAM9=AGE*LG10(DAMAGE+10)
 7 COMPUTE         I2FTCR=AGE**2*SQRT(FRETHAW)
 8 COMPUTE         I2PRECI=AGE**2*ANNPREC
 9 COMPUTE         LDAMCOL=LG10(DAMCOL+10)
10 COMPUTE         II2AGECOL=SQRT(AGE)*AGECOL*LDAMCOL/THICK
11 COMPUTE         I2FATR=AGE**2*SQRT(FAT)
12 REGRESSION      VARIABLES=ACTPCI,I1LDAM9,I2FTCR,I2PRECI,
13                 II2AGECOL,I2FATR
14                 REGRESSION=ACTPCI WITH I1LDAM9,I2FTCR,I2PRECI,
15                 II2AGECOL,I2FATR(2)
16 STATISTICS      ALL

***** REGRESSION PROBLEM REQUIRES    150 DBLEWORDS WORKSPACE, NOT INCLUDING RESIDUALS *****

17 READ INPUT DATA
```

* M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * * * VARIABLE LIST 1
REGRESSION LIST 1

DEPENDENT VARIABLE.. ACTPCI

VARIABLE(S) ENTERED ON STEP NUMBER 1.. I2FATR
IILDAM
I2FTCR
I2PREC
II2AGE

MULTIPLE R	0.81[illegible]4	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
R SQUARE	0.66559	REGRESSION	5.	74240.54915	14848.10983	140.91603
ADJUSTED R SQUARE	0.66087	RESIDUAL	354.	37300.44808	105.36850	
STANDARD ERROR	10.26492					

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
I2FATR	-0.5609340E-04	-0.23349	0.00001	29.920
IILDAM	-0.2206655	-0.26780	0.03824	33.301
I2FTCR	-0.2577991E-02	-0.20808	0.00041	39.185
I2PREC	-0.5407277E-03	-0.25634	0.00008	44.934
II2AGE	-0.1928937	-0.27884	0.02435	62.754
(CONSTANT)	97.37488			

------------- VARIABLES NOT IN THE EQUATION -------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F

ALL VARIABLES ARE IN THE EQUATION

STATISTICS WHICH CANNOT BE COMPUTED ARE PRINTED AS ALL NINES.

* M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * *   VARIABLE LIST 1
REGRESSION LIST 1

DEPENDENT VARIABLE..   ACTPCI

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
I2FAIR	0.63466	0.40279	0.40279	-0.63466	-0.5609340E-04	-0.23349
I1LDAM	0.74064	0.54854	0.14575	-0.69355	-0.2206555	-0.26780
I2FTCR	0.76258	0.58153	0.03299	-0.37470	-0.2577991E-02	-0.20308
I2PREC	0.77866	0.60631	0.02477	-0.55906	-0.5407277E-03	-0.25634
II2AGE	0.81584	0.66559	0.05928	-0.39589	-0.1928937	-0.27384
(CONSTANT)					97.37488	

APPENDIX F

DEVELOPMENT OF AN IMPROVED PCI PREDICTION MODEL

```
RUN NAME        IMPROVED PCI PREDICTION MODEL
PRINT BACK      CONTROL
VARIABLE LIST   ACTPCI,AGE,AGECOL,FRETHAW,ANNPREC,FAT,DAMAGE,DAMCOL,THICK
INPUT FORMAT    FREEFIELD
# OF CASES      UNKNOWN
COMPUTE         I1LDAM9=AGE*LG10(DAMAGE+10)
COMPUTE         I2FTCR=AGE**2*SQRT(FRETHAW)
COMPUTE         I2PRECI=AGE**2*ANNPREC
COMPUTE         LDAMCOL=LG10(DAMCOL+10)
COMPUTE         II2AGECOL=SQRT(AGE)*AGECOL*LDAMCOL/THICK
COMPUTE         I2FATR=AGE**2*SQRT(FAT)
COMPUTE         III1LDAM9=I1LDAM9**2
COMPUTE         III2AGECOL=II2AGECOL**2
COMPUTE         DAMFT=I1LDAM9*I2FTCR
COMPUTE         DAMAG=I1LDAM9*II2AGECOL
COMPUTE         PREAG=I2PRECI*II2AGECOL
REGRESSION      VARIABLES=ACTPCI,I1LDAM9,
                II1LDAM9,III2AGECOL,DAMFT,DAMAG,
                I2FATR,PREAG
                REGRESSION=ACTPCI WITH I1LDAM9,
                II1LDAM9,III2AGECOL,DAMFT,DAMAG,
                I2FATR,PREAG(2)
STATISTICS      ALL

***** REGRESSION PROBLEM REQUIRES    232 DBLEWORDS WORKSPACE, NOT INCLUDING RESIDUALS *****

READ INPUT DATA
```

```
* * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G R E S S I O N  * * * * * * * * * * * *   VARIABLE LIST 1
                                                                                                                   REGRESSION LIST 1

DEPENDENT VARIABLE..      ACTPCI

VARIABLE(S) ENTERED ON STEP NUMBER  1..     PREAG
                                            IILDAM
                                            IIILDA
                                            III2AG
                                            DAMFT
                                            DAMAG
                                            I2FATR

MULTIPLE R             0.83298        ANALYSIS OF VARIANCE    DF      SUM OF SQUARES      MEAN SQUARE          F
R SQUARE               0.69385        REGRESSION              7.        70759.86128      10108.55161     106.19599
ADJUSTED R SQUARE      0.68732        RESIDUAL              328.        31221.56435         95.18770
STANDARD ERROR         9.75642

------------------ VARIABLES IN THE EQUATION ------------------        ------------ VARIABLES NOT IN THE EQUATION -------------

VARIABLE          B              BETA      STD ERROR B       F         VARIABLE     BETA IN     PARTIAL   TOLERANCE        F

  PREAG     -0.3236294E-04    -0.26200      0.00001       24.927
  IILDAM    -0.7351402        -0.91887      0.06975      111.074
  IIILDA     0.4368143E-02     0.52098      0.00066       43.961
  III2AG    -0.1543106E-02    -0.37958      0.00030       26.205
  DAMFT     -0.5992802E-04    -0.11856      0.00002       11.733
  DAMAG      0.4666657E-02     0.40285      0.00112       17.280
  I2FATR    -0.6721296E-04    -0.28586      0.00001       47.970
(CONSTANT)   98.18948

ALL VARIABLES ARE IN THE EQUATION

STATISTICS WHICH CANNOT BE COMPUTED ARE PRINTED AS ALL NINES.
```

* M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * *   VARIABLE LIST 1
REGRESSION LIST 1

DEPENDENT VARIABLE..   ACTPCI

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
FREAG	0.40635	0.16512	0.16512	-0.40635	-0.3236294E-04	-0.26200
IILDAM	0.69730	0.48623	0.32111	-0.69122	-0.7351402	-0.91887
IIILDA	0.78375	0.61426	0.12803	-0.46285	0.4368143E-02	0.52098
III2AG	0.78539	0.61684	0.00259	-0.34779	-0.1543106E-02	-0.37958
DAMFT	0.79925	0.63880	0.02195	-0.35917	-0.5992802E-04	-0.11856
DAMAG	0.80565	0.64908	0.01028	-0.39406	0.4666657E-02	0.40285
I2rATR	0.83298	0.69385	0.04477	-0.62105	-0.6721296E-04	-0.28586
(CONSTANT)					98.18948	

APPENDIX G

DEVELOPMENT OF A MODIFIED IMPROVED PCI PREDICTION MODEL

```
 1 RUN NAME        MODIFIED IMPROVED PCI PREDICTION MODEL
 2 PRINT BACK      CONTROL
 3 VARIABLE LIST   ACTPCI,AGE,AGECOL,FRETHAU,ANNPREC,FAT,DAMAGE,DAMCOL,THICK
 4 INPUT FORMAT    FREEFIELD
 5 N OF CASES      UNKNOWN
 6 COMPUTE         I1LDAM9=AGE*LG10(DAMAGE+10)
 7 COMPUTE         I2FTCR=AGE**2*SQRT(FRETHAU)
 8 COMPUTE         I2PRECI=AGE**2*ANNPREC
 9 COMPUTE         LDAMCOL=LG10(DAMCOL+10)
10 COMPUTE         II2AGECOL=SQRT(AGE)*AGECOL*LDAMCOL/THICK
11 COMPUTE         I2FATR=AGE**2*SQRT(FAT)
12 COMPUTE         II1LDAM9=I1LDAM9**2
13 COMPUTE         III2AGECOL=II2AGECOL**2
14 COMPUTE         DAMFT=I1LDAM9*I2FTCR
15 COMPUTE         DAMAG=I1LDAM9*II2AGECOL
16 COMPUTE         PREAG=I2PRECI*II2AGECOL
17 REGRESSION      VARIABLES=ACTPCI,I1LDAM9,
18                 II1LDAM9,III2AGECOL,DAMFT,DAMAG,
19                 I2FATR,PREAG
20                 REGRESSION=ACTPCI WITH I1LDAM9,
21                 II1LDAM9,III2AGECOL,DAMFT,DAMAG,
22                 I2FATR,PREAG(2)
23 STATISTICS      ALL

***** REGRESSION PROBLEM REQUIRES    232 DBLEWORDS WORKSPACE, NOT INCLUDING RESIDUALS *****

24 READ INPUT DATA
```

* M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * * *   VARIABLE LIST 1
REGRESSION LIST 1

DEPENDENT VARIABLE..   ACIPCI

VARIABLE(S) ENTERED ON STEP NUMBER 1..   PREAG
IILDAM
IIILDA
III2AG
DAMFT
DAMAG
I2FAIR

MULTIPLE R	0.84239
R SQUARE	0.70962
ADJUSTED R SQUARE	0.70385
STANDARD ERROR	9.59237

ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F
REGRESSION	7.	79152.21384	11307.45912	122.88901
RESIDUAL	352.	32388.78339	92.01359	

------------------ VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
PREAG	-0.31010597E-04	-0.25682	0.00001	31.041
IILDAM	-0.7467159	-0.90622	0.06762	121.937
IIILDA	0.44566643E-02	0.51608	0.00064	48.151
III2AG	-0.14923424E-02	-0.35166	0.00029	26.311
DAMFT	-0.69286956E-04	-0.14980	0.00002	18.117
DAMAG	0.44551706E-02	0.36671	0.00105	17.910
I2FAIR	-0.65998112E-04	-0.27472	0.00001	49.990
(CONSTANT)	98.26473			

-------------- VARIABLES NOT IN THE EQUATION --------------

VARIABLE	BETA IN	PARTIAL	TOLERANCE	F

ALL VARIABLES ARE IN THE EQUATION

STATISTICS WHICH CANNOT BE COMPUTED ARE PRINTED AS ALL NINES.

* M U L T I P L E   R E G R E S S I O N * * * * * * * * * * * * *   VARIABLE LIST 1
REGRESSION LIST 1

DEPENDENT VARIABLE..   ACTPCI

SUMMARY TABLE

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
[illegible]	0.41627	0.17328	0.17328	-0.41627	-0.3101097E-04	-0.25582
[illegible]	0.70273	0.49383	0.32056	-0.69355	-0.7457189	-0.90622
[illegible]	0.79351	0.62966	0.13582	-0.45346	0.4456663E-02	0.51008
[illegible]	0.79432	0.63094	0.00129	-0.33517	-0.1493424E-02	-0.35146
[illegible]	0.81077	0.65734	0.02640	-0.39099	-0.6928678E-04	-0.14080
[illegible]	0.81755	0.66839	0.01104	-0.38447	0.4455170E-02	0.36871
[illegible]	0.84239	0.70962	0.04124	-0.63466	-0.6599812E-04	-0.27472
(CONSTANT)					98.24473	

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Captain Michael W. Dronen is a graduate of the Virginia Military Institute, from which he received his Bachelor of Science Degree in Civil Engineering in 1977. As an Air Force civil engineering officer, Captain Dronen has enjoyed assignments at both Mountain Home AFB ID and RAF Mildenhall, England. His duties have included: Design Engineer, Readiness and Logistics Officer and Chief of Construction Surveillance. Subsequent to completing his studies at AFIT, Captain Dronen is to be reassigned to the 833 Civil Engineering Squadron, Holloman AFB NM.