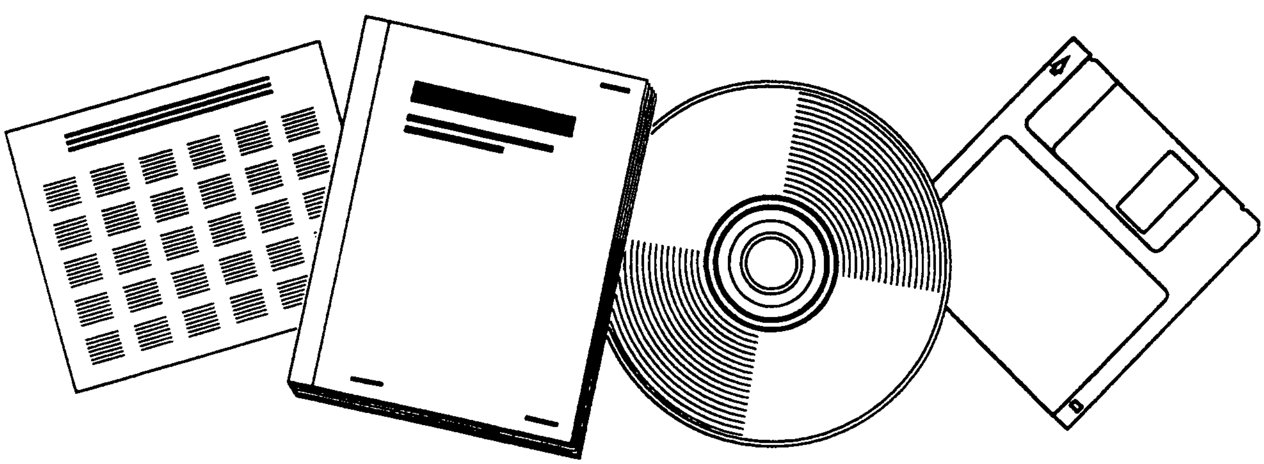
PB98-114788

NTIS
Information is our business.

DIVISION OF RESEARCH: PERFORMANCE EVALUATION OF PAVEMENTS CONSTRUCTED UNDER QUALITY ASSURANCE SPECIFICATIONS

MAY 97



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

DIVISION OF RESEARCH

PB98-114788

PERFORMANCE EVALUATION OF

PAVEMENTS CONSTRUCTED UNDER

QUALITY ASSURANCE SPECIFICATIONS

FINAL REPORT

MAY 1997

REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

TECHNICAL *Summary*

INDOT Research

Technology Transfer and Project Implementation Information

PERFORMANCE EVALUATION OF PAVEMENTS CONSTRUCTED UNDER QUALITY ASSURANCE SPECIFICATIONS

Introduction

In the mid 1980's, Indiana's hot mix asphalt pavements were experiencing high levels of rutting as well as other forms of distresses within a few years of construction. Changes in the crude sources, heavier traffic loading, increased truck traffic and possible construction problems were thought to cause these distresses. After reviewing INDOT specifications, a decision was made to slightly modify them in an attempt to produce the necessary quality. The largest modifications were to aggregate gradation and to field compaction methods in order to meet density and air voids requirements. These new Quality Assurance (QA) specifications have now become the standard INDOT specifications. This study was conducted to compare the performance of in-service pavements placed under QA specifications with in-service pavements placed without using the QA specifications.

Findings

The condition histories of the QA and Non-QA pavement sections were documented from 1991 through the 1994. Higher condition indices (PCI) were observed for QA pavement sections than for Non-QA pavement sections. No difference was found in unit cost between QA and Non-QA pavement sections.

Implementation

The Indiana Department of Transportation now uses QA specifications for all bituminous pavement construction. The idea of QA is currently being furthered as INDOT moves to the use of warranty mixes to insure the quality of bituminous pavements.

For Further Information:

Contact either John Haddock or Khaled Galal at (765) 463-1521.

Final Report

PERFORMANCE EVALUATION OF PAVEMENTS CONSTRUCTED UNDER QUALITY ASSURANCE SPECIFICATIONS

By

Shakor R. Badaruddin, P.E.
Materials and Research Engineer

Indiana Department of Transportation
Division of Research
1205 Montgomery Street, P.O. Box 2279
West Lafayette, Indiana 47906-0279
Tel. 317-463-1521
Fax. 317-497-1665

August 1996

The contents of this report reflect the views of the author, who is solely responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of Indiana Department of Transportation. This report does not constitute a standard specification or regulation.

Table of Contents

List of Figures

List of Figures

List of Tables

PERFORMANCE EVALUATION OF PAVEMENTS CONSTRUCTED UNDER QUALITY ASSURANCE SPECIFICATION

By

Shakor R Badaruddin, P.E.

1.0 Introduction

In the mid-eighties, some bituminous pavements in Indiana were having high levels of rutting within a few years of construction. Other forms of distresses such as thermal cracking, longitudinal and lateral cracking and bleeding were also occurring. Many factors were thought to cause these including changes in crude source [1], heavier traffic loading [2], increased truck traffic [3], and possible construction problems. The main objective of INDOT in this regard being the production of quality pavements that would have a longer service life, the Department demanded a solution to these issues.

After reviewing the INDOT construction specifications, it was decided that with slight modification they had the capability to produce the necessary quality pavements. However this required assuring quality during mix production and compaction. Essentially, INDOT decided to modify the aggregate gradation and control field compaction to meet density and air void requirements. It has been shown in an NCHRP report [4] that mix design and field compaction are the two most important factors affecting pavement performance.

The Quality Assurance concept fulfills these requirements and has been implemented in Indiana since 1987 on selected projects. The number of QA projects has increased every year to the point where QA Specifications have become the Standard Specifications.

In order to evaluate the implementation of QA specifications, a study was carried out to compare the performance of in-service bituminous pavements laid under QA with pavements laid using the standard specifications of the mid-eighties (or non-QA specifications). The evaluation includes field as well as laboratory tests and the QA pavements are showing better performance.

A questionnaire was sent out to solicit response from a random sample of people involved with QA, regarding its implementation in Indiana.The recipients of the questionnaire included material suppliers, contractors, designers, planners and field personnel. The goal of the questionnaire was to assess "user" response from all the different participants in the QA program, whether it was well received and what suggestions could be obtained to further improve it.

2.0 Literature Review

Quality Assurance in construction practice is very much desired because it would ensure or validate all work to be of good quality thus preventing anything to "slip through the crack". The philosophy of Quality Assurance [5] has been described as being a systematic way of ensuring that organized activities are carried out the way they are planned. According to the Institute of Quality Assurance of United Kingdom [6], a formal definition of QA is given as "all activities and functions concerned with the attainment of quality". QA then is a systematic way of guaranteeing quality control (QC). Comparing QA to QC, Sandberg [5] wrote " QA includes, but is broader than QC, which is an integral part of it". Undoubtedly then, QA is the direction the pavement construction industry should be headed.

Agencies adopting QA concepts translate them into specifications that suit their respective needs. Thus, QA specifications vary from agency to agency, but all have the vital ingredient of assuring quality through built-in verification tests before and during the construction stage.

Fundamental to the QA concept is the transferring of responsibility for achieving quality to the contractor, who is then rewarded or penalized depending on the level of work quality produced. WASHTO [7] found that a QA specification assures quality at lower cost while incurring lower contractor claims. To achieve these objectives, WASHTO identified the necessity of having three important factors; trained state personnel, involvement and participation of the construction industry, and a qualified statistician for training state inspectors.

In Oklahoma [8] an on going six week module to train personnel on QA concepts and knowledge on pavement materials has proven very useful in the implementation of QA in the state. Contractors were uneasy in the beginning about the drastic changes from the normal construction practices that they had always been used to, but slowly came to appreciate it when they saw the quality of the product. Similar sentiments have been expressed by Indiana contractors.

In the United Kingdom [9], material and construction quality is verified and certified by an independent third party. This third party is required to belong to an organization that is accredited by the NACCB (National Accredition Council for Certification Bodies). Thus, the United Kingdom model for Quality Assurance which uses a third party is quite involved and may not be suitable for the paving industry of this country, unless evidence of its superiority could be manifested.

While most QA specifications are based on quantitatively prescribing material properties and proportions, Gastmans [10] makes use of a G-Index to ensure quality. This index is a number derived from knowledge of mixture properties such as Marshall Stability, Flow, Void Content, and Binder Content. An ideal mixture has an index equal to one; an index greater than one indicates superior mixture, and less than one means inferior or poor quality construction. The G-Index is a new concept and its use and effectiveness as a QA tool has not yet been reported by other researchers.

3.0 Questionnaire

A questionnaire was sent out to a sample of people involved with the Quality Assurance (QA) program in Indiana. This was to obtain a complete picture of the impact that implementation of QA specifications had on the pavement industry. The recipients of the questionnaire included those directly involved with QA like contractors and INDOT field personnel as well as those who are indirectly involved like material suppliers and INDOT planning officials. The questionnaire was designed to be anonymous so that responses were unbiased. In this way it was hoped a true picture would be achieved. A copy of the Questionnaire is attached in Appendix A.

Overall, about eighty sets of questionnaires were sent out in Indiana as well as to other Mid-Western States where contractors and material suppliers had their offices. About fifty-five were received back by the extended dead line. A tabulation of the responses is given in Table 1. The response was overwhelmingly in favor of QA. The distribution by involvement of those surveyed is given in Figure 1.

Table 1 gives a relatively clear analysis about the overall reaction to QA in Indiana. Eighty-four percent of those surveyed said QA was needed to assure quality, while seventy-three percent said it was better than Standard (or non-QA) INDOT specifications. The benefits of QA include resolving of dispute about quality by resampling, penalty system making contractor aware of his losses, and overall

Table 1. Tabulation of Responses to the Questionnaire on Quality Assurance Implementation

Summary of QA Questionnaire Responses	
Do we need QA projects?	84% YES 2% NO 14% DON'T KNOW
Is QA better than non-QA?	73% YES 11% NO 13% THE SAME 3% DON'T KNOW
Involvement in QA?	36% ADMIN. 27% TESTING 20%SUPPLIERS 24% CONTRACTOR 5% OTHER
How many projects have you bid?	7% (1-5) 29% (6-10) 64% (>10)
Do you prefer to supply for QA projects?	62% YES 14% NO 23% DON'T CARE
Is QA more effective?	76% YES 18% NO 9% DON'T KNOW
Is QA more efficient?	66% YES 25% NO 7% DON'T KNOW
Is penalty an incentive for Quality?	64% YES 29% NO 7% DON'T KNOW
What about QA management?	36% GOOD 49% FAIR 9% POOR 5% DON'T KNOW
Is QA cost effective?	69% YES 18% NO 13% DON'T KNOW
Does QA take more time?	62% YES 13% NO 13% SAME 13% OTHER
Do you prefer QA if you are a Contractor ?	40% YES 40% NO 20% DON'T CARE
Do you prefer QA of you are the client?	78% YES 6% NO 16% DON'T CARE
Should all projects be QA?	40% YES 55% NO 5% OTHER
Does resampling help solve disputes?	75% YES 25% NO
Are personnel well trained?	51% YES 49% NO

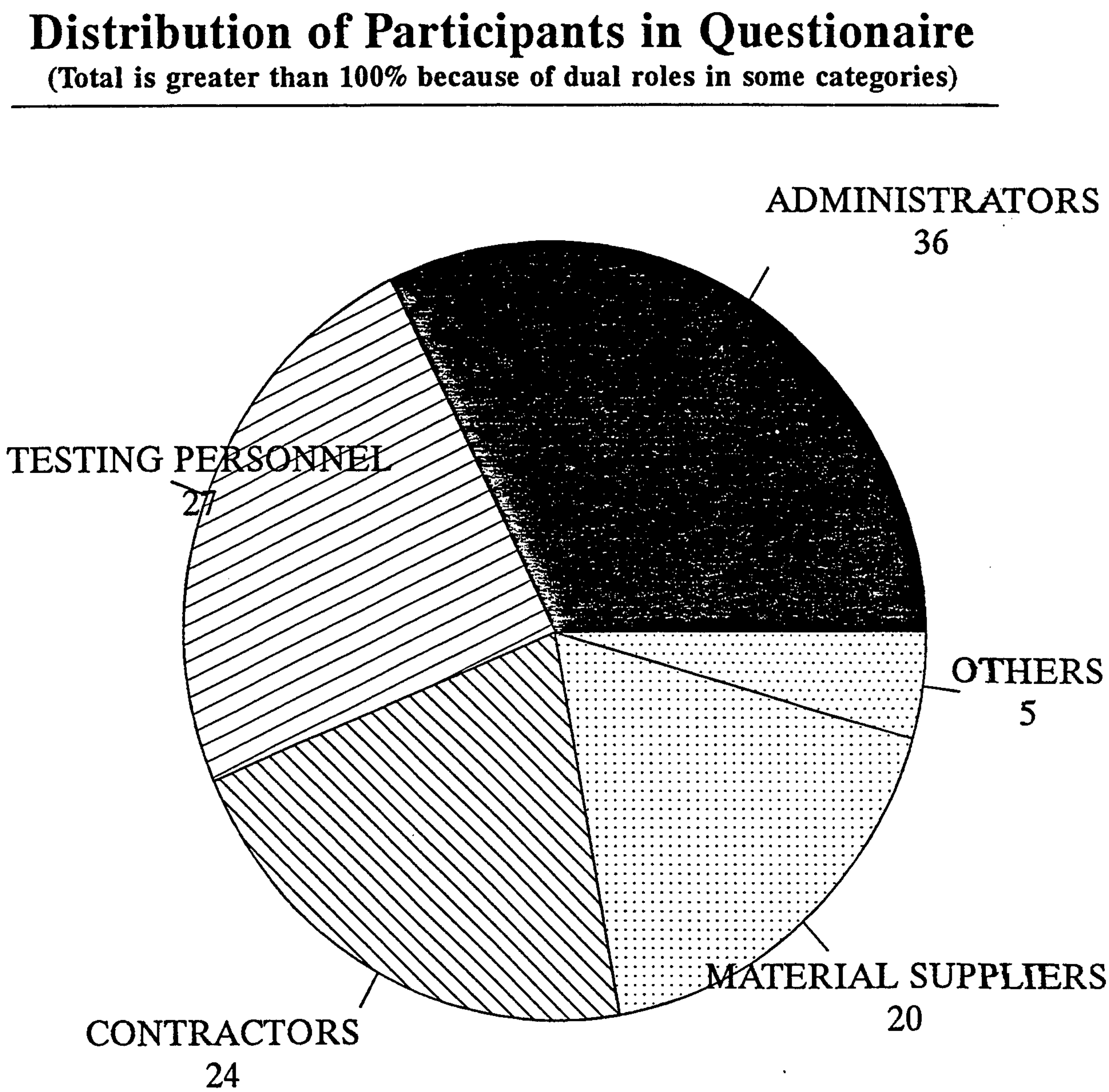


Figure 1. Percent Participation in QA Survey

improvement of efficiency as a result of the penalties.

3.1 Comments

By far the greatest concern addressed by most responders was regarding inadequately trained State personnel. Comments were made that State personnel were not well versed with QA causing construction work to be slowed down. Also, State supervisors indicated that staff turnover affected work especially since the hiring and training of new personnel took time during the busy construction season. Increased work and low wages were cited as main reasons for leaving State jobs to join the pavement contractors, or to other jobs.

One other major comment was made by the contractors who complained about the aggregate gradation being too tight and the difficult of meeting or satisfying this requirement during mix production. Others wanted a relaxation of the tight air void content requirement. However, it should be noted that among the key elements of the QA specifications that have made the project successful, is the control on aggregate gradation as well as air voids from mix design. Thus although these elements present a greater challenge to produce QA mixtures and the subsequent pavement, contractors are gradually being persuaded that QA specification works and is here to stay; contractors comment that they are adapting and getting used to it. This attitude is evident from some of the comments received, and is not unique to Indiana [7].

Some responses from state personnel were negative mainly regarding the greater paper work that QA required. Also, they were not satisfied at their knowledge level and wanted more training. Many written responses from contractors were received wanting QA specifications in all bituminous construction work in Indiana. This is reflective of comments from contractors who are implementing it on their own in city and county work as well as private jobs (11).

4.0 Design of Experiment

The original proposal [12] had several factors as main effects and some covariables. The main factors included were:

Factors	Levels	
1) Aggregate Type	3	-Gravel -Slag -Crushed Stone
2) Base Type	2	-Flexible -Rigid
3) Project Type	2	-QA Specifications -Standard Specifications
4) Dust Collection	2	-Bag House -Wet Wash
5) Truck Traffic	3	-High -Medium -Low
6) Plant Type	2	-Drum -Batch

7) Climate	2	-North -South
8) Pre-Existing Condition	2	-Good -Bad

The factors Climate and Pre-Existing Condition were not meant to be treated as main effects but as covariables. A copy of the original design of experiment layout is given in Appendix B. Also the experimental design is unbalanced due to different levels of factors thus it could not be fractioned if required.

After reevaluation of the original design layout, it was realized that there were insufficient completed QA projects to fill the cells in the layout shown in Appendix B. Thus a new experimental design was made which retained the important factors in the original design thought necessary to provide the needed information for the study. The new experimental design is a 2^4 factorial layout as shown in Figure 2. The 4 factors at two levels each are as follows:

Factors	Levels	
Aggregate Type (Binder)	2	- Gravel - Crushed Stone
Base Type	2	- Flexible - Rigid
Project Type	2	- QA - Standard Specifications

Base Type	Aggregate Type	QA HIGH	QA LOW	NON-QA HIGH	NON-QA LOW
FLEXIBLE	CRUSHED	SR67 [R-16912]	US31 [RS-16580]	US 41 R-16442	SR 38 RS-16667
FLEXIBLE	UNCRUSHED	N/A	US 136 R-16885	N/A	SR 1 RS-16080
RIGID	CRUSHED	I-65 RS-16963	US 41 RS-16690	US 41 R-16685	SR 18 R-15995
RIGID	UNCRUSHED	I-65 [R-17024]	US 41 RS-16692	N/A	SR 1 RS-16263

(Header key: PROJECT TYPE: QA / NON-QA; TRAFFIC: HIGH / LOW; AGGREGATE TYPE: CRUSHED / UNCRUSHED; BASE TYPE: FLEXIBLE / RIGID)

Figure 2. Design of Experiment Layout

Truck Traffic	2	- High - Low

Two factors, Dust Collection system and Plant Type were dropped. The dust collection systems are related to plant type, thus there is a strong correlation between the two. This would not allow a factorial study to be carried out by not filling sufficient number of cells in the experimental design. The predominant plant type in Indiana is the drum drier. Thus including these two factors in the study would bias the study, and they were consequently dropped. Also, INDOT Specifications [14] do not identify any preference for either dust collection system or plant type.

The layout of the revised experimental design was given in Figure 2. This is a 2^4 factorial design where all factors have two levels each. For the aggregate factor, slag was dropped because its use is largely limited to the northern region of the State, thus including it in the study would be introducing a regional bias. Two levels for base type are flexible and rigid are included mainly to investigate their effect on the performance of the new pavement. The two levels for project type are QA and Standard Specifications (non-QA). Finally, two levels for truck traffic, high and low were selected based on the INDOT traffic classification given in Table 2. The intermediate level was dropped mainly because any effect due to traffic could be seen by comparing the high versus low traffic effects, and also because it was desired to maintain the study as a 2^4 factorial so that, if necessary,

Table 2. CRITERIA FOR TRAFFIC LEVELS IN INDIANA

TRAFFIC / ROAD TYPE	AADT			TRUCKS	
	LOW	MEDIUM	HIGH	LOW	HIGH
TWO LANE	1 - 5000	5001 - 14,000	>14,000	<1450	>1450
FOUR LANE	1 - 7000	7001 - 20,000	>20,000	<1450	>1450
MORE THAN FOUR LANE	-	-	ALL ADT	<1450	>1450

fractioning the experiment would be possible.

The covariables Climate and Precondition were dropped because the locations of QA projects did not allow sufficient pavements from opposite climatic ends of Indiana to be selected; pavement Precondition was impossible to quantify beyond the PSI measure because the project was initiated in 1989 well after the pavements had been laid in place. The PSI (Present Servicibility Index) is a measure of pavement surface condition that is used as an indication whether it needs minor or major rehabilitation work. The pavements selected in the study all had very poor PSI prior to resurfacing ranging from 1.9 to 2.8 as shown in Table 3, obtained from the Pavement Roughness Inventory maintained by the Division of Research.

4.1 Method of Analysis

All data gathered were subjected to normality testing to ensure that variances are homogeneous. This is the prerequisite to applying ANOVA and other statistical techniques for investigating significance. Paired t-tests where applicable were used to compare means. A full factorial analysis using the SAS-GLM [13] procedure is planned when more data is collected to investigate all main effects and their first order interactions. All second order and higher interactions will be pooled together to increase the degree of freedom and thus the power of the test. The higher order interactions can be difficult to explain and thus the analysis would focus only on the main effects.

5.0 Testing

Two kinds of testing were carried out, field and laboratory tests. In the field, the condition of the pavement, PCI [15] was determined every year from 1991. The pavements in the study were constructed in 1987/88, but the PCI's were not done until 1991 to allow for traffic related distress (if any to develop). The condition surveys were performed in two different stages for both QA and non-QA pavement sections.

Table 3. Reconstruction Details About Pavements in Study

Contract No.	Road	Year completed	Type	Thickness (in)	PSI
R-16912	SR-67	1988	QA	3	2.7
R-16963	I-65	1988	QA	2	2.8
R-17024	I-65	1988	QA	3	2.7
RS-16580	US-31	1988	QA	1.5	2.6
RS-16885	US-136	1987	QA	2	2.3
RS-16690	US-41	1987	QA	1.25	2.0
RS-16692	US-41	1987	QA	2.25	2.0
RS-16442	US-41	1987	Non-QA	1.5	2.2
RS-16685	US-41	1987	Non-QA	2	1.9
RS-16667	SR-38	1987	Non-QA	2	2.5
RS-16080	SR-1	1987	Non-QA	1.5	2.5
RS-15995	SR-18	1987	Non-QA	1	2.2
RS-16263	SR-1	1987	Non-QA	1.25	2.7

Stage I includes the condition survey results from the 1991 and 1992 seasons. Stage II includes the condition survey results from the 1993 and 1994 seasons. Stage II results are documented at the end of this report (Addendum). A tabulation of the field data and information of each project evaluated is given in Table 4.

Friction testing of the pavement surfaces was also carried out on the QA pavements but analysis of these results is not complete and will be included in the final report. However, initial results do not show any difference between QA and Non-QA pavements.

Laboratory testing was carried out to determine physical properties of the mixtures including air void content, penetration and absolute viscosity. These tests were conducted by the Materials and Test Division of INDOT and the results are used in this paper. The laboratory data from cores taken from QA pavements throughout Indiana is presented in Table 5.

6.0 Analysis

Analysis of data in Tables 4 and 5 was carried out in two steps. First was the comparison of performance of QA pavements against non-QA pavements to observe differences, distress development and severity, and overall condition. Next, an analysis of the data for QA pavements was made to observe the effects of traffic, age and void content on pavement performance.

6.1 QA Versus Non-QA Pavements

The comparison of QA and non-QA pavements was carried out using the field data for two years. The pavements in the experimental design in Figure 2, were surveyed to obtain their respective condition indices. The locations of each sampling

Table 4. Details of Projects Selected For Field Evaluation

PROJECT TYPE	HIGHWAY	CONTRACT NUMBER	LENGTH (miles)	TOTAL COST		UNIT COST PER MILE	PCI 1991	PCI 1992
				AT BIDDING	FINAL CONSTRUCTED			
QA	SR 67	R–16912	4.62	$886,218.10	$843,323.62	$182,537.58	93	87
QA	I–65	R–16963	8.387	$5,938,325.22	$5,984,197.70	$713,508.73	90	75
QA	I–65	R–17024	3.463	$3,299,320.20	$3,270,324.04	$944,361.55	91	90
QA	US 31	RS–16580	5.5	$289,797.60	$279,110.90	$50,747.44	95	88
QA	US 136	RS–16885	2.47	$785,503.50	$955,576.54	$386,873.09	78	69
QA	US 41	RS–16690	7.91	$1,760,431.94	$1,640,774.49	$207,430.40	88	73
QA	US 41	RS–16692	2.78	$1,301,094.86	$1,303,313.59	$468,817.84	90	76
NON–QA	US 41	R–16442	0.141	$69,199.50	$65,002.33	$461,009.43	82	78
NON–QA	US 41	RS–16685	3.42	$988,715.25	$859,115.11	$251,203.25	86	85
NON–QA	SR 38	RS–16667	2.88	$262,944.30	$264,599.00	$91,874.65	74	64
NON–QA	SR 1	RS–16080	8.6	$829,255.35	$935,227.35	$108,747.37	71	70
NON–QA	SR 18	R–15995	0.19	$267,114.15	$277,699.11	$1,461,574.26	63	61
NON–QA	SR 1	RS–16263	4.01	$1,049,023.20	$1,066,164.70	$265,876.48	83	80

Table 5. Data for QA Pavements Used in Analysis

CONTRACT#	MIX TYPE	TIME (MO.)	FIELD VOIDS	CORE VOIDS	PEN. (0.1 mm)	VISC. (Poise)	TOTAL VEHICLES	MIX DESIGN ASP%
RS-16556	SURF. 9	0	4.8		60	2081	0	5
(LV)		20	4.8	2.5	39	4952	2600000	
		38	4.8	2.2	35	7210	4900000	
RS-16561	BIND. 9	0	7.6		60	2081	0	6
(LV)		22	7.6	6.5	37	6176	2100000	
		50	7.6	5.9	38	6713	4900000	
	SURF. 11	0	9.4		60	2081	0	6
		21	9.4	4.4	39	5848	2000000	
		49	9.4	3.5			4800000	
RS-16565	BIND. 9	0	8.8		60	2081	0	6
		22	8.8	5	34	6502	3800000	
		42	8.8	5	35	6449	7200000	
RS-16566	BIND. 8	0	6.7		60	2081	0	5
		25	6.7	6	32	8253	2300000	
		47	6.7	5.3	26	11843	4300000	
RS-16567	BIND. 8	0	7.4		60	2081	0	6
		24	7.4	10.2	24	15502	4200000	
		44	7.4	10.2	20	25305	7700000	
RS-16569	BIND. 9	0	8.4		60	2081	0	6
		23	8.4	10.1	30	11752	7200000	
		45	8.4	11	21	20123	14200000	
RS-16570	BIND. 9	0	8.7		60	2081	0	6
		25	8.7	7	28	12674	5000000	
		47	8.7	7.5	21	18380	9400000	
RS-16572	BIND. 8	0	7.7		63	2081	0	6.1
		22	7.7	3.8			8600000	
		40	7.7	3.2	32	9689	15600000	
	MOD. SURF.11	0	8.4		63	2081	0	6
		21	8.4	6.1			8200000	
		39	8.4	4.1	35	9356	15200000	
RS-16573	BIND. 8	0	9.2		63	2081	0	7.8
		23	9.2	7.8			3400000	
		47	9.2	4.4	31	7762	6900000	
	SURF. 11	0	7.5		63	2081	0	6.4
		23	7.5	5.4			3400000	
		47	7.5	5.2	33	7464	6900000	
RS-16575	BIND. 8	0	7		63	2081	0	6
		24	7	7.6	40	4713	5900000	
		41	7	6.8	32	6988	10100000	
	MOD. SURF. 11	0	10.1		63	2081	0	6.2
		23	10.1	4.3	51	3038	5700000	
		40	10.1	4.2	32	6901	9800000	

Continued Table 5

CONTRACT#	MIX TYPE	TIME (MO.)	FIELD VOIDS	CORE VOIDS	PEN. (0.1 mm)	VISC. (Poise)	VEHICLES (x10^6)	MIX DESIGN ASP%
RS−16580	BIND. 8	0	6.9		73	2020	0	6
		14	6.9	5.5	36	14542	4000000	
		36	6.9	4	33	16305	10400000	
	SURF. 11	0	9.5		73	2020	0	5.3
		14	9.5	5	52	6512	4000000	
		36	9.5	4.8	38	9136	10400000	
RS−16584	BASE 5	0			73	2010	0	6.2
		19		6.2	41	6119	1700000	
		41		5.6	35	8908	3700000	
	SURF. 11	0	7.6		73	2010	0	8
		18	7.6	5.6	42	5392	1600000	
		40	7.6	5	25	11724	3700000	
RS−16585	BASE 5	0			77	2029	0	5
		18		6.5	51	4524	6500000	
		40		5.5	39	6737	14600000	
	BIND. 9	0	10.1		77	2029	0	6.5
		17	10.1	8.2	43	8488	6200000	
		39	10.1	7.3	30	17116	14200000	
	MOD. SURF. 11	0	9.6		77	2029	0	6
		16	9.6	8.8	36	14950	5800000	
		38	9.6	8	27	23184	13800000	
R−16647	BASE 5	0			63	2081	0	6
		16		5	37	5481	9300000	
		34		4.5	28	8861	19700000	
	BIND 9	0	8		63	2081	0	6
		15	8	6.6	47	4126	8700000	
		33	8	6.3	28	10610	19100000	
	MOD. SURF. 11	0	8.4		63	2081	0	8
		15	8.4	9.5	26	11722	8700000	
		33	8.4	8.9	19	30385	19100000	
RS−16669	BIND. 11	0	10.8		73	2020	0	6
		16	10.8	9	36	11633	3500000	
		39	10.8	8.3	29	18477	8400000	
RS−16673	BIND. 9	0	11		60	1938	0	7.5
		19	11	9.9	22	20692	3900000	
		41	11	8.8	18	35471	3400000	
RS−16677	MOD. SURF. 11	0	8.9	0	63	2081	0	7.4
		17	8.9	7.9	48	4480	3900000	
		49	8.9	6.7	31	9743	11200000	
RS−16680	MOD. SURF. 11	0	8.8		72	1901	0	6.1
		22	8.8	6	46	4459	5100000	
		49	8.8	5.5	26	13786	11500000	

Continued Table 5

CONTRACT#	MIX TYPE	TIME (MO.)	FIELD VOIDS	CORE VOIDS	PEN. (0.1 mm)	VISC. (Poise)	VEHICLES (x10^6)	MIX DESIGN ASP%
RS-16682	BIND. 8	0	10.2		72	1901	0	7
		20	10.2	8.2	38	4831	9000000	
		39	10.2	8.4	41	4604	17600000	
	MOD. SURF. 11	0	10.5		72	1901	0	6
		20	10.5	5.9	35	6051	9000000	
		39	10.5	5.4	36	5614	17600000	
RS-16684	BIND. 8	0	8.6		60	1938	0	6
		20	8.6	6.8			4400000	
		38	8.6	5.9	40	5997	8300000	
	MOD SURF. 11	0	8.2		60	1938	0	5.9
		19	8.2	5.7			4200000	
		37	8.2	5	45	6082	8100000	
RS-16690	BASE 5	0			60	1938	0	6
		16		6.1	44	4138	7600000	
		38		5.3	42	4694	18100000	
	BIND. 9	0	8.7		60	1938	0	6
		16	8.7	5.1	56	3108	7600000	
		38	8.7	4.6	41	4594	18100000	
	SURF. 11	0	6.9		60	1938	0	6
		15	6.9	4.6	27	11674	7100000	
		37	6.9	4	20	26277	17600000	
RS-16692	BIND. 8	0	7.9		60	1938	0	6.1
		18	7.9	6			6700000	
		40	7.9	5.9	30	10373	14800000	
	MOD. SURF.11	0	8.2		60	1938	0	6
		16	8.2	6.2	42	5282	5900000	
		38	8.2	5.6	21	18795	14100000	
RS-16693	BASE 5	0			60	1938	0	6
		16		4.3	45	3887	5300000	
		38		4	42	4328	12700000	
	BIND. 9	0	6.4		60	1938	0	6
		15	6.4	3.2	48	3893	5000000	
		37	6.4	2.8	44	4731	12300000	
	MOD. SURF.11	0	12.4		60	1938	0	6
		15	12.4	5.5	26	9859	5000000	
		37	12.4	5	27	14874	12300000	
R-16885	BIND. 8	0	8.6		63	2081	0	6
		20	8.6	5.6	48	3465	4400000	
		38	8.6	4.5	26	10607	8300000	
	SURF. 11	0	8.2		63	2081	0	5.9
		19	8.2	6.4	25	12842	4200000	
		37	8.2	5.8	24	16243	8100000	

Continued Table 5

CONTRACT#	MIX TYPE	TIME (MO.)	FIELD VOIDS	CORE VOIDS	PEN. (0.1 mm)	VISC. (Poise)	VEHICLES (x10^6)	MIX DESIGN ASP%
R-16911	BIND. 8	0	8.4		73	2010	0	7
		24	8.4	8.9	32	10265	16600000	
		46	8.4	9.6	21	26143	31700000	
	MOD. SURF. 11	0	11.4		73	2010	0	7
		21	11.4	7.3	24	17806	14500000	
		43	11.4	9	22	31815	29700000	
R-16912	BIND. 8	0	8.6		63	2081	0	7
		23	8.6	7.7	31	8758	12100000	
		45	8.6	7.9	34	5234	23600000	
	MOD. SURF. 11	0	10.6		63	2081	0	7.7
		22	10.6	6.8	32	8273	11600000	
		44	10.6	6.6	26	11212	23100000	
R-16963	BIND. 8	0	9		20	1938	0	6.1
	(NBL)	17	9	9	28	10355	12800000	
		28	9	7.6	22	20112	21000000	
	BIND. 8	0	8.9		60	1938	0	6.1
	(NBL)	8	8.9	7.5	28	14782	6000000	
		19	8.9	6.6	24	17836	14200000	
	MOD. SURF. 11	0	10.9		60	1938	0	6
	(NBL)	16	10.9	8.2	26	14151	12000000	
		27	10.9	8	16	26460	20200000	
	MOD. SURF. 11	0	9.9		60	1938	0	6
	(NBL)	7	9.9	8.3	30	10343	5200000	
		18	9.9	8.6	22	19166	13500000	
R-17014	BIND. 9	0	9.2		73	2020	0	5.3
		17	9.2	5.3	43	6292	20400000	
		28	9.2	4	45	6538	33600000	
	SURF. 11	0	12.7		73	2020	0	6
		15	12.7	7.4	51	4782	18000000	
		26	12.7	6.4	35	10847	31200000	
R-17024	BASE 5	0			63	2081	0	6
		19		4.4	48	4594	16400000	
		38		4.4	43	4486	32700000	
	BIND. 9	0	7.9		63	2081	0	6
		19	7.9	5	38	5958	16400000	
		38	7.9	6.3	40	5586	32700000	
	MOD. SURF. 11	0	8.8		63	2081	0	6.1
		20	8.8	5.2	41	4694	17200000	
		39	8.8	4.6	4	5436	33600000	

site are given in Figure 3. The detailed construction information for these pavements was shown in Table 4. The total cost is shown in two columns, indicating the cost at bid, and the actual cost after the project was completed. The condition surveys recorded detailed descriptions and measurements of cracks and rut depths which were used in the comparison.

There is a list of nineteen visible distresses that can be measured at three levels of severity, low, moderate and high. For each pavement in the study several sections are surveyed to obtain an average PCI for the entire pavement. Each measured distress is converted into a deduction point that is then added into a cumulative deduction total for all the other distresses on the pavement. The condition of a pavement, or PCI, equals to 100 minus this cumulative distress number. A pavement in perfect condition has a PCI of 100. Thus a higher PCI indicates lower distress and therefore better performing pavement, vice versa.

Figure 4 shows an overall higher PCI value for the QA pavements as compared to the non-QA ones by an average of 10 points. A plot of the maximum rut depth on each pavement section in Figure 5 shows greater amount of rutting in the non-QA pavements. On some of the non-QA pavements (SR 38), the rut depth has doubled to 0.6 inch in just one year. The largest rut depth value among the QA pavements is 0.375 (3/8) inch which is low [15].

A comparison of pavement cracking for 1991 and 1992 is

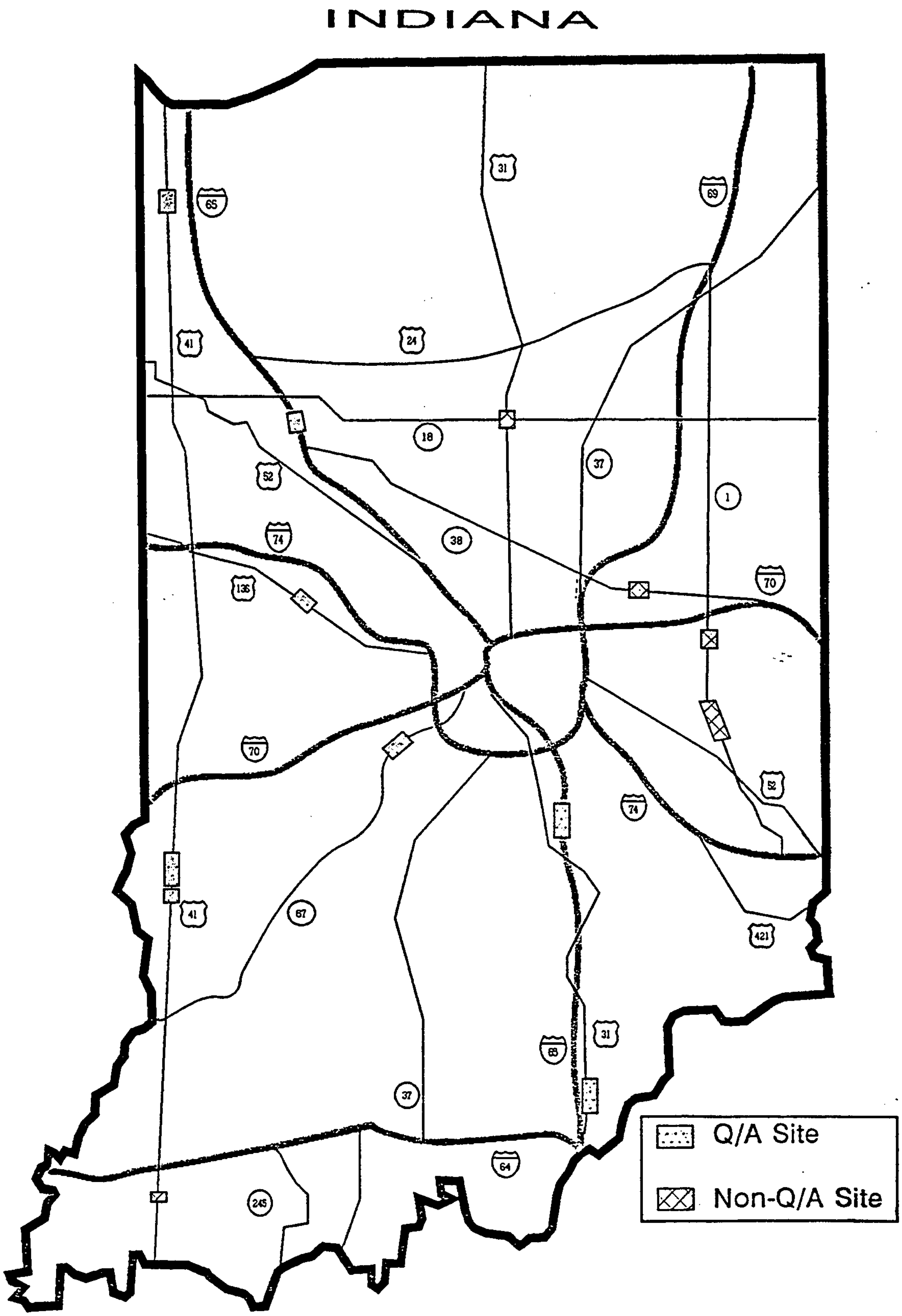


Figure 3. Locations of QA and Non-QA Sites

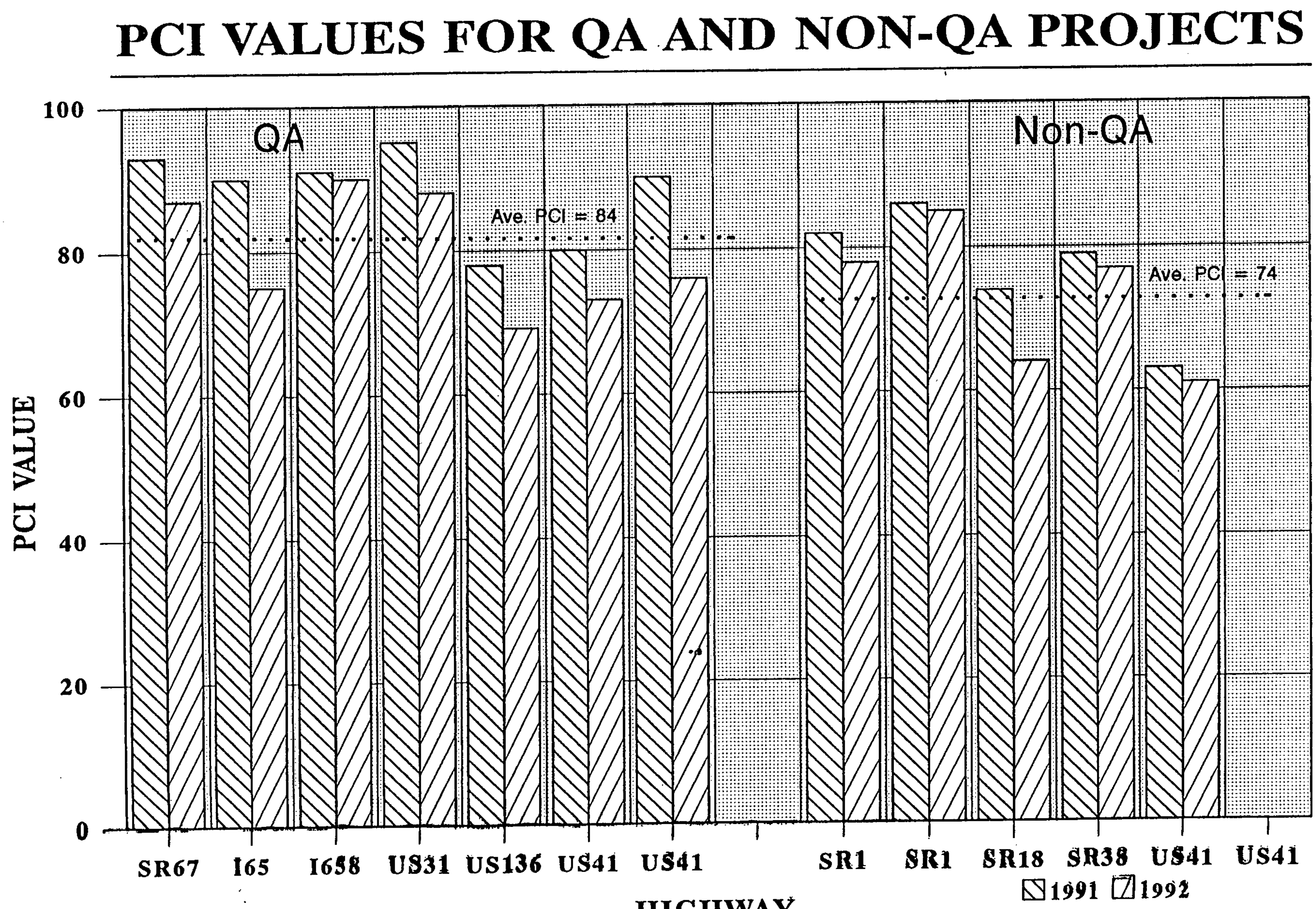


Figure 4. Plot Showing PCI Values for QA and non-QA Projects

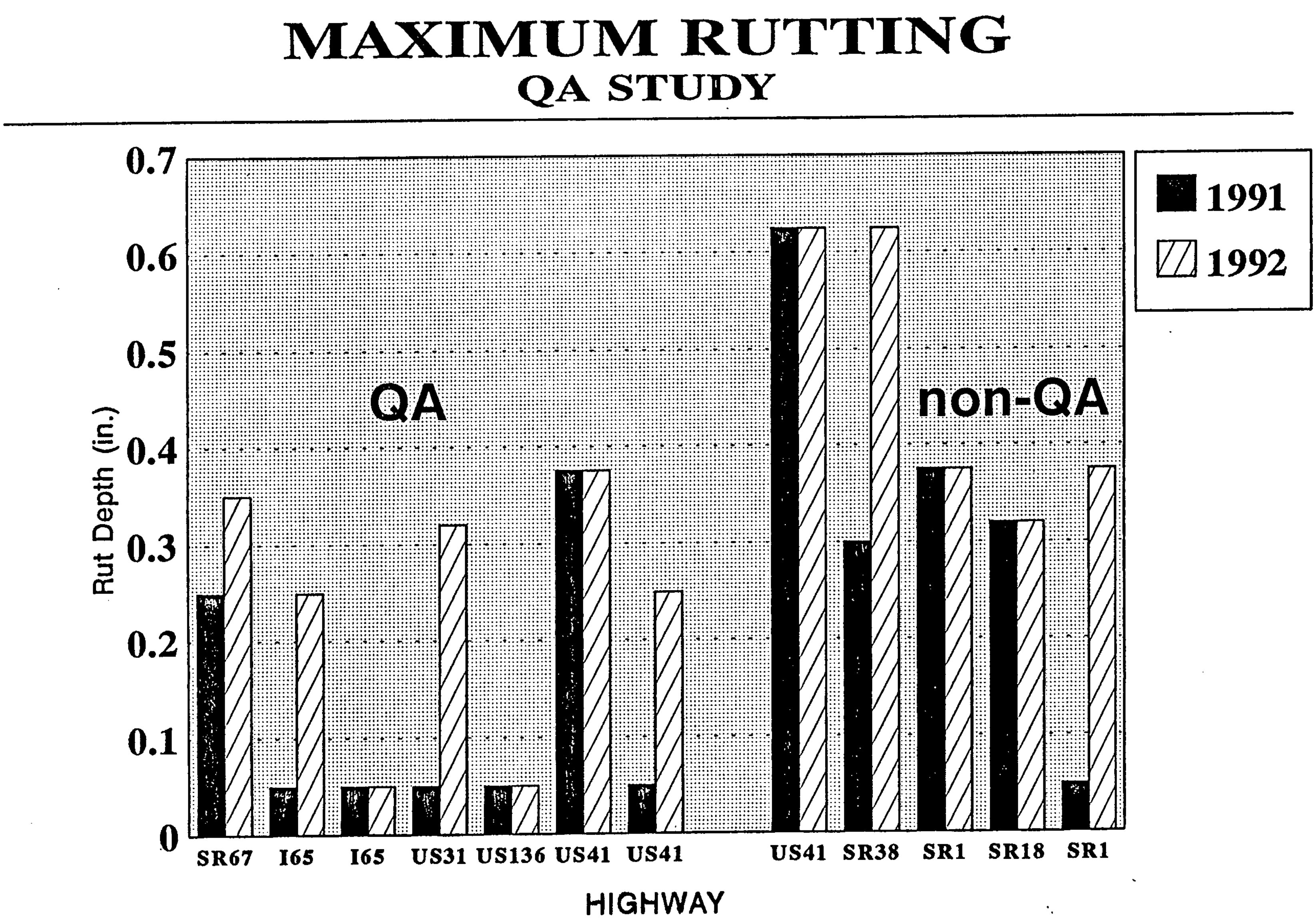


Figure 5. Comparison of Maximum Rutting Between QA and non-QA Projects

shown in Figures 6 and 7. The measure for alligator and block cracking is in terms of square footage of area. Figure 6 shows the crack measurements in 1991. Only two severity levels were noticed, and at each level the cracks were about the same for both QA and non-QA pavements except for alligator cracks that predominate in the latter.

In Figure 7 crack measurements for 1992 are shown at three severity levels. At the low severity level there is little difference in crack magnitude between QA and non-QA pavements except for alligator cracking which is more dominant in the latter.

The limited amount of alligator cracks in the pavement after about five years in service indicate that there is adequate structural capacity in this thickness design of each pavement; the different levels of distress between QA and non-QA thus is due other factors such as construction control.

The medium severity cracking shows high levels of block cracking and some alligator cracks in the non-QA pavements, while longitudinal and edge cracks are greater in the QA pavements. The crack patterns in the QA pavements are perhaps indicative of a stiffer mat that resists rutting but may crack easier. This observation can only be confirmed by obtaining samples from those pavements and comparing them with the Non-QA ones, which is expected to be done next and reported in the final report. At the high severity levels in Figure 7, there are more cracks in the non-QA pavements. Since mat thicknesses were designed separately for the QA and non-QA pavements,

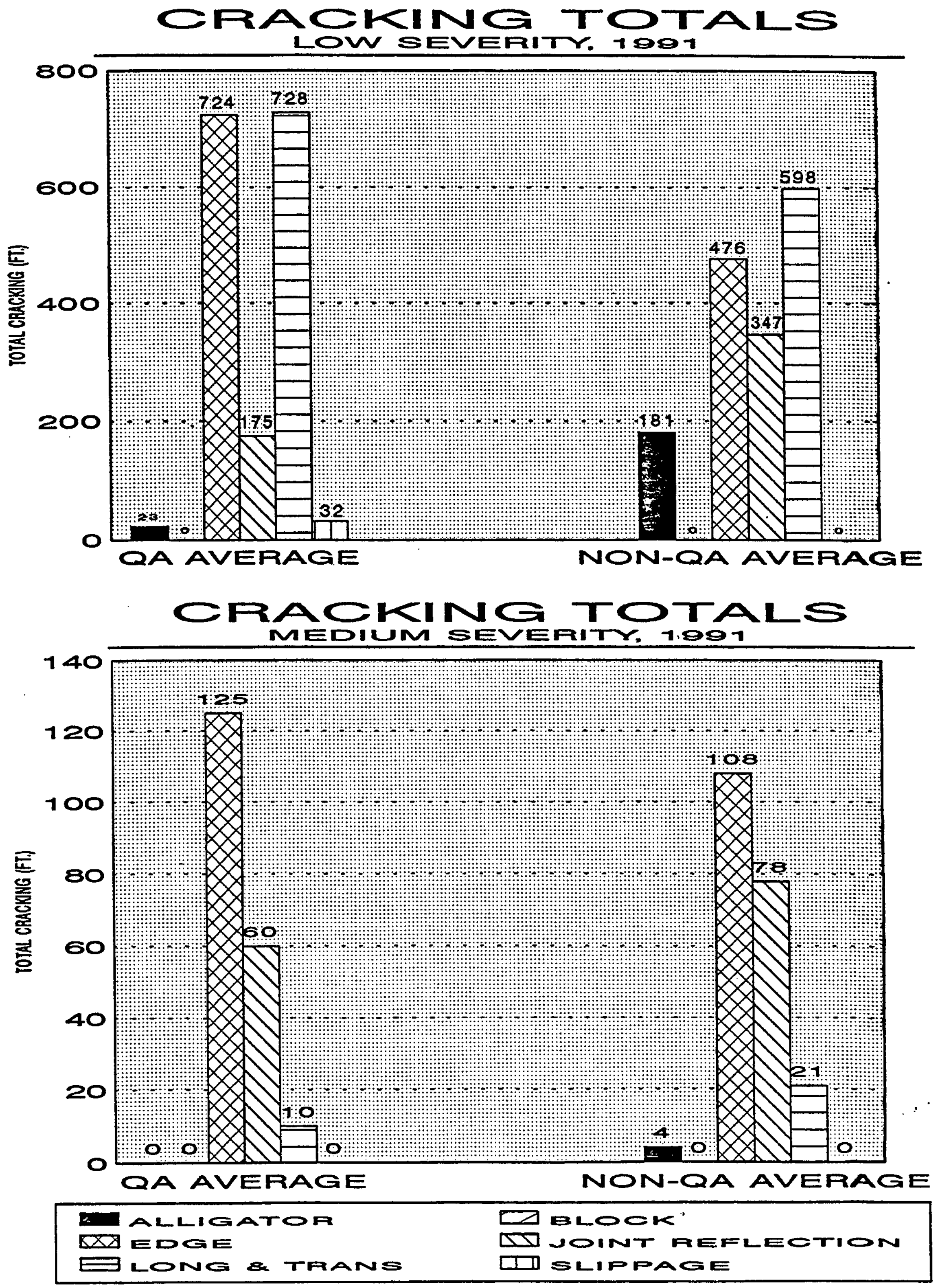


Figure 6. Comparison of Various Cracking Distresses in 1991

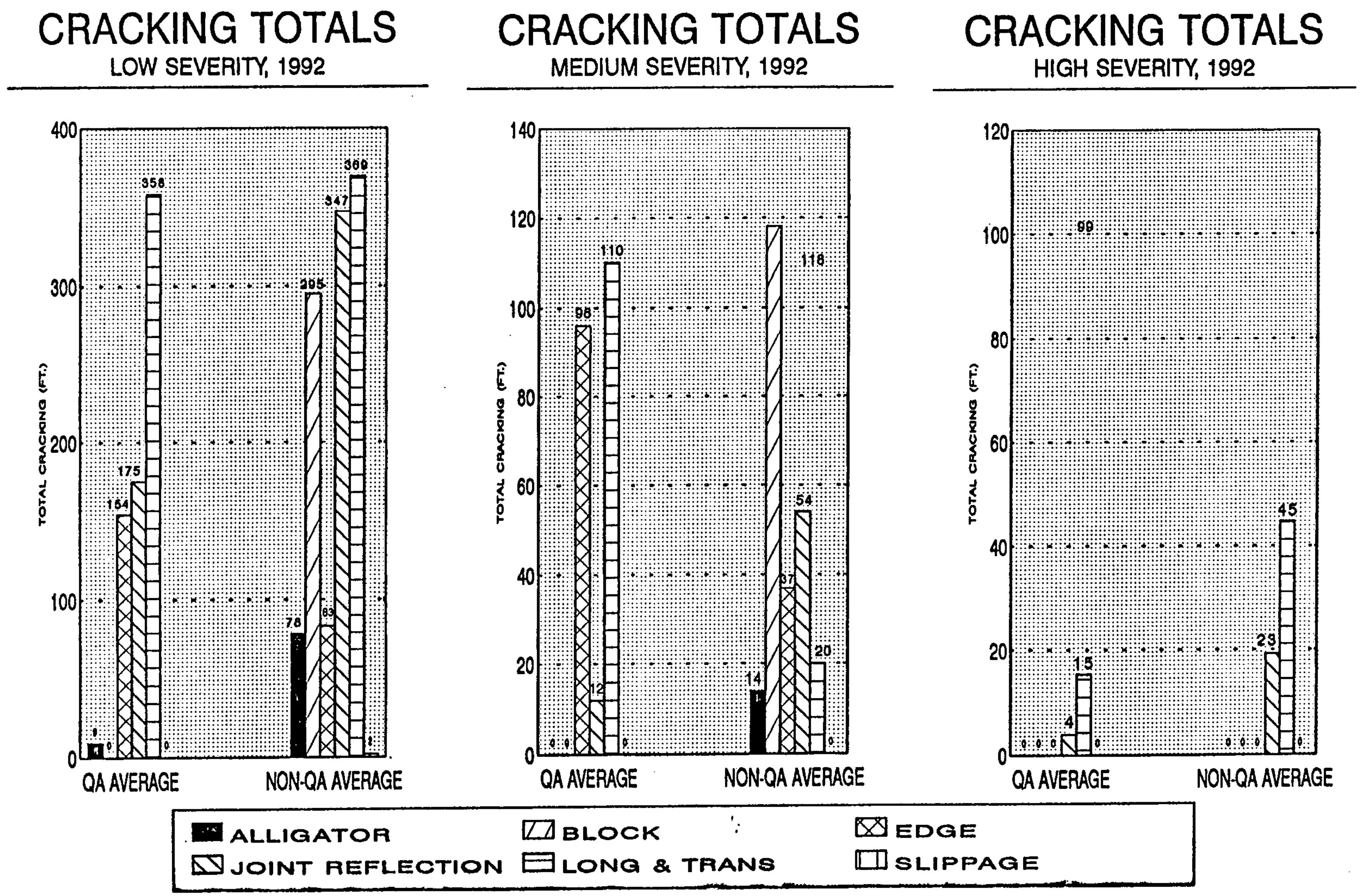


Figure 7. Plot Showing Comparison of Various Cracking Distresses in 1992

based on what was actually required by each pavement the comparisons carried out in this study are valid. Fixing the mat thickness for comparing distress formation, would not make a fair comparison of distress development because it would then be biased towards one specification, and against the other.

A comparison of unit cost between the two project types showed no significance difference at 10% alpha, as presented in Table 6. A low F-value of 1.02 indicates that the test for equality of variance is insignificant, meaning there is no difference between the two sets of unit cost data. Further, a high P-value of 0.4791 confirms the no difference in unit cost result. This indicates that the QA requirement of transferring responsibility for quality to the contractor, and the additional testing for verification, did not increase the unit cost of the project. Thus, quality pavement was produced without incurring additional costs.

6.2 Analysis of Laboratory Data

Analysis of QA data in Table 5 showed pavement behavior that is indicative of material characteristics that explain the better performance of the QA pavements. Figure 8 shows the loss of air voids compared to as laid condition of all surface mats, with respect to time. On the average about 3 percent air voids were lost in all the pavements during the first twenty months. This amounts to approximately 0.1" settlement for a given 3" mat, which is negligible and thus very acceptable.

Table 6. Statistical Compariosn of Unit Cost

TWO SAMPLE T – TESTS FOR QA VS NONQA

VARIABLE	SAMPLE MEAN	SIZE	S.D.	S.E.
QA	4.220E+05	7	3.169E+05	1.198E+05
NONQA	3.548E+05	6	3.206E+05	1.309E+05

		T	P
EQUAL VARIANCES	0.38	11	0.7116
UNEQUAL VARIANCES	0.38	10.7	0.7121

	F	NUM DF	DEN DF	P
TESTS FOR EQUALITY OF VARIANCES	1.02	5	6	0.4791

CASES INCLUDED 13 MISSING CASES 1

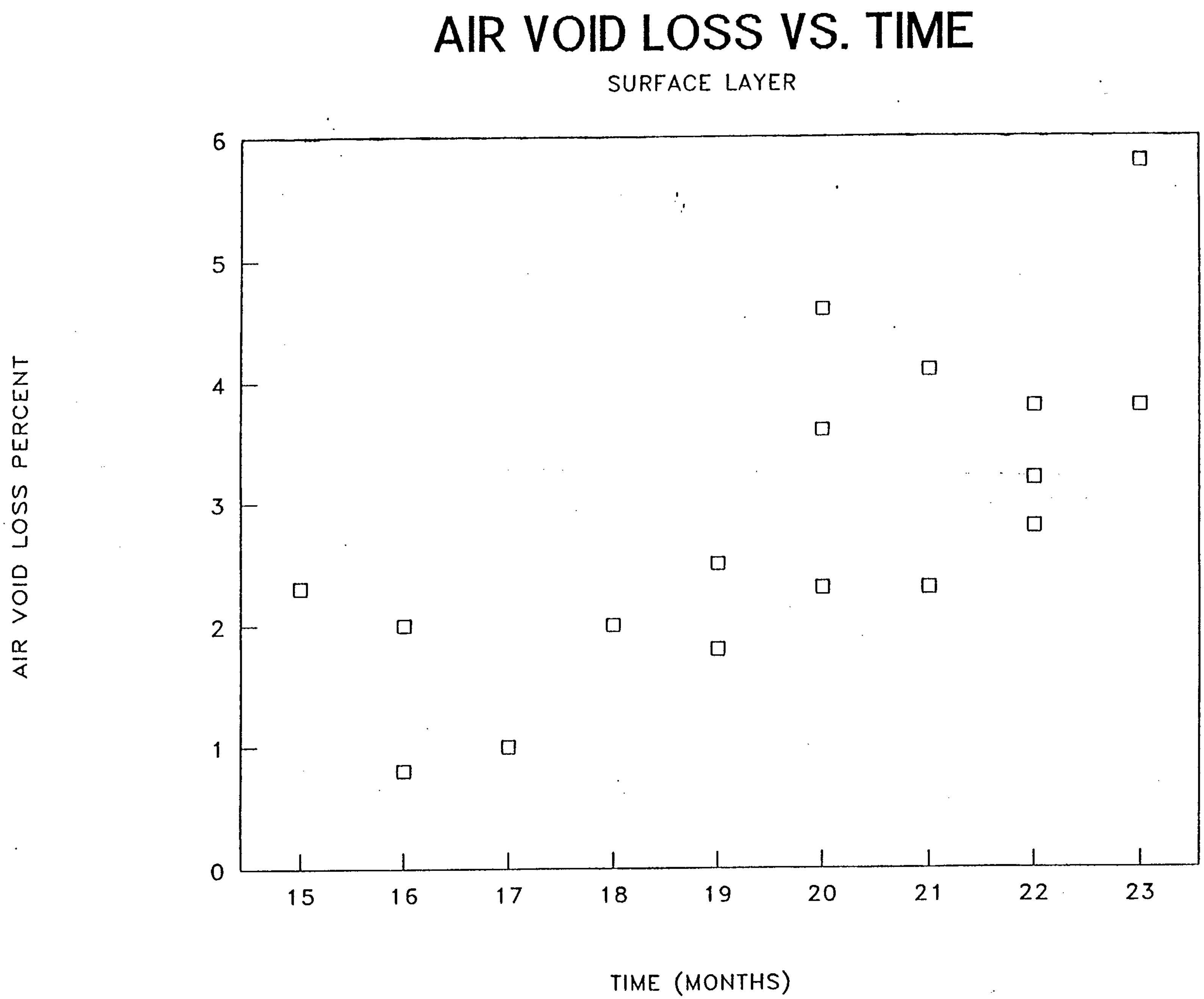


Figure 8. Loss of Air Voids in Pavement Mat

The maximum voids lost in Figure 8 is about 6 percent in twenty three months, which translates to about .2" settlement. The maximum ruts measured on the pavement shown in Figure 7 indicate that QA pavements experienced about 0.05" to 0.35" of rut until 1992 (about 60 months). This result agrees with projected void loss in QA pavements and settlements that had occurred in 23 months shown in Figure 8. The non-QA pavements are experiencing higher ruts as shown in Figure 7. Thus QA construction control of bituminous pavements by use of air voids shows pavements to have lower rut depths for the same period compared to non-QA pavements.

Two plots in Figures 9 and 10 show typical material characteristics due to age. Figure 9 indicates an expected loss in penetration due to the presence of higher air voids. This could be due to a higher rate of binder oxidation. A similar effect is shown in Figure 10 where higher air voids generally causes higher viscosity in the binder

6.3 Design of Experiment analysis

Analysis of factors shown in the design of experiment layout of figure 2 was not carried out. The original plan was to obtain samples for testing from the pavements shown in Figure 2, and conduct a 2^4 factorial analysis with the data. However due to time limitations associated with the completion of this project, this analysis was not performed.

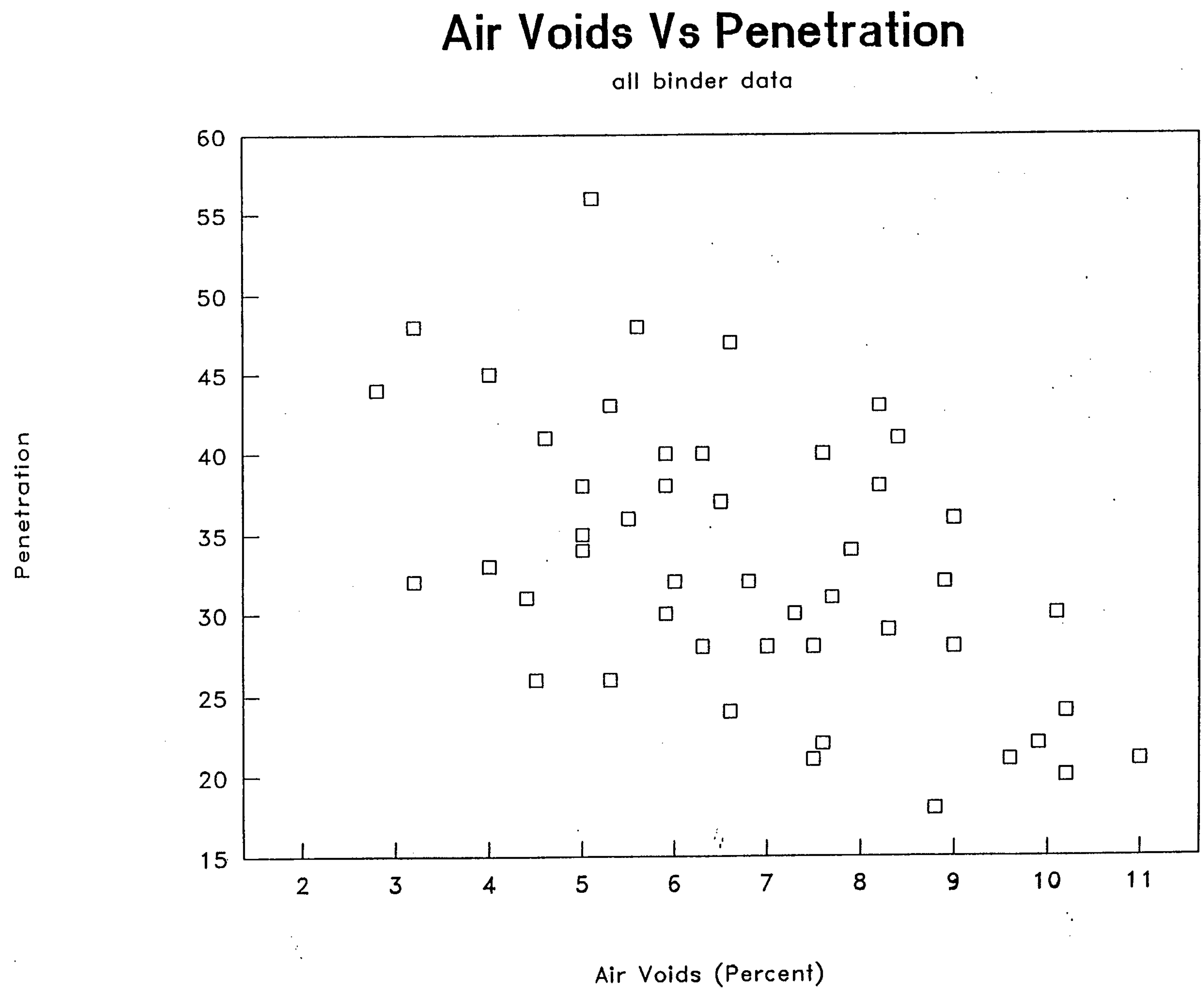


Figure 9. Plot of Air Voids Vs. Penetration

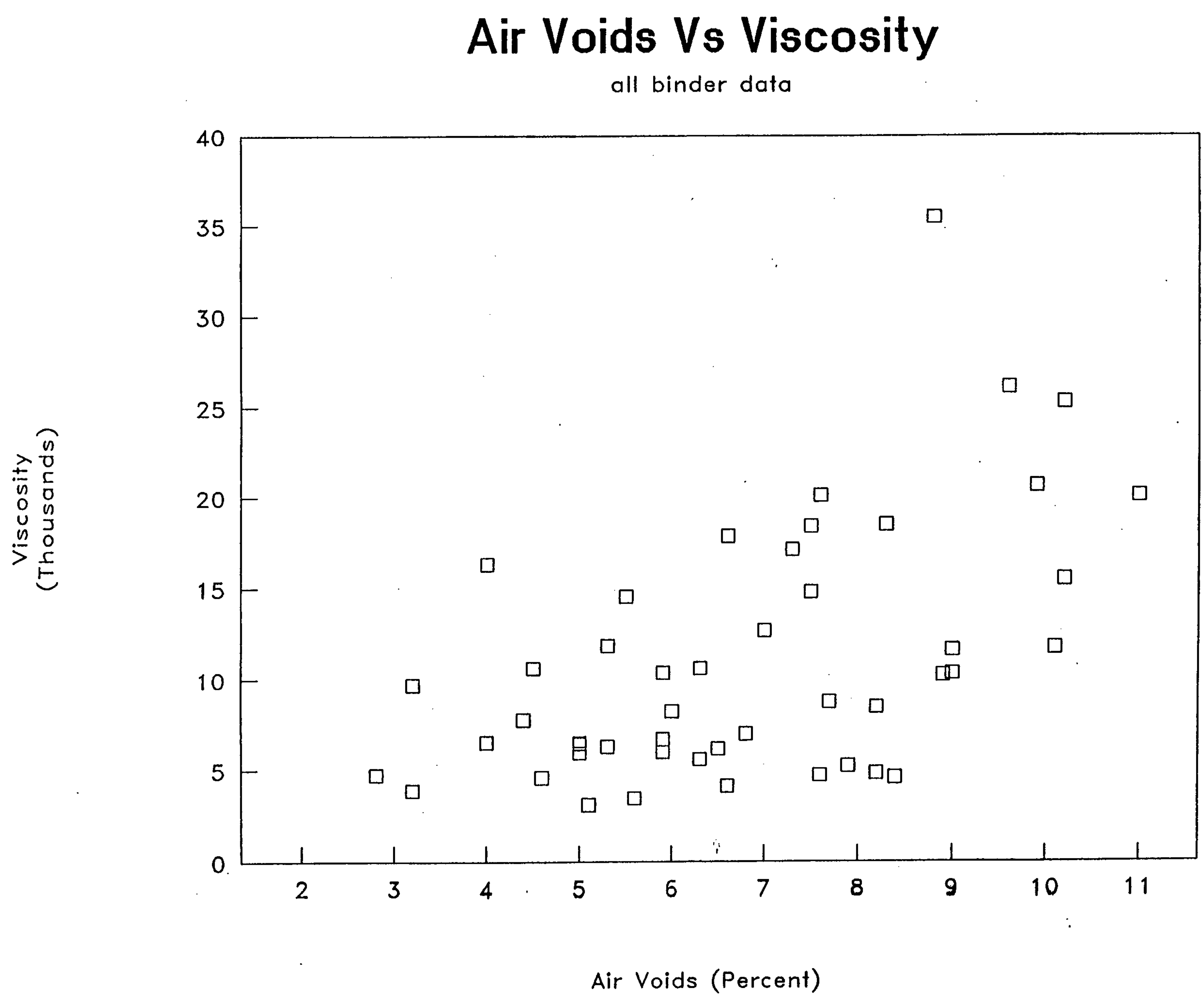


Figure 10. Plot of Air Voids Vs. Viscosity

CONCLUSION

The need to produce quality bituminous pavements in Indiana and to control distress formation, resulted in the implementation of QA specifications on selected projects by INDOT. A performance evaluation was carried out to compare pavements constructed under the QA specifications with those constructed using the standard specifications (non-QA). The results of this evaluation are presented in this report, and indicate the superior performance of QA pavements as follows:

1) Higher condition indices (PCI) indicating better pavements. On average the QA pavements were 10 points higher than the non-QA pavements.
2) Less Rutting. The maximum rut depth on the worst QA pavement was 0.375 inches compared to 0.625 on the worst non-QA pavement.
3) Fewer cracks. Three levels of cracking (low, medium and high) were evaluated. At each level, the QA pavements had the same number or fewer cracks than non-QA pavements.
4) No difference in unit cost. A cost analysis using statistical methods revealed that there was no significance difference in the project unit cost between QA and non-QA projects. Thus, quality pavements were produced under QA specifications with no increase in project unit cost.

REFERENCES

1. V. P. Pauzinauskas. Anti-stripping Additives in Paving Mixtures. Proceedings, Association of Asphalt Paving Technologists, Vol. 51, 1981.
2. Huhtala, M., J. Pihlajamaki, and M. Pienimaki, "Effects of Tires and Tire Pressures on Road Pavement", Transportation Research Record 1227, Transportation Research Board, Washington D.C., 1989.
3. Hudson, S.W. and Seeds, S.B., "Evaluation of Increased Pavement Loading and Tire Pressure", Transportation Research Record 1207, Transportation Research Board, National Research Council, Washington, D.C., USA, 1988.
4. Hughes, C.S., NCHRP Report No. 152, Compaction of Asphalt Pavement, Transportation Research Board, National Research Council, Washington, D.C., USA, 1989.
5. Sandberg ACE, Quality Assurance and Management of Construction, Paper 1: Materials, Testing and Performance, A Sino-British Highways and Urban Traffic Conference, Beijing. 1986.
6. Quality Systems, BS5750, British Standard Institution Document, London.
7. WASHTO Model Quality Assurance Specifications, Final Report, Western Association of State Highway and Transportation Officials, South Dakota, 1991.

8. J. Erwin, "A Look at What Some States are Doing .... QC-QA Training Program in Oklahoma", American Association of State Highway and Transportation Officials, AASHTO Quarterly Magazine, Vol. 70, No. 2, 1991.

9. S. Ramsey, "Quality Assurance", Highways, Vol. 57, No. 1945, January 1989.

10. A. Gastmans, "Quality Assurance in Asphalt Mixes", Proceedings, Association of Asphalt Paving Technologists, Vol. 59, 1990.

11. Walker, R.P, "Bituminous Quality Assurance Status Report", Proceedings, 75th Annual Road School, Purdue University, March, 1989.

12. R. S. McDaniel and L. T. Chapin, "Performance Evaluation of Materials Placed Under Quality Assurance Specifications: Design of Experiment", Original Proposal, 1989.

13. SAS User's Guide: Statistics Version Edition 5, SAS Institute INC., North Carolina, USA.

14. Standard Specifications, Indiana Department of Transportation, 1993.

15. Shahin, M.Y. and S.D. Kohn, "Pavement Maintenance Management For Roads And Parking Lots," Construction Engineering Research Laboratory, U.S. Army Corps of Engineers, Report No. CERL-TR-M-294, October 1981.

APPENDIX A

APPENDIX A

Q.A. Questionnaire

1. Do we need Q.A. projects?

   a) yes   b) no   c) don't know

2. Do you feel Q.A. projects are better than conventional projects?

   a) yes   b) no   c) same   d) don't know

3. What's your involvement in Q.A.?

   a) Admin.   b) Test   c) Supplier   d) Contractor   e) Others ________

   ____

4. If you are a contractor, how many projects have you bid (if any)?

   a) 1 - 5   b) 6 - 10   c) > 10

   How many projects have been awarded to you? ________

5. If you are a supplier, do you prefer supplying for Q.A. projects?

   a) yes   b) no   c) does not matter

   Why? ____

   ____

6. Do you feel the Q.A. method is more effective in producing better products?

   a) yes   b) no

7. Do you feel this Q.A. method is more efficient in producing better products?

   a) yes   b) no

8. Does the Q.A. method of penalties provide sufficient incentive towards quality?

   a) yes   b) no

   Comments: ___________________________________

   ____

9. What do you think about the overall management of the Q.A. project?

   a) Good b) Fair c) Poor d) Other ______________________

   ____

10. Is the Q.A. cost effective?

   a) yes b) no

   Comments: ______________________

   ____

11. What are your general comments about Q.A. projects?

   ____

   ____

12. Does Q.A. consume more time overall from design to construction?

   a) yes b) no c) same

   If yes, please comment ______________________

   ____

13. If you're a contractor, would you prefer a Q.A. or conventional highway project?

   a) Q.A. b) non-Q.A. c) doesn't matter

   Why? ______________________

   ____

14. If you're the client, would you prefer a Q.A. project to a conventional project?

   a) yes b) no c) doesn't matter

   Comments: ______________________

   ____

15. Would you recommend all highway pavement projects be done by the Q.A. method?

   a) yes b) no c) ______________________

16. What could be done to improve the Q.A. Program?____________________

____

17. In the event of dispute, does resampling help in resolving it?

    a) yes   b) no

    Comment ____________________________________

    ____

18. Is adequate training provided for State and Contractor's personnel?

    a) yes   b) no

    Comment ____________________________________

    ____

DD070278

APPENDIX B

APPENDIX B

			S	QA			Non-QA		
P	A	B	D / T	HIGH (0)	MEDIUM (1)	LOW (2)	HIGH (0)	MEDIUM (1)	LOW (2)
FLEX (0)	STONE (0)	Batch (0)	(0)						
			(1)						
		Drum (1)	(0)						
			(1)						
	GRAVEL (1)	Batch (0)	(0)						
			(1)						
		Drum (1)	(0)						
			(1)						
	SLAG (2)	Batch (0)	(0)						
			(1)						
		Drum (1)	(0)						
			(1)						
RIGID (1)	STONE (0)	Batch (0)	(0)						
			(1)						
		Drum (1)	(0)						
			(1)						
	GRAVEL (1)	Batch (0)	(0)						
			(1)						
		Drum (1)	(0)						
			(1)						
	SLAG (2)	Batch (0)	(0)						
			(1)						
		Drum (1)	(0)						
			(1)						

ADDENDUM

Follow-up Monitoring Survey

By

Brian J. Coree, Ph.D., P.E.

This Addendum provides a summary of the follow-on pavement condition histories of the QA and Non-QA sections in this project. The Draft Report provided details of PCI surveys conducted in 1991 and 1992. This report includes the results of PCI surveys undertaken in 1993 and 1994. The results so reported do not change the conclusions and recommendations made in the draft report, however they do provide them with a greater degree confidence, and while not statistically definitive, indicate that the **rates** of change of PCI or rutting or cracking may not be hugely different from year to year, they appear to lead to relative steady-state magnitudes (QA vs Non-QA) which are differentiated by an almost constant amount.

Table A1 and Figure A1 present the PCI Histories for the two sets of sections. It appears that in each case, the average PCI is becoming asymptotic to a linear trend, and that the QA PCI magnitudes are approximately 5% larger (better) than those observed in the Non-QA sections.

Table A2 and Figure A2 present the Rutting Histories for the two data sets. The conclusion is similar to that stated above. Rutting increases steadily for both data sets, however, those observed in the QA sections averages 50% of the Non-QA sections.

Table A3 and Figure A3 gives the corresponding information for cracking. In this case a composite cracking measure is used in the summary, where the observed cracking extents are weighted by severity level (1 x Low, 2 x Medium and 3 x High) to provide an overall measure. The observed pattern is generally similar as before, with the difference that the Non-QA sections exhibited approximately 50% more cracking than the QA sections after 1991.

Table A1: Summary of Pavement Condition Histories

PROJECT TYPE	HIGHWAY	CONTRACT NUMBER	LENGTH (miles)	Pavement Condition Indices (PCI) 1991	1992	1993	1994
QA	SR 67	R-16912	4.62	93	87	82	78
QA	I-65	R-16963	8.387	90	75	69	64
QA	I-65	R-17024	3.463	91	90	89	87
QA	US 31	RS-16580	5.5	95	88	83	79
QA	US 361	RS-16885	2.47	78	69	65	62
QA	US 41	RS-16690	7.91	88	73	66	61
QA	US 41	RS16692	2.78	90	76	69	67
			Average	89.29	79.71	74.71	71.14
Non-QA	US 41	R-16442	0.141	82	78	74	*
Non-QA	US 41	RS-16685	3.42	86	85	84	84
Non-QA	SR 38	RS-16667	2.88	74	64	56	50
Non-QA	SR 1	RS-16080	8.6	71	70	68	67
Non-QA	SR 18	R-15995	0.19	63	61	59	57
Non-QA	SR 1	RS-16263	4.01	83	80	77	73
			Average	76.50	73.00	69.67	66.20

Note: * denotes section not available for PCI survey

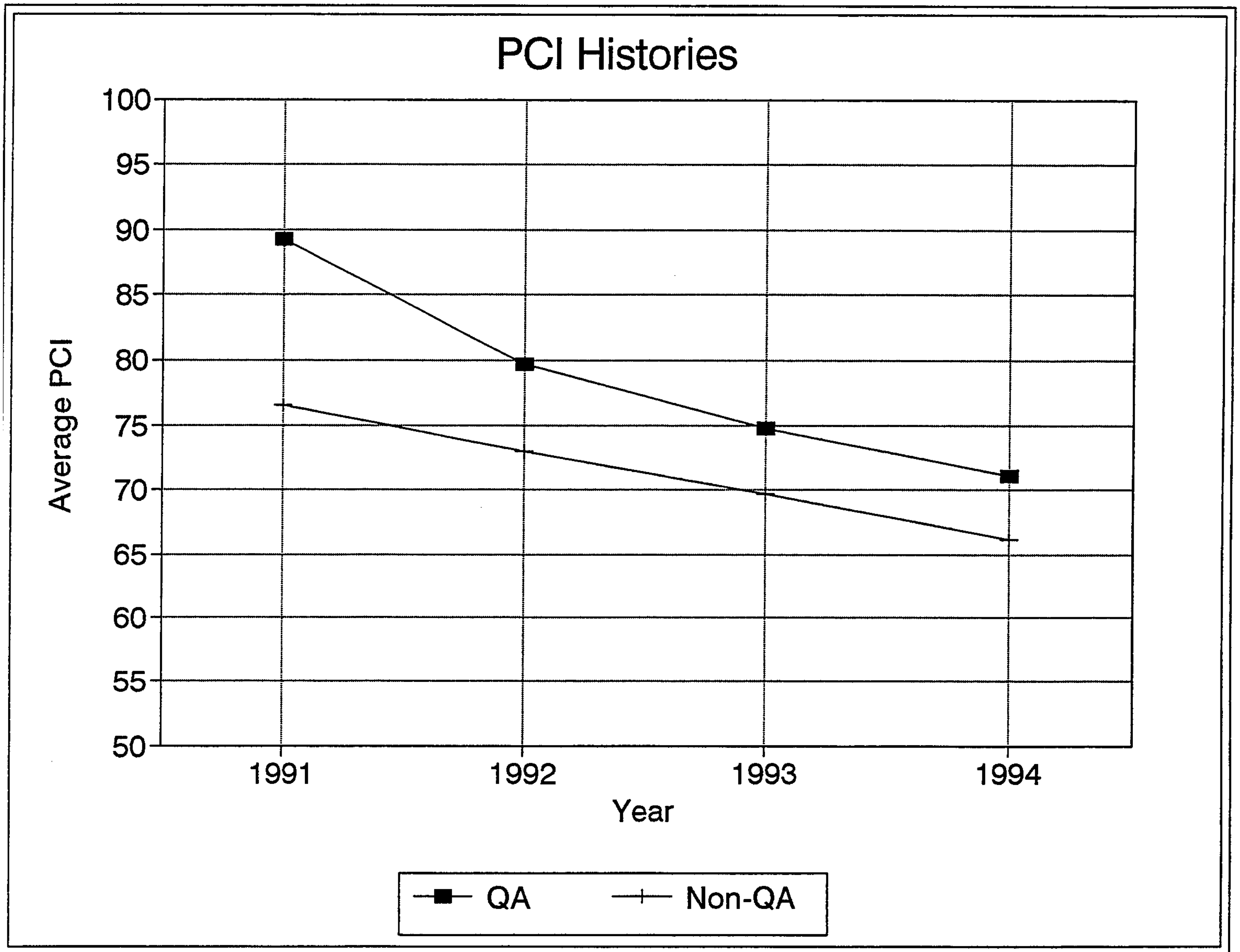

PCI Histories
100
95
90
85
80
75
70
65
60
55
50
Average PCI
1991
1992
1993
1994
Year
QA
Non-QA

Table A2: Summary of Pavement Rutting Histories

PROJECT TYPE	HIGHWAY	CONTRACT NUMBER	LENGTH (miles)	Permanent Deformation (Rut) in.			
				1991	1992	1993	1994
QA	SR 67	R-16912	4.62	0.24	0.35	0.43	0.48
QA	I-65	R-16963	8.387	0.05	0.25	0.31	0.37
QA	I-65	R-17024	3.463	0.05	0.05	0.07	0.08
QA	US 31	RS-16580	5.5	0.05	0.31	0.44	0.48
QA	US 361	RS-16885	2.47	0.05	0.05	0.06	0.09
QA	US 41	RS-16690	7.91	0.38	0.38	0.40	0.44
QA	US 41	RS16692	2.78	0.05	0.25	0.32	0.37
			Average	0.12	0.23	0.29	0.33
Non-QA	US 41	RS-16685	3.42	0.61	0.61	0.73	0.75
Non-QA	SR 38	RS-16667	2.88	0.30	0.62	0.71	0.79
Non-QA	SR 1	RS-16080	8.6	0.38	0.38	0.44	0.46
Non-QA	SR 18	R-15995	0.19	0.32	0.32	0.37	0.41
Non-QA	SR 1	RS-16263	4.01	0.05	0.38	0.47	0.63
			Average	0.33	0.46	0.54	0.61

Note: * denotes section not available for PCI survey

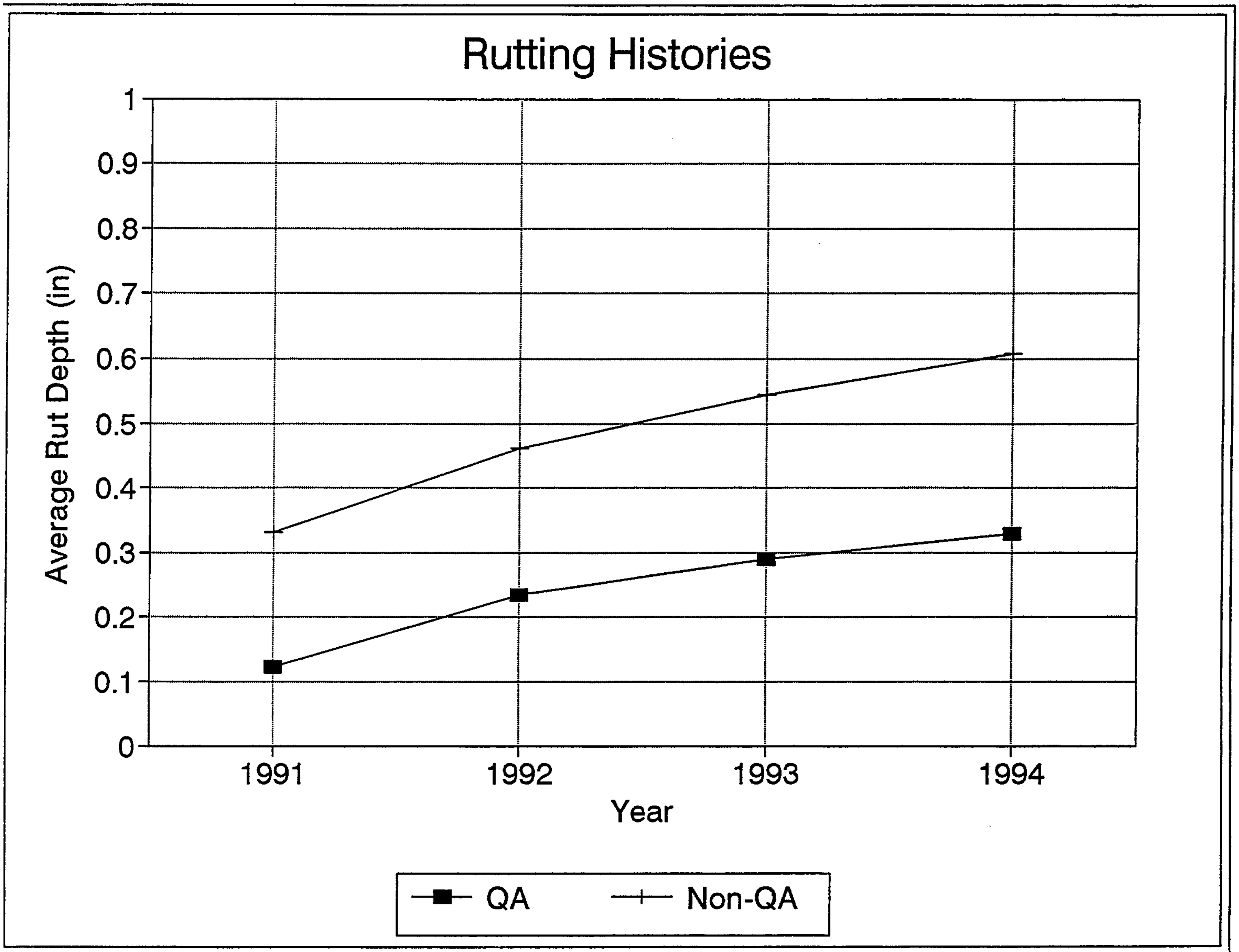
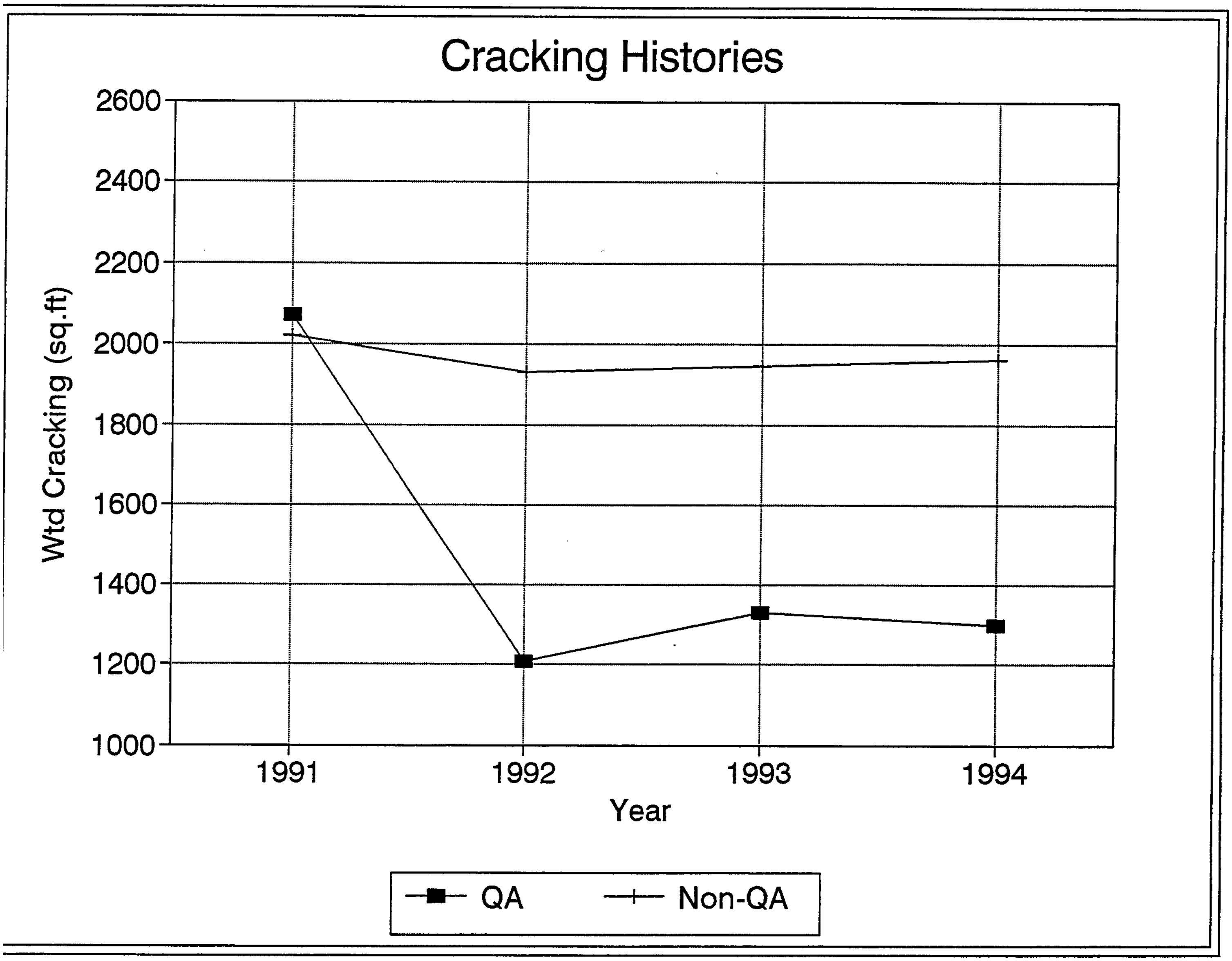

Rutting Histories
Average Rut Depth (in)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1991
1992
1993
1994
Year
QA
Non-QA

Table A3: Summary of Cracking Histories

PROJECT TYPE	SEVERIT LEVEL	Cracking Extent by Severity (sq. ft)			
		1991	1992	1993	1994
QA	Low	1682	696	737	688
QA	Medium	195	218	235	250
QA	High	0	19	31	28
	Wtd. Sum	2072	1208	1331	1300
Non-QA	Low	1602	1172	1125	1078
Non-QA	Medium	211	243	257	281
Non-QA	High	0	68	77	81
	Wtd. Sum	2024	1930	1947	1964

Note: Weighted sum is the result of the following transformation:
Wtd Sum = 1*(Low) + 2*(Medium) + 4*(High)


Cracking Histories
2600
2400
2200
2000
1800
1600
1400
1200
1000
Wtd Cracking (sq.ft)
1991
1992
1993
1994
Year
QA
Non-QA

NTIS does not permit return of items for credit or refund. A replacement will be provided if an error is made in filling your order, if the item was received in damaged condition, or if the item is defective.

Reproduced by NTIS

National Technical Information Service
Springfield, VA 22161

This report was printed specifically for your order from nearly 3 million titles available in our collection.

For economy and efficiency, NTIS does not maintain stock of its vast collection of technical reports. Rather, most documents are printed for each order. Documents that are not in electronic format are reproduced from master archival copies and are the best possible reproductions available. If you have any questions concerning this document or any order you have placed with NTIS, please call our Customer Service Department at (703) 605-6050.

About NTIS

NTIS collects scientific, technical, engineering, and business related information — then organizes, maintains, and disseminates that information in a variety of formats — from microfiche to online services. The NTIS collection of nearly 3 million titles includes reports describing research conducted or sponsored by federal agencies and their contractors; statistical and business information; U.S. military publications; multimedia/training products; computer software and electronic databases developed by federal agencies; training tools; and technical reports prepared by research organizations worldwide. Approximately 100,000 *new* titles are added and indexed into the NTIS collection annually.

For more information about NTIS products and services, call NTIS at 1-800-553-NTIS (6847) or (703) 605-6000 and request the free *NTIS Products Catalog,* PR-827LPG, or visit the NTIS Web site **http://www.ntis.gov**.

NTIS
Your indispensable resource for government-sponsored information—U.S. and worldwide