A STATISTICAL ANALYSIS OF IOWA PREMATURE CONCRETE PAVEMENT DETERIORATION

Final Report
for
Iowa DOT Research Project HR-1063

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Pooled Fund Study of Premature Concrete Pavement Deterioration

Supplementary Study: Final Report
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Region 7 Pooled Fund Study
Lead State Iowa

Iowa Department of Transportation
Research Project HR-1063

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I. Introduction

This supplementary project has been undertaken as an effort to continue work previously completed in the Pooled Fund Study of Premature Concrete Pavement Deterioration. As such, it shares the objective of "Identifying the variables that are present in those pavements exhibiting premature deterioration," by collecting additional data and performing statistical analysis of those data. The approach and philosophy of this work are identical to that followed in the above project, and the Pooled Fund Study Final Report provides a detailed description of this process.

This project has involved the collection of data for additional sites in the state of Iowa. These sites have then been added to sites collected in the original study, and statistical analysis has been performed on the entire set. It is hoped that this will have two major effects. First, using data from only one state allows for the analysis of a larger set of independent variables with a greater degree of commonality than was possible in the multi-state study, since the data are not limited by state to state differences in data collection and retention. Second, more data on additional sites will increase the degrees of freedom in the model and hopefully add confidence to the results.

II. Data Collection

Data were collected using the same survey developed in the original projects. The Iowa D.O.T. submitted 15 additional sites for analysis. These were combined with the original sites from Iowa, giving a total of 27 sites. Table 2.1 lists the location of each of the sites and indicates whether the site exhibited any pattern cracking.

Since fairly complete data were available for each site, is was possible to include a larger number of independent variables in the final statistical analysis than in the first

study. Table 2.2 lists the 40 independent variables considered in the statistical analysis. (N.B. Variables 1 and 2, site number and set, are not truly independent variables.)

Sate Site No.	Road Number	Beginning Mile Post	Pattern Cracking
1	US 20	124.87	Y
2	US 20	130.75	Y
3	US 20	130.2	N
4	US 20	125.65	N
5	I-80	106.9	N
6	I-80	110.9	Y
7	I-80	115.25	N
8	I-80	209.65	Y
9	I-35	121.46	Y
10	IA-175	156.45	N
11	US 218	90.08	N
12	US 218	73.25	Y
13	I-80	59.9	N
14	IA-330	5.55	N
15	IA-330	14.11	N
16	US 169	152.96/154.35	N
17	IA-2	2.09	Y
18	US 63	168.18	N
19	IA 14	72.46	N
20	US 169	154.35	Y
21	US 20	305.86	N
22	US 30	243.5	N
23	IA 22	60.14	N
24	US 20	157.93	N
25	US 61	85.64	N
26	US 61	123.17	N
27	IA 330	0.61	N

Table 2.1: Listing of sites included in the study, their location, and whether they exhibited some degree of pattern cracking.

Variable	Abbreviation	Description
1	Site	Site Number (1-27)*
2	Set	Set Number (1=sites 1-12, 2=sites 13-27)*
3	Date	Date of Construction
4	Age	Age of Pavement
5	Lehigh	Use of Lehigh Cement (1=yes, 2=no)
6	Davenport	Use of Davenport Cement (1=yes, 2=no)
7	C3S	Total C3S Content of Cement
8	C2S	Total C2S Content of Cement
9	C4AF	Total C4AF Content of Cement
10	C3A	Total C3A Content of Cement
11	S03	Total Sulfate Content of Cement
12	Alk	Total Alkali Content of Cement
13	Strength	7 Day Compressive Strength of Cement
14	Freeze Thaw Loss	ASTM C666-B Results for Coarse Aggregate
15	FA SO3	Fly Ash Sulfate Content
16	FA Alk	Fly Ash Alkali Content
17	FA LOI	Fly Ash Loss on Ignition
18	Cement	Total Amount of Cement in Mix
19	Water	Total Amount of Water in Mix
20	Coarse Agg	Total Amount of Coarse Aggregate in Mix
21	Fine Agg	Total Amount of Fine Aggregate in Mix
22	Fly Ash	Total Amount of Fly Ash in Mix
23	Total Alkali	Total Alkali Content of Cementitious Materials
24	Total Sulfate	Total Sulfate Content of Cementitious Materials**
25	Dump Truck	Type of Truck (0=Agitating Truck, 1=Dump Truck)
26	Min Slump	Minimum Slump Recorded on Site
27	Max Slump	Maximum Slump Recorded on Site
28	Avg Slump	Average Slump Recorded on Site
29	Min Air	Minimum Air Content Recorded on Site
30	Max Air	Maximum Air Content Recorded on Site
31	Avg Air	Average Air Content Recorded on Site
32	Thickness	Slab Thickness
33	Cut Width	Width of Saw Cuts
34	Base Course Thickness	Thickness of Base Course
35	Base Course Perm	Permeability of Base Course (1=permeable)
36	Min T	Minimum Temperature Measured on Site
37	Max T	Maximum Temperature Measured on Site
38	Traffic	Traffic (ESAL) Experienced by Pavement
39	Hard Air	Air Content Measured for Hardened Concrete
40	Concrete Strength	Average Strength of Hardened Concrete (28 day)
41	Alkali (Mix)	Alkali Content of the Entire Mix
42	Sulfate (Mix)	Sulfate Content of the Entire Mix

* Not included in analysis: not a truly independent variable.
** Not included in analysis: variable lacks sufficient variation.

Table 2.2: List of variables considered in this for inclusion in the models built in this study.

III. Results

Using multiple correlation software, a statistical model has been developed which correlates "pattern cracking" deterioration to a number of independent variables. In order to build this model, it has been necessary to take a number of steps to provide the most accurate results. First, the dependent variable of deterioration was taken as the total percentage of deteriorated pavement, as reported by the Iowa D.O.T. For example, if it was reported that 90% of a pavement exhibited some sort of pattern cracking, then the dependent variable would be equal to 0.9. Second, 4 pavements which exhibit significant deterioration, but no "pattern cracking" have been excluded from the analysis. This has been done to eliminate a possible confounding deterioration mechanism from the analysis. It has also resulted in a reduction of the number of non-deteriorated sites in the study (15 out of 23, instead of 19 out of 27) and increased the ratio of bad to good sites. This provides a more balanced database for statistical analysis.

Using the above conditions, a model has been constructed to describe the effect of 4 independent variables on "pattern cracking." This model will be presented in two slightly different forms, as this will provide insight into the relative importance of individual variables and illustrate the role of outliers.

The statistical model was initially constructed by bringing in variables with the highest T values. This procedure results in a model including Concrete Strength, with a T value of -2.58, and the product of Total Alkali and Total Sulfate, with a T value of 3.32. This indicates that a stronger concrete tends to be more resistant to premature deterioration and that increases in sulfate or alkali content tend to increase the chances of

premature deterioration, particularly when both are increased simultaneously. This model has an R^2 value of only 43.44%, but no other variables have T values over 2. The statistics for this model have been summarized in table 3.1.

Variable	Coefficient(effect)	T Value	R^2
Total Alkali * Total Sulfate	positive	3.32	0.03
Concrete Strength	negative	-2.58	0.03
R^2 Value=		0.4344	

Table 3.1: Statistics for model including site 20.

In the model shown above, site 20 has an externally studentized residual above 2.5. Generally, any site with a value over 3 for this indicator would be excluded without question, so site 20 is a borderline outlier. For this reason a model has been constructed excluding site 20. This model includes Concrete Strength, with a T value of -3.21, the product of Total Alkali and Total Sulfate, with a T value of 5.47, and the Amount of Coarse Aggregate, with a T value of -2.61. This model has an R^2 of 67%, which results from excluding an outlier and bringing in another independent variable. Statistics for this model have been summarized in table 3.2. Output tables from Multiple Correlation Analysis have been included in Appendix A to show the building of the above models. These should be considered only as a supplement to the above discussion.

Variable	Coefficient(effect)	T Value	R^2
Total Alkali * Total Sulfate	positive	5.47	0.1
Concrete Strength	negative	-3.21	0.02
Coarse Aggregate	negative	-2.61	0.09
R^2 Value=		0.6724	

Table 3.2: Statistics for model excluding site 20.

Clearly, the most important variable included in the above models is the product of Total Alkali and Total Sulfate levels. This result is in complete agreement with the models developed in the initial study. However, both models illustrate that there is a great deal of unexplained variation, as indicated by fairly low R^2 values. This reflects the incomplete nature of historical data as well as the complexity of this system. Broadly, the results of this supplementary project support the conclusions of the initial work, without revealing any crucial new information. Given the large number of new variables considered, this lends credibility to the conclusions of the original study.

IV. Conclusions

- Models developed through this supplementary study broadly support, and do not contradict, previous conclusions.
- The most significant factors identified are a) the combination of Total Alkali and Total Sulfate and b) Concrete Strength.
- The variables identified through these studies should provide direction for the design of future experiments.

Appendix A

Table A.1: Variable Listing as produced by Multiple Correlation.

Table A.2: Model statistics prior to the addition of any variables.

Table A.3: Model statistics after the addition of 1 variable.

Table A.4: Model statistics after the addition of 2 variables.

Table A.5: Model statistics prior to the addition of any variables (Site 20 excluded).

Table A.6: Model statistics after the addition of 1 variable (Site 20 excluded).

Table A.7: Model statistics after the addition of 2 variables (Site 20 excluded).

Table A.8: Model statistics after the addition of 3 variables (Site 20 excluded).

Table A.1: Variable Listing as produced by Multiple Correlation.

8/19/1997

Variable Listing

#	Var	Label
1:	Var 1	Site
2:	Var 2	Set
3:	Var 3	Date
4:	Var 4	Age
5:	Var 5	Lehigh
6:	Var 6	Davenport
7:	Var 7	C3S
8:	Var 8	C2S
9:	Var 9	C4AF
10:	Var 10	C3A
11:	Var 11	SO3
12:	Var 12	Alk
13:	Var 13	Strength
14:	Var 14	Freeze Thaw Loss
15:	Var 15	FA SO3
16:	Var 16	Fa Alk
17:	Var 17	FA LOI
18:	Var 18	Cement
19:	Var 19	Water
20:	Var 20	Coarse Agg
21:	Var 21	Fine Agg
22:	Var 22	Fly Ash
23:	Var 23	Tot Alk
24:	Var 24	Tot Sulf
25:	Var 25	Dump Truck
26:	Var 26	Min Slump
27:	Var 27	Max Slump
28:	Var 28	Avg. Slump
29:	Var 29	Min Air
30:	Var 30	Max Air
31:	Var 31	Avg Air
32:	Var 32	Thickness
33:	Var 33	Cut Width
34:	Var 34	Base Couse Thick
35:	Var 35	Base Course Perm
36:	Var 36	Min T
37:	Var 37	Max T
38:	Var 38	traffic
39:	Var 39	Har Air
40:	Var 40	Concrete Strength
41:	Var 41	Alkali (Mix)
42:	Var 42	Sulfate (Mix)
43:	Var 43	Damage
44:	V23 * V24	Tot Alk * Tot Sulf
45:	V41 * V42	Alkali M * Sulf M
46:	V37 * V24	Max T * Tot Sulf
47:	V37 * V23	Max T * Tot Alk

Table A.2: Model statistics prior to the addition of any variables.

8/19/1997

Dependent Var. : 43 Damage

Sy.x = 0.29015 RSQ = 0.0000 Deg Freedom = 22

VARIABLES IN THE EQUATION

Var	Coefficient	T	RSQ	LABEL

VARIABLES NOT IN THE EQUATION

VAR	3	4	5	6	7	8	9
T	0.23	-0.53	2.32	-1.84	-0.22	-0.20	-0.42
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	10	11	12	13	14	15	16
T	1.05	2.56	1.10	-0.30	0.40	0.70	0.96
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	17	18	19	20	21	22	23
T	0.61	-0.10	0.82	-0.36	0.36	0.03	1.39
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	24	26	27	28	29	30	31
T	2.34	2.15	-0.98	-0.19	2.44	-0.12	0.96
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	32	33	34	35	36	37	38
T	-0.85	-1.89	-0.98	-1.14	0.27	-0.55	-0.39
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	39	40	41	42	44	45	46
T	-1.43	-1.71	1.33	2.20	2.62	2.40	1.91
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	47						
T	1.08						
RSQ	0.00						

ROWS DELETED : 10 18 22 27

Table A.3: Model statistics after the addition of 1 variable.

8/19/1997

Dependent Var. : 43 Damage

Sy.x = 0.25787 RSQ = 0.2461 Deg Freedom = 21

VARIABLES IN THE EQUATION

Var	Coefficient	T	RSQ	LABEL
0	-2.72974046E-01			Intercept
44	2.02612463E+03	2.62	0.00	Tot Alk * Tot Sulf

VARIABLES NOT IN THE EQUATION

VAR	3	4	5	6	7	8	9
T	-0.28	0.23	1.40	-1.38	-1.25	0.94	-0.69
RSQ	0.04	0.10	0.19	0.06	0.12	0.17	0.01
VAR	10	11	12	13	14	15	16
T	0.73	1.23	0.06	-0.76	0.40	-1.17	-0.91
RSQ	0.03	0.38	0.20	0.02	0.00	0.41	0.45
VAR	17	18	19	20	21	22	23
T	-1.34	0.66	0.53	-1.04	1.27	-1.45	-1.46
RSQ	0.42	0.08	0.02	0.05	0.09	0.24	0.74
VAR	24	26	27	28	29	30	31
T	0.98	1.05	-1.24	-0.71	1.29	-0.31	0.45
RSQ	0.39	0.26	0.00	0.03	0.29	0.00	0.06
VAR	32	33	34	35	36	37	38
T	-1.47	-1.20	-0.25	-0.37	0.14	-0.58	-0.86
RSQ	0.03	0.12	0.11	0.12	0.00	0.00	0.02
VAR	39	40	41	42	45	46	47
T	-0.04	-2.58	-1.38	0.65	-0.05	0.38	-1.05
RSQ	0.35	0.03	0.71	0.47	0.89	0.44	0.54

OWS DELETED : 10 18 22 27

Table A.4: Model statistics after the addition of 2 variables.

8/19/1997

Dependent Var. : 43 Damage

Sy.x = 0.22887 RSQ = 0.4344 Deg Freedom = 20

VARIABLES IN THE EQUATION

Var	Coefficient	T	RSQ	LABEL
0	6.59355979E-01			Intercept
40	-2.11706897E-04	-2.58	0.03	Concrete Strength
44	2.31212899E+03	3.32	0.03	Tot Alk * Tot Sulf

VARIABLES NOT IN THE EQUATION

VAR	3	4	5	6	7	8	9
T	-0.14	0.15	0.70	-0.64	-0.64	0.48	-0.04
RSQ	0.05	0.10	0.29	0.18	0.20	0.21	0.09
VAR	10	11	12	13	14	15	16
T	-0.02	0.29	0.09	0.07	0.27	-0.60	-0.18
RSQ	0.14	0.50	0.20	0.15	0.01	0.46	0.51
VAR	17	18	19	20	21	22	23
T	-0.80	0.54	0.76	-1.41	1.51	-0.62	-0.53
RSQ	0.47	0.09	0.03	0.06	0.09	0.35	0.79
VAR	24	26	27	28	29	30	31
T	0.13	0.84	-0.88	-0.04	1.32	-0.11	1.25
RSQ	0.48	0.28	0.04	0.12	0.29	0.01	0.13
VAR	32	33	34	35	36	37	38
T	-0.47	-0.07	0.31	0.31	-0.25	-0.63	-0.21
RSQ	0.24	0.33	0.16	0.19	0.03	0.00	0.11
VAR	39	41	42	45	46	47	
T	0.18	-0.22	0.20	0.78	-0.50	-0.46	
RSQ	0.35	0.78	0.50	0.90	0.51	0.58	

ROWS DELETED : 10 18 22 27

Table A.5: Model statistics prior to the addition of any variables (Site 20 excluded).

8/19/1997

Dependent Var. : 43 Damage

Sy.x = 0.28558 RSQ = 0.0000 Deg Freedom = 21

VARIABLES IN THE EQUATION

Var	Coefficient	T	RSQ	LABEL

VARIABLES NOT IN THE EQUATION

VAR	3	4	5	6	7	8	9
T	-0.13	-0.25	1.95	-1.58	0.23	-0.67	-0.22
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	10	11	12	13	14	15	16
T	1.28	2.41	1.49	-0.32	0.52	1.11	1.42
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	17	18	19	20	21	22	23
T	1.03	-0.07	0.78	-0.61	0.49	0.42	2.30
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	24	26	27	28	29	30	31
T	2.20	2.23	-0.86	-0.06	2.53	-0.07	0.91
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	32	33	34	35	36	37	38
T	-0.82	-2.16	-1.20	-1.35	0.67	0.37	-0.18
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	39	40	41	42	44	45	46
T	-1.52	-1.56	2.30	2.33	3.48	3.39	3.11
RSQ	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VAR	47						
T	2.29						
RSQ	0.00						

ROWS DELETED : 10 18 20 22 27

Table A.6: Model statistics after the addition of 1 variable (Site 20 excluded).

8/19/1997

Dependent Var. : 43 Damage

Sy.x = 0.23090 RSQ = 0.3774 Deg Freedom = 20

VARIABLES IN THE EQUATION

Var	Coefficient	T	RSQ	LABEL
0	-4.07412245E-01			Intercept
44	2.50386674E+03	3.48	0.00	Tot Alk * Tot Sulf

VARIABLES NOT IN THE EQUATION

VAR	3	4	5	6	7	8	9
T	-1.32	1.21	0.31	-0.77	-0.71	0.42	-0.41
RSQ	0.09	0.16	0.33	0.11	0.08	0.13	0.00
VAR	10	11	12	13	14	15	16
T	1.08	0.42	0.38	-1.00	0.67	-0.99	-0.68
RSQ	0.02	0.47	0.17	0.03	0.00	0.38	0.41
VAR	17	18	19	20	21	22	23
T	-1.16	1.03	0.38	-1.99	2.06	-1.14	-0.75
RSQ	0.39	0.09	0.03	0.08	0.12	0.20	0.73
VAR	24	26	27	28	29	30	31
T	0.15	0.80	-1.14	-0.65	1.03	-0.29	0.20
RSQ	0.47	0.28	0.00	0.03	0.31	0.00	0.07
VAR	32	33	34	35	36	37	38
T	-1.71	-1.47	-0.41	-0.51	0.89	1.48	-0.64
RSQ	0.03	0.10	0.10	0.11	0.00	0.07	0.01
VAR	39	40	41	42	45	46	47
T	0.32	-2.68	-0.56	0.24	0.44	1.37	0.08
RSQ	0.36	0.02	0.70	0.49	0.88	0.40	0.52

ROWS DELETED : 10 18 20 22 27

Table A.7: Model statistics after the addition of 2 variables (Site 20 excluded).

8/19/1997

Dependent Var. : 43 Damage

Sy.x = 0.20186 RSQ = 0.5480 Deg Freedom = 19

VARIABLES IN THE EQUATION

Var	Coefficient	T	RSQ	LABEL
0	4.60968447E-01			Intercept
40	-1.94558356E-04	-2.68	0.02	Concrete Strength
44	2.72558672E+03	4.30	0.02	Tot Alk * Tot Sulf

VARIABLES NOT IN THE EQUATION

VAR	3	4	5	6	7	8	9
T	-1.20	1.17	-0.58	0.04	-0.06	-0.07	0.29
RSQ	0.10	0.17	0.41	0.22	0.15	0.17	0.08
VAR	10	11	12	13	14	15	16
T	0.32	-0.72	0.43	-0.17	0.55	-0.41	0.07
RSQ	0.13	0.56	0.17	0.16	0.01	0.42	0.47
VAR	17	18	19	20	21	22	23
T	-0.61	0.94	0.62	-2.61	2.47	-0.28	0.31
RSQ	0.43	0.10	0.03	0.09	0.12	0.32	0.78
VAR	24	26	27	28	29	30	31
T	-0.88	0.59	-0.79	0.04	1.09	-0.07	1.02
RSQ	0.54	0.29	0.04	0.11	0.31	0.01	0.14
VAR	32	33	34	35	36	37	38
T	-0.70	-0.33	0.16	0.19	0.50	1.49	0.04
RSQ	0.24	0.33	0.15	0.18	0.04	0.08	0.10
VAR	39	41	42	45	46	47	
T	0.57	0.88	-0.25	1.43	0.46	0.86	
RSQ	0.36	0.78	0.51	0.89	0.50	0.56	

ROWS DELETED : 10 18 20 22 27

Table A.8: Model statistics after the addition of 3 variables (Site 20 excluded).

8/19/1997

Dependent Var. : 43 Damage

Sy.x = 0.17656 RSQ = 0.6724 Deg Freedom = 18

VARIABLES IN THE EQUATION

Var	Coefficient	T	RSQ	LABEL
0	1.32896603E+00			Intercept
20	-2.33031906E+00	-2.61	0.09	Coarse Agg
40	-2.04635154E-04	-3.21	0.02	Concrete Strength
44	3.17482679E+03	5.47	0.10	Tot Alk * Tot Sulf

VARIABLES NOT IN THE EQUATION

VAR	3	4	5	6	7	8	9
T	-1.89	1.73	0.03	0.29	-1.50	1.46	-1.35
RSQ	0.12	0.18	0.45	0.22	0.34	0.37	0.36
VAR	10	11	12	13	14	15	16
T	1.67	-0.72	0.70	0.10	-0.03	-0.42	0.04
RSQ	0.28	0.57	0.18	0.17	0.07	0.42	0.47
VAR	17	18	19	21	22	23	24
T	-0.63	0.62	0.78	-0.28	-0.16	0.55	-1.05
RSQ	0.43	0.13	0.03	0.97	0.32	0.78	0.54
VAR	26	27	28	29	30	31	32
T	1.09	-0.93	0.18	0.91	-0.59	0.11	-1.33
RSQ	0.31	0.04	0.12	0.32	0.05	0.29	0.26
VAR	33	34	35	36	37	38	39
T	-1.57	-0.64	-0.77	0.31	0.92	-0.36	0.19
RSQ	0.43	0.23	0.29	0.05	0.15	0.12	0.38
VAR	41	42	45	46	47		
T	0.96	-0.53	1.16	-0.25	0.83		
RSQ	0.78	0.52	0.90	0.54	0.56		

OWS DELETED : 10 18 20 22 27
