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Correlation Between Bridge Vibration And Bridge Deck Cracking: A Qualitative Study

SREENIVAS ALAMPALLI

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CORRELATION BETWEEN BRIDGE VIBRATION AND BRIDGE DECK CRACKING: A QUALITATIVE STUDY

Sreenivas Alampalli, Engineering Research Specialist II

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New York State Department of Transportation, State Campus, Albany, New York 12232-0869

ABSTRACT

In recent years, many New York State bridge engineers have suspected that bridge vibration induced by vehicular traffic significantly influenced deck cracking. Several remedial measures were considered, including modifying the deflection criteria recommended by AASHTO bridge design standards, which would have had a major impact on construction costs. The New York State Department of Transportation initiated a research project to systematically study the possible correlation between bridge deck cracking and bridge vibration. Vibration and cracking severities of most steel girder bridges with concrete decks, built in New York between 1990 and 1997, were obtained through a statewide survey and field inspection. Data were analyzed using statistical methods. Results indicate a strong correlation between bridge vibration and deck cracking. A recommendation to further study this relation, using quantitative data was made. Since this is an observational study, these correlations do not imply that bridge vibration is the primary cause of the bridge deck cracking.

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I. INTRODUCTION

A. BACKGROUND

The New York State Department of Transportation (NYSDOT) continuously studies various factors adversely affecting the structural integrity of its bridges, as part of continuous efforts to improve the quality of New York's transportation infrastructure system. Bridge decks are one such component. Bridge deck cracking has historically been an issue for transportation agencies worldwide due to its role in reducing structural life. Water, laden with de-icing salt, permeates through cracks in the bridge deck and significantly accelerates the degradation of concrete decks. The structure's useful life is reduced and bridge maintenance needs are increased.

Recently, the NYSDOT has improved bridge deck quality by reducing deck permeability and cracking potential through improved concrete properties, deck design, and construction procedures. Some of these changes include pozzuolanic substitutions (fly-ash and micro-silica) for a portion of cement used in bridge deck concrete (*1,2*), use of isotropically reinforced bridge decks (*3*), and changing the relative position of longitudinal and transverse reinforcement in the bridge deck (*4*). These changes positively influenced the deck quality, but did not eliminate the deck cracking (*1*).

Field engineers consider bridge vibration induced by the vehicular traffic a major factor influencing the bridge deck cracking. This study, therefore, focused on examining the possible relationship between bridge vibration and deck cracking. Parameters defining the vibration are amplitude, frequency, and characteristics of the vehicular traffic. However, recent studies concluded that characteristics of the vehicular traffic do not play a significant role in bridge vibration (*5*), and therefore it was not considered as a variable in this study.

B. STUDY OBJECTIVE

The objective of this research was to conduct a qualitative study to ascertain if a correlation existed between bridge vibration and bridge deck cracking. If results indicate that bridge vibration does influence deck cracking, then the intent is to determine which bridges are deemed critical for further analysis. This requires defining a frame work for a follow-up quantitative study, which includes field testing of a small number of bridges representing the bridge population in New York State.

The scope of the project is limited to qualitative study of bridges, with concrete decks on steel stringers, built since 1990. Note that this is an observational study, and thus, a correlation between bridge vibration and deck cracking does not imply that bridge vibration is the primary cause of the bridge deck cracking.

C. STUDY APPROACH

A decision to obtain data on the extent of cracking and vibration experienced by each of the bridge decks in New York State was made after consultation with the Structural Engineering Services Unit of the Structures Design and Construction Division. Analysis of the data would reveal if any correlation exists between deck cracking and vibration. New York State has more than 10,000 bridges. An in-depth survey evaluating the decks of all the state's bridges is not feasible. After discussions with bridge engineers, the study was limited to steel girder superstructures built between 1990 and 1997.

A roster of bridges was prepared using the Department's database and sent to field engineers for investigation. Bridge inspectors were asked to physically inspect each of their assigned bridge decks, and report on the existence of deck cracking (type and severity) and bridge vibration (severity). Guidelines were provided for rating deck cracking and vibration. These guidelines are described in the next section.

For each of the selected bridges, various other parameters were determined. Some parameters were obtained from the New York State's bridge inventory and inspection system (BIIS), and others were obtained through a survey questionnaire. The parameters included average annual daily traffic (AADT), number of spans, length of each span, and type of bearing at the beginning and end of each span. Other data collected from engineer-in-charge records and visual inspection of the bridges included environmental conditions during the deck pour, curing methods used, whether or not staged construction was used, and whether the bridge was poured in sections or continuously.

Once the results were compiled, statistical methods were used to examine if a relationship between bridge vibration and deck cracking exists. The next course of action is dependant on the results of this analysis. If there is a statistically significant relationship reported between the bridge vibration and the deck cracking, further experimental studies are warranted to determine which bridge features associated with bridge vibration are playing a major role in deck cracking. If no statistical relationship is found, then an investigation into other possible causes of deck cracking is needed.

II. STATEWIDE SURVEY

A survey questionnaire was prepared and sent to field engineers. The information that was collected by visual inspection included the severity of deck cracking, type of cracking, and severity of bridge vibration. Field engineers were requested to make a field visit to visually inspect the bridge for reporting the deck cracking and bridge vibration severities for each of the spans.

Visual inspections are very subjective in nature. In order to decrease the subjectivity involved with this type of inspection and data collection process, an arbitrary severity rating system was prepared and provided to each bridge inspector along with the questionnaire. Severity ratings were based on a scale from 0 to 5 (5 being the most severe). Detailed definitions of the rating system used are described below.

A. DECK CRACKING SEVERITY RATING

Three categories of cracking were considered in this study. They are longitudinal cracking, transverse cracking and an overall rating to evaluate the extent of cracking on the entire span. A scale of 0 to 5 was used to rate the deck cracking severity as follows:

0. No cracking
1. Low severity
2. Used to shade between ratings of 1 and 3
3. Moderate severity
4. Used to shade between ratings of 3 and 5
5. High severity

<u>Longitudinal cracks:</u> These are the cracks predominantly parallel to the bridge deck centerline. The length of the cracks was measured in meters and width was measured in millimeters. The longitudinal crack ratings are explained below and shown in Figure 1.

Low severity (1) -- Bridge deck exhibits partial length longitudinal cracking. Cracks do not run for more than one-third of the length of the span. Cracks are less than 1 mm wide.

Moderate severity (3) -- Bridge deck exhibits some full length longitudinal cracks. Most cracks are partial length. Most cracks are less than 1 mm wide. Longitudinal cracks occur every 3-4 meters along the cross section of the bridge.

High severity (5) -- Bridge deck exhibits mostly full length longitudinal cracks. Most cracks are wider than 1mm. Cracks occur every 2-3 meters along the cross section of the bridge.

Transverse cracks: These cracks are predominantly perpendicular to the bridge deck centerline. "Y" cracks are counted as a single crack. The length and width of the crack were measured in meters and millimeters, respectively. The transverse crack ratings are explained below and shown in Figure 2.

Low severity (1) -- Bridge deck exhibits mostly partial width transverse cracks. The cracks are less than 1 mm wide.

Moderate severity (3) -- Bridge deck exhibits partial and full width transverse cracks. Cracks are mostly less than 1 mm wide. Transverse cracks occur every 5 meters.

High severity (5) -- Bridge deck exhibits full width transverse cracks with widths greater than 1mm. Some partial width cracking is also evident. Transverse cracks occur every 2-3 meters. Significant "Y" cracking at edges.

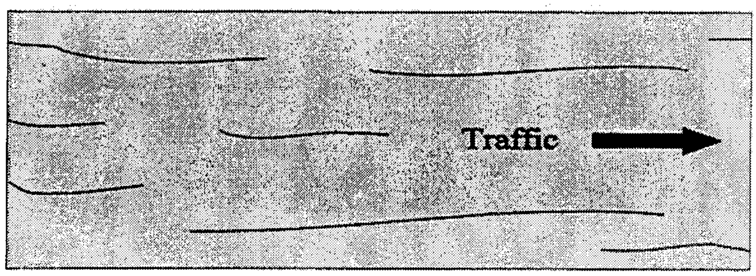
Overall cracking severity: The same rating system was used to rate the entire deck. The rating was increased by 1 if there was significant spalling, map cracking, or durability cracking. Severity ratings were characterized by a 4 or 5 if significant transverse and longitudinal cracking existed. A description of the localized cracking was documented along with appropriate severity levels when localized cracking was present.

B. BRIDGE VIBRATION SEVERITY RATING

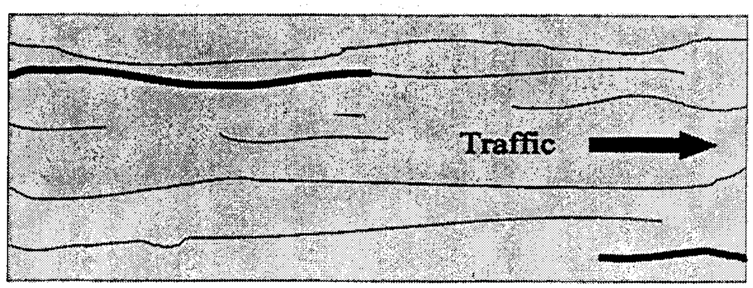
Deck vibration was also rated on a scale of 1 to 5. Low vibrations induced by traffic loads were rated as 1 (low severity), moderate vibrations were rated as 3 (moderate severity), and very noticeable vibrations were rated as 5 (high severity). A rating of 2 was used to shade between 1 and 3, and 4 was used to shade between 3 and 5.

It is not easily possible or practical to quantitatively evaluate/measure bridge vibration (both amplitude and frequency) through visual inspection or with simple instrumentation by field personnel. Hence, it should be noted that these ratings are more subjective and make the results of the study qualitative.

Low Severity (1):Longitudinal Cracking



Moderate Severity (3):Longitudinal Cracking



High Severity (5):Longitudinal Cracking

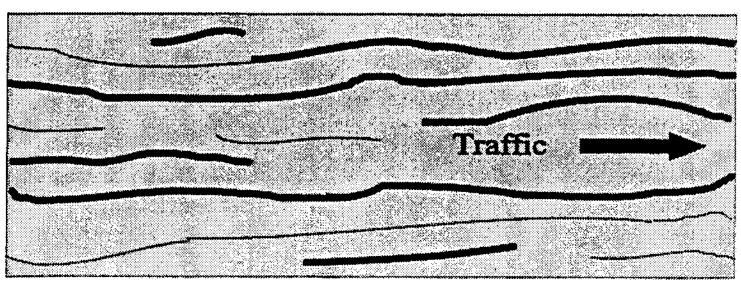
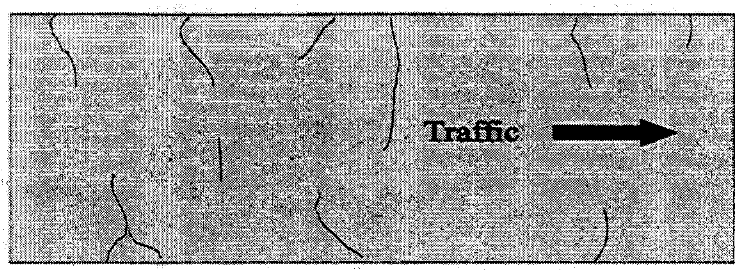
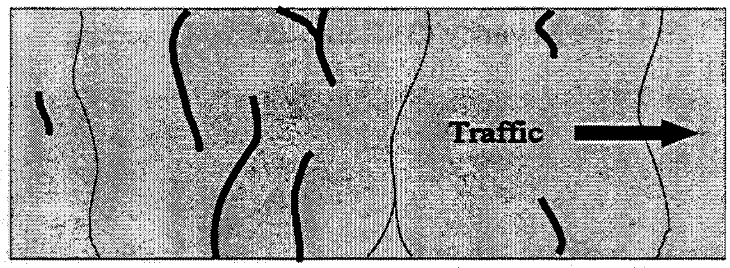


Figure 1. Longitudinal cracking severity guide.

Low Severity (1): Transverse Cracking



Moderate Severity (3): Transverse Cracking



High Severity (5): Transverse Cracking

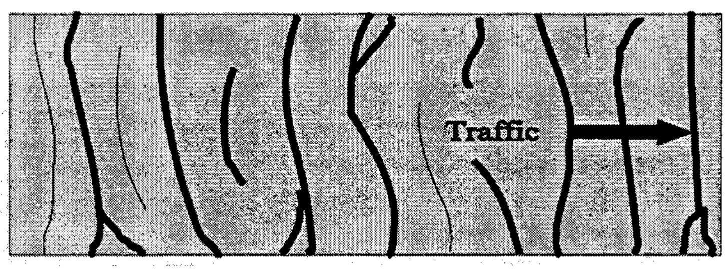


Figure 2. Transverse cracking severity guide.

III. SURVEY RESULTS

A total of 384 bridge spans were inspected by field engineers. Their responses are summarized in Appendix A. This section provides salient details of the raw data pertaining to the inspected bridge population. Results from the statistical analysis will be discussed in the next section.

Figure 3 shows the number of bridge spans in the population sorted by the year constructed; and thus is indicative of the years the bridge is in-service. Of the 384 bridge spans (233 bridges) inspected, 242 exhibited some form of cracking. Figure 4 shows the number of bridges along with their deck cracking severity rating. Two hundred-twenty-seven decks cracked transversely, 44 cracked longitudinally, and 29 bridge decks exhibited both forms of cracking. Environmental conditions during the deck pour, curing procedures used, and construction information were not provided for all the bridges. For this reasons, these data were not used in the further analysis. However, these details will be helpful to compare this information with the severity ratings in a secondary analysis. Figure 5 shows the number of bridge spans in each of the vibration severity ratings.

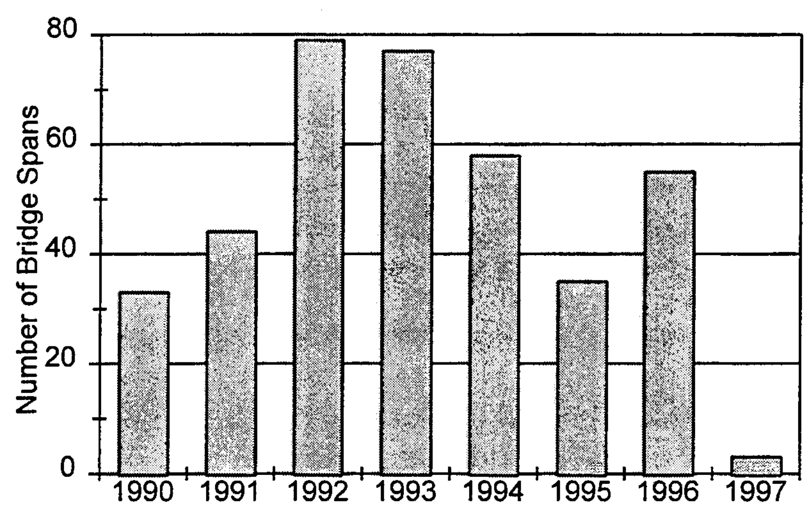


Figure 3. Inspected bridge spans sorted by year constructed.

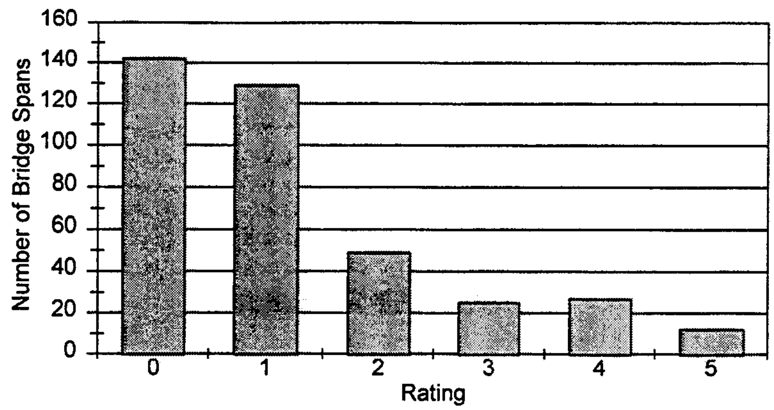


Figure 4. Inspected bridge spans sorted by crack rating.

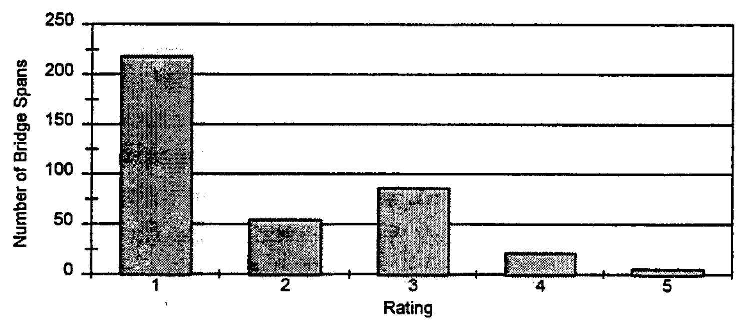


Figure 5. Inspected bridge spans sorted by vibration rating.

IV. DATA ANALYSIS

Statistical methods were used to analyze the responses from the survey. One inspection survey was not included in the analysis due to incomplete data. Thus, only data from 383 bridges were analyzed and the results are presented in this section.

First, One-way Analysis of Variance (ANOVA) was used to study the correlation of each of the following parameters on deck cracking severity (*6*).

1. Vibration severity
2. Traffic volume
3. Span length
4. Beginning bearing type
5. End-bearing type

Statgraphics software (*7*) was used to perform the required calculations and plot graphs. The effects of the individual parameters on deck cracking were first determined. Then multi-factor ANOVA analyses were used to examine the effects of two or more factors on one variable (i.e. deck cracking). The interaction effects of bridge vibration, span length, and traffic volume on bridge deck cracking were examined using Multi-factor ANOVA analyses.

A. EFFECT OF VIBRATION SEVERITY

A careful examination of the vibration data shown in Figure 5 indicates very few bridges with vibration ratings of 4 and 5. In order to make the statistical analysis valid, the vibration ratings (CVIB) were reduced into three groups, by combining ratings of 2 and 3 into one group; and ratings of 4 and 5 into another group as shown in Fig. 6.

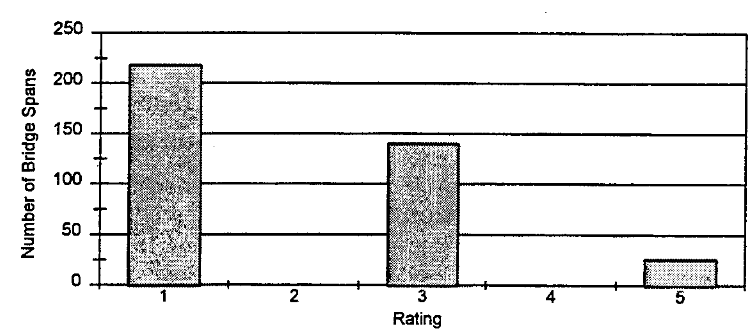


Figure 6. Inspected bridge spans sorted by modified vibration rating.

As described above, a one-way Analysis of Variance was performed to determine the correlation between vibration severity (CVIB) and observed deck cracking severity (SEV). The test results concluded that the vibration severity influences the cracking severity significantly. Detailed analysis is shown in Appendix B.

B. EFFECT OF TRAFFIC VOLUME

The traffic volume data used in the analysis, i.e. Average Annual Daily Traffic (AADT), was classified into three groups:

1. Low volume: AADT $\leq$ 1000
2. Medium volume: 1000 < AADT $\leq$ 5000, and
3. High volume: AADT > 5000

Analysis (see Appendix B) indicated that AADT does influence the cracking severity and very low volume bridges exhibit less cracking. This confirms what is expected from practice. At the same time, there is no statistically significant differences between cracking of medium and high volume bridges, indicating that they can be combined for further analysis. Thus, for a multi-factor ANOVA, only two groups will be used, low volume (AADT $\leq$ 1000) and high volume (AADT>1000).

C. EFFECT OF SPAN LENGTH

The bridge spans were classified based on their length into following three groups for analysis:

1. Long span bridges: Span Length > 60 m
2. Medium span bridges: 30 m < Span Length $\leq$ 60 m
3. Small span bridges: Span Length $\leq$ 30 m

Results (see Appendix B) indicated that span length does influence the cracking severity, with longer spans exhibiting more cracking. The results also showed that there is no statistically significant differences between cracking of bridges with spans less than 30-m long, and spans between 30 m to 60 m long, indicating that they can be combined. Thus, for a multi-factor ANOVA, only two groups of span lengths will be used, spans 60 m or shorter, and spans longer than 60 m.

D. EFFECT OF BEARINGS

Influence of bearings on deck cracking severity was examined (see Appendix B). Since there are many different types of bearings, they were classified into 6 main groups, as follows:

1. Elastomeric Bearing (Free/Expansion)
2. Elastomeric Bearing (Fixed)
3. Pot Bearing (Fixed)
4. Pot Bearing (Free/Expansion)
5. None
6. Others (include discs, rockers, multi-rotational, etc.)

Analysis similar to that described previously was conducted for beginning and end bearing influence on deck cracking. Results indicated that there is no statistically significant difference between the cracking severity and type of bearing. Thus, type of bearing is not considered in further analysis.

E. INTERACTION EFFECTS

Multi-factor ANOVA is useful in examining the effects of two or more factors on one variable. Thus, multi-factor ANOVA is used here to examine the effects of bridge vibration, span length, and traffic volume (AADT) on bridge deck cracking. As illustrated in the previous section, bridge vibration is divided into 3 ranges - low, medium, and noticeable or severe. The traffic volume was divided into 2 categories - low with AADT$\leq$1000, and high with AADT>1000. Similarly, span lengths have been divided into two categories - short spans with lengths $\leq$ 60 m, and large spans which are longer than 60 m.

This analysis (see Appendix B) determines the factors having a statistically significant effect on deck cracking, and also tests for significant interactions among the factors considered. The results indicated that vibration severity and span length have a statistically significant effect on bridge deck cracking in the 95% confidence level. Overall, bridges with noticeable vibration combined with long span lengths exhibit significant bridge deck cracking.

V. CONCLUSIONS

Correlation between bridge vibration and bridge deck cracking was studied through field inspection of 384 steel bridge spans with concrete decks. The influence of span length, bearing type, and traffic volume on the deck cracking were investigated along with bridge vibration. The scope of the project is limited to the qualitative study of bridges with concrete decks on steel stringers, constructed between 1990 and 1997. The results indicate the following:

1. Vibration severity is the most significant parameter influencing bridge deck cracking. Higher severity equates to higher deck cracking. Decks with noticeable vibration cracked most severely.

2. Longer spans exhibit more deck cracking than shorter spans.

3. Traffic volume is the least significant factor, of the three considered, in influencing the bridge deck cracking. But, high traffic volume generated more cracking than low traffic volume.

4. Bridge bearings do not influence the deck cracking severity.

5. Bridges with noticeable vibration combined with longer span lengths exhibited significant bridge deck cracking.

Due to the subjective nature of the vibration severity indicator used, further experimental studies are warranted to determine the quantitative effect of bridge vibration on bridge deck cracking, and the role of other structural features on deck cracking associated with bridge vibration.

VI. RECOMMENDATIONS

The results indicate that bridge vibration influences deck cracking. The bridges with noticeable vibration and longer spans may induce more bridge deck cracking. Since vibration response severities were qualitative indices, quantitative data should be obtained for a sample of bridges. Since resources are limited, vibration data collection from the following brides is recommended (see Table 1). This list was generated using stratified random sampling principles and represent the bridge population under each modified vibration severity rating and span length categories (*8*).

Table 1. Randomly selected bridges to be field tested.

Bridge ID (BIN)	Cracking Severity (Rating)	Vibration Severity (Rating)	Traffic Volume (AADT)	Span Length (m)
4005580	5	5	13750	77
4005580	5	5	13750	63
1093109	2	3	4650	34
1002760	2	3	2857	39
4020060	4	3	9541	67
1010550	0	1	10785	23
1074732	1	1	1000	48
1035670	1	1	2212	39
2260640	1	3	5700	69
1074812	0	1	13500	25
1048090	4	1	1944	65
3331460	1	1	4758	58
2220210	1	3	4452	36
3368130	1	2	5600	53
1041160	2	4	3980	35
1091321	3	4	6925	28
1077100	3	1	12417	66
1026390	0	1	1511	34
1019900	0	1	2093	26
1077160	0	1	11972	26

Measurement of displacements and accelerations induced by ambient traffic, and the first three modal frequencies of the selected bridges is recommended. These data can be used to get quantitative information on the influence of bridge vibration on deck cracking. They can also be compared with known vehicular vibration characteristics to eliminate resonance issues affecting bridge deck cracking.

ACKNOWLEDGMENTS

The author gratefully acknowledges the bridge inspectors for inspecting each of the bridges selected for this study and collecting relevant data. Frank Owens, formerly with the Department, contributed significantly in the initial stages of the study, preparation of the survey, and data collection. Duane Carpenter of the Structures Design and Construction Division assisted in extracting the bridge information from the bridge inventory database. Joseph C. Savoie of the Structures Design and Construction Division provided necessary input at all stages of this study. Dr. Deniz Sandhu of the Transportation Research and Development Bureau provided advice in conducting the statistical analysis, and Dr. Jorge Haddock of the Rensselaer Polytechnic Institute reviewed the report.

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APPENDIX A

SURVEY RESULTS

SURVEY RESULTS

BIN (Note 1)	AADT	PAN LENGTI (ft)	BEGINING BEARING	END BEARING	CRACKED	LONG	TRANS	CRACKING SEVERITY	VIBRATION SEVERITY
1007540	7376	93	EXP Elastomeric	FIX Elastomeric	N	N	N	0	3
1017990	3574	160	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1020480	885	192	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	3
1020630	4417	67	FIX Elastomeric	EXP Elastomeric	N	N	N	0	2
1022450	9100	140	None	None	Y	Y	Y	1	3
1022550	2030	66	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1
1024710	6913	200	FIX Disc Bearing	EXP Disc Bearing	Y	Y	Y	4	2
1025310	11785	185	EXP Pot Bearing	EXP Pot Bearing	N	N	N	0	3
1025310	11785	225	None	FIX Pot Bearing	N	N	N	0	3
1025310	11785	265	None	EXP Pot Bearing	N	N	N	0	3
1025310	11785	225	None	EXP Pot Bearing	N	N	N	0	3
1025310	11785	185	None	EXP Pot Bearing	N	N	N	0	3
1026300	12662	50	EXP Elastomeric	FIX Elastomeric	N	N	N	0	3
1026300	12662	70	None	EXP Elastomeric	N	N	N	0	3
1026300	12662	50	None	EXP Elastomeric	N	N	N	0	3
1026320	13358	120	FIX Pot Bearing	EXP Pot Bearing	Y	Y	Y	1	3
1033281	10041	120	EXP Elastomeric	FIX Elastomeric	Y	Y	Y	1	4
1033282	10041	120	EXP Elastomeric	FIX Elastomeric	Y	Y	Y	1	4
1038690	2857	174	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	2
1054150	9600	184	EXP Pot Bearing	EXP Pot Bearing	Y	N	Y	3	3
1093109	4650	125	EXP Elastomeric	FIX Elastomeric	Y	N	Y	2	3
1093109	4650	111	None	EXP Elastomeric	Y	N	Y	2	3
2200460	12300	72	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	2
3200600	50	121	FIX Elastomeric	EXP Elastomeric	N	N	N	0	2
3300920	106	89	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
3301740	250	135	FIX Elastomeric	EXP Elastomeric	N	N	N	0	2
3303080	971	90	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	1
3303080	971	165	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	1	1
3304000	640	185	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
3305510	4550	148	EXP Elastomeric	EXP Elastomeric	Y	Y	Y	3	2
3305510	4550	185	None	FIX Elastomeric	Y	Y	Y	3	2
3305510	4550	185	None	EXP Elastomeric	Y	Y	Y	3	2
3305510	4550	148	None	EXP Elastomeric	Y	Y	Y	3	2
3368290	4550	144	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	1
3368290	4550	144	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	2	1
3368290	4550	144	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	1
3368290	4550	144	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	2	1
3368290	4550	139	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	1
3368290	4550	180	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	2	1
3368290	4550	139	EXP Pot Bearing	EXP Pot Bearing	Y	N	Y	2	1
4005580	13750	207	EXP Pot Bearing	EXP Pot Bearing	Y	N	Y	5	5
4005580	13750	253	None	EXP Pot Bearing	Y	N	Y	5	5
4005580	13750	300	None	FIX Pot Bearing	Y	N	Y	5	5
4005580	13750	253	None	EXP Pot Bearing	Y	N	Y	5	5
4005580	13750	207	None	EXP Pot Bearing	Y	N	Y	5	5

1002760	2857	127	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	2	2.5
1002760	2857	139	None	EXP Pot Bearing	Y	N	Y	2	2.5
1002760	2857	144	None	EXP Pot Bearing	Y	N	Y	2	2.5
1010550	10785	75	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1010630	9341	96	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1018861	1374	150	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	4
1018861	1374	150	None	EXP Pot Bearing	Y	N	Y	2	4
1018862	1374	150	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	4
1018862	1374	150	None	EXP Pot Bearing	Y	N	Y	2	4
1020320	2010	105	EXP Elastomeric	FIX Elastomeric	Y	N	Y	2	2
1020320	2010	105	None	EXP Elastomeric	Y	N	Y	2	2
1029360	4500	59	None	None	N	N	N	0	1
1038820	1193	230	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	3
1038820	1193	230	None	EXP Pot Bearing	Y	N	Y	1	3
1052070	20144	66	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
3307190	507	42	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1
3307190	507	42	None	EXP Elastomeric	N	N	N	0	1
4018871	11000	134	EXP Pot Bearing	EXP Pot Bearing	N	N	N	0	3
4018871	11000	167	None	EXP Pot Bearing	N	N	N	0	3
4018871	11000	146	None	FIX Pot Bearing	N	N	N	0	3
4018871	11000	120	None	EXP Pot Bearing	N	N	N	0	3
4018872	1374	134	EXP Pot Bearing	EXP Pot Bearing	N	N	N	0	3
4018872	1374	167	EXP Steel Sliding	EXP Pot Bearing	N	N	N	0	3
4018872	1374	146	None	FIX Pot Bearing	N	N	N	0	3
4018872	1374	139	None	EXP Pot Bearing	N	N	N	0	3
4020060	9541	220	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	3.5	3
4020060	9541	220	None	EXP Pot Bearing	Y	N	Y	1	3
4020060	9541	150	None	EXP Pot Bearing	Y	N	Y	3	3
1016490	3503	160	EXP Disc Bearing	EXP Disc Bearing	N	N	N	0	1
1016490	3503	180	None	FIXED Multi-Rota	N	N	N	0	1
1016490	3503	180	None	EXP Disc Bearing	N	N	N	0	1
1016490	3503	180	None	EXP Disc Bearing	Y	N	Y	1	1
1016490	3503	160	None	EXP Disc Bearing	N	N	N	0	1
1021720	13991	132	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1022111	23621	159	EXP Disc Bearing	FIXED Multi-Rota	N	N	N	0	1
1022112	23621	159	EXP Disc Bearing	FIXED Multi-Rota	N	N	N	0	1
1023010	4805	120	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1023650	4264	127	EXP Elastomeric	FIX Elastomeric	Y	Y	N	1	1
1025842	49234	55	EXP Elastomeric	EXP Elastomeric	Y	N	Y	1	1
1025842	49234	62	None	FIX Elastomeric	Y	N	Y	1	1
1025842	49234	45	None	EXP Elastomeric	N	N	N	0	1
1025842	49234	45	None	EXP Elastomeric	N	N	N	0	1
1025851	49234	72	EXP Elastomeric	EXP Elastomeric	Y	Y	N	1	1
1025851	49234	93	None	FIX Elastomeric	Y	Y	N	1	1
1025851	49234	54	None	EXP Elastomeric	Y	Y	N	1	1
1025852	49234	77	EXP Elastomeric	EXP Elastomeric	Y	Y	N	1	1
1025852	49234	98	None	FIX Elastomeric	Y	Y	N	1	1
1025852	49234	57	None	EXP Elastomeric	Y	Y	N	1	1
1034220	3482	150	Other FIXED	Other FIXED	Y	N	Y	1	1
1035670	2212	129	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1035730	5472	128	EXP Elastomeric	FIX Elastomeric	Y	N	Y	4	1
1035730	5472	128	None	EXP Elastomeric	Y	N	Y	4	1
1040291	4106	106	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	3
1040292	4106	100	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	3

1043390	2561	69	EXP Disc Bearing	FIXED Multi-Rota	Y	N	Y	1	1
1043390	2561	130	None	EXP Disc Bearing	Y	N	Y	1	1
1043390	2561	69	None	EXP Disc Bearing	Y	N	Y	1	1
1043450	14026	100	EXP Disc Bearing	FIXED Multi-Rota	Y	N	Y	1	1
1043450	14026	100	None	EXP Disc Bearing	Y	N	Y	1	1
1048680	14879	99	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	1
1048680	14879	99	None	EXP Pot Bearing	Y	N	Y	1	1
1048900	0	150	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1048929	14028	137	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1048929	14028	104	None	EXP Elastomeric	Y	N	Y	1	1
1060620	7264	102	EXP Elastomeric	Other FIXED	Y	Y	N	1	1
1060620	7264	102	None	Other FIXED	Y	Y	N	1	1
1060620	7264	102	None	EXP Elastomeric	Y	Y	Y	1	1
1074690	8377	105	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1074690	8377	105	None	EXP Elastomeric	Y	N	Y	1	1
1074701	600500	111	FIX Elastomeric	EXP Elastomeric	Y	Y	Y	1	1
1074702	500	111	FIX Elastomeric	EXP Elastomeric	Y	Y	Y	1	1
1074710	1000	105	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1074710	1000	105	None	EXP Elastomeric	Y	N	Y	1	1
1074731	1000	156	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	1	1
1074732	1000	156	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	1	1
2034240	10537	108	EXP Elastomeric	FIX Elastomeric	N	N	N	0	3
2034240	10537	72	None	EXP Elastomeric	N	N	N	0	3
2257760	1268	110	FIX Pot Bearing	EXP Pot Bearing	N	N	N	0	1
3317890	1621	121	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
3319010	1410	96	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1
4011030	8643	180	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
4443330	12514	170	EXP Pot Bearing	FIX Pot Bearing	Y	Y	N	1	1
4443350	9291	160	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1001210	2948	55	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1011660	6274	82	EXP Pot Bearing	EXP Pot Bearing	N	N	N	0	1
1011660	6274	140	None	FIX Pot Bearing	N	N	N	0	1
1011660	6274	82	None	EXP Pot Bearing	N	N	N	0	1
1012350	15379	86	None	None	N	N	N	0	1
1022920	16237	147	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	3
1024550	3522	90	EXP Elastomeric	FIX Elastomeric	N	N	Y	0	1
1027830	7019	146	FIX Pot Bearing	EXP Pot Bearing	Y	Y	Y	1	1
1027870	7450	163	EXP Elastomeric	FIX Elastomeric	Y	Y	Y	3	3
1028200	5699	150	EXP Pot Bearing	EXP Pot Bearing	Y	N	Y	1	1
1028200	5699	190	None	FIX Pot Bearing	Y	N	Y	4	3
1028200	5699	190	None	EXP Pot Bearing	Y	N	Y	3	2
1028200	5699	150	None	EXP Pot Bearing	Y	N	Y	3	2
1028200	5699	133	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	1
1028200	5699	165	None	EXP Pot Bearing	Y	N	Y	3	2
1028200	5699	133	None	EXP Pot Bearing	Y	N	Y	4	2
1030180	4208	161	None	None	N	N	N	0	1
1041520	6300	89	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1042560	12508	69	None	None	Y	Y	Y	1	1
1044230	30300	54	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1044230	30300	80	None	EXP Elastomeric	Y	N	Y	1	1
1044230	30300	54	None	EXP Elastomeric	Y	N	Y	1	1
1071471	3538	105	EXP Elastomeric	FIX Elastomeric	Y	Y	Y	3	3
1071501	3538	138	EXP Elastomeric	FIX Elastomeric	Y	Y	N	1	1
1074561	8769	140	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1

1074562	8769	140	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
2260580	1355	81	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1
2260640	5700	219	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	3
2260640	5700	219	None	EXP Pot Bearing	Y	N	Y	1	3
2260640	5700	191	EXP Pot Bearing	EXP Pot Bearing	Y	N	Y	1	3
2260640	5700	226	None	FIX Pot Bearing	Y	N	Y	1	3
2260640	5700	226	None	EXP Pot Bearing	Y	N	Y	1	3
2260640	5700	191	None	EXP Pot Bearing	Y	N	Y	1	3
2263810	839	76	EXP Pot Bearing	EXP Pot Bearing	N	N	N	0	1
2263810	839	104	None	FIX Pot Bearing	N	N	N	0	1
2263810	839	104	None	EXP Pot Bearing	N	N	N	0	1
2263810	839	76	None	EXP Pot Bearing	N	N	N	0	1
3027760	5140	109	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	1
3027760	5140	109	None	EXP Pot Bearing	Y	N	Y	1	1
3324840	978	195	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
3326910	1000	140	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
3326990	8809	95	None	None	Y	Y	Y	1	1
3327100	1000	120	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
3327920	3760	115	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
3328390	315	178	FIX Pot Bearing	EXP Pot Bearing	N	N	N	0	1
3368440	4100	122	None	None	N	N	N	0	1
4454030	4735	73	None	EXP Pot Bearing	N	N	N	0	1
4454030	4735	119	None	EXP Pot Bearing	Y	N	Y	4	3
4454030	4735	73	None	None	N	N	N	0	1
4454090	1062	76	EXP Elastomeric	EXP Elastomeric	N	N	N	0	1
4454090	1062	137	None	FIX Elastomeric	Y	N	Y	4	3.5
4454090	1062	76	None	EXP Elastomeric	N	N	N	0	1
4454130	5103	132	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
4454130	5103	55	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
6012270	5000	158	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1010180	8195	126	None	EXP Elastomeric	Y	N	Y	5	3.5
1010180	8195	126	EXP Elastomeric	FIX Elastomeric	Y	N	Y	5	3.5
1011380	1020	109	None	EXP Pot Bearing	N	N	N	0	1
1011380	1020	145	None	EXP Pot Bearing	Y	N	Y	1	1
1011380	1020	109	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1012480	2528	175	FIX Pot Bearing	EXP Pot Bearing	N	N	N	0	1
1012520	4503	80	None	EXP Pot Bearing	Y	N	Y	1	1
1012520	4503	155	None	EXP Pot Bearing	Y	N	Y	1	1
1012520	4503	130	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	1
1012550	1358	130	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1012660	6919	82	None	None	N	N	N	0	1
1012910	3608	165	EXP Elastomeric	FIX Elastomeric	Y	Y	Y	2	1
1012930	11780	133	None	EXP Elastomeric	Y	N	Y	2	2
1012930	11780	133	None	None	Y	N	Y	2	2
1014940	7307	124	None	None	N	N	N	0	2
1015020	5465	126	FIX Pot Bearing	EXP Pot Bearing	Y	Y	N	1	3
1015050	4881	153	None	None	N	N	N	0	1
1016340	7393	130	None	EXP Elastomeric	N	N	N	0	1
1016340	7393	130	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1042860	1915	127	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1042860	1915	127	None	EXP Elastomeric	Y	N	Y	1	1
1046880	1479	107	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1046890	1479	132	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1048090	1944	214	FIX Pot Bearing	EXP Pot Bearing	Y	Y	Y	4	1

1074800	4000	115	None	EXP Pot Bearing	Y	Y	Y	1	1
1074800	4000	175	None	EXP Pot Bearing	Y	N	Y	1	1
1074800	4000	115	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1074811	13500	83	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1074812	13500	83	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1074821	13500	104	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1074822	13500	104	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1074830	4000	128	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1074840	4000	128	FIX Elastomeric	EXP Elastomeric	Y	Y	N	1	1
1074851	13500	73	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1074852	13500	73	FIX Elastomeric	EXP Elastomeric	Y	Y	N	1	1
1074861	2873	121	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1074862	2873	115	EXP Elastomeric	FIX Elastomeric	Y	Y	N	1	1
1074881	2873	85	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1074882	2873	85	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1074900	5300	188	None	EXP Pot Bearing	N	N	N	0	1
1074900	5300	191	EXP Pot Bearing	EXP Pot Bearing	Y	N	Y	1	1
1074900	5300	187	FIX Pot Bearing	EXP Pot Bearing	N	N	N	0	1
1074900	5300	191	None	EXP Pot Bearing	N	N	N	0	1
1074900	5300	184	None	EXP Pot Bearing	N	N	N	0	1
1074900	5300	174	None	FIX Pot Bearing	N	N	N	0	1
1077150	7393	127	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1090980	3419	131	None	None	N	N	N	0	1
2214000	1970	140	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
2218180	1378	126	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1
2218210	4186	137	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
3331460	4758	189	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
3331460	4758	134	None	EXP Elastomeric	Y	N	Y	1	1
1000780	2643	176	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	1	1
1000800	2643	151	EXP Elastomeric	FIX Elastomeric	Y	N	Y	2.5	2
1007041	4342	112	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	3	3
1007042	4342	112	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	3.5	3
1008550	1854	131	None	FIX Pot Bearing	Y	N	Y	1	3
1008550	1854	117	None	EXP Pot Bearing	Y	N	Y	1	3
1008850	1854	130	None	None	Y	N	Y	1	3
1010170	7633	105	None	FIX Elastomeric	Y	N	Y	1	3
1010170	7633	118	None	None	Y	N	Y	1	3
1017250	2213	160	EXP Elastomeric	FIX Elastomeric	Y	N	Y	4	2
1017250	2213	160	None	EXP Elastomeric	Y	N	Y	4	2
1017299	3186	122	EXP Elastomeric	FIX Elastomeric	Y	N	Y	3	2
1017299	3186	127	None	EXP Elastomeric	Y	N	Y	3	2
1018950	2852	108	EXP Elastomeric	FIX Elastomeric	N	N	N	0	2
1018960	4486	97	EXP Elastomeric	FIX Elastomeric	Y	N	Y	2	3
1018960	4486	130	None	EXP Elastomeric	Y	N	Y	2	3
1018960	4486	97	None	EXP Elastomeric	Y	N	Y	2	3
1021270	2109	144	EXP Elastomeric	FIX Elastomeric	Y	N	Y	3	2
1021270	2109	171	None	EXP Elastomeric	Y	N	Y	3	2
1021280	1159	127	None	None	Y	N	Y	3	2
1023980	4089	120	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	2
1023980	4089	120	None	EXP Elastomeric	Y	N	Y	1	2
1027250	1016	120	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	3
1027250	1016	120	None	EXP Elastomeric	Y	N	Y	1	3
1027260	2974	110	EXP Elastomeric	FIX Elastomeric	Y	N	Y	2	3
1027260	2974	140	None	EXP Elastomeric	Y	N	Y	2	3

1027260	2974	110	None	EXP Elastomeric	Y	N	Y	2	3
1027270	2938	120	EXP Elastomeric	FIX Elastomeric	Y	N	Y	2	3
1027270	2938	120	None	EXP Elastomeric	Y	N	Y	2	3
1027560	739	84	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	2
1062080	6103	102	EXP Pot Bearing	EXP Pot Bearing	Y	N	Y	1	3
1062080	6103	137	None	FIX Pot Bearing	Y	N	Y	1	3
1062080	6103	102	None	EXP Pot Bearing	Y	N	Y	1	3
1074780	3526	103	EXP Pot Bearing	EXP Pot Bearing	Y	N	Y	1	3
1074780	3526	138	None	FIX Pot Bearing	Y	N	Y	1	3
1074780	3526	103	None	EXP Pot Bearing	Y	N	Y	1	3
2219650	6514	120	EXP Elastomeric	FIX Elastomeric	Y	N	Y	3	2
2219650	6514	120	None	EXP Elastomeric	Y	N	Y	3	2
2220210	4452	119	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	1	3
2220210	4452	145	None	FIX Pot Bearing	Y	N	Y	1	3
2220210	4452	119	None	EXP Pot Bearing	Y	N	Y	1	3
2220220	19500	237	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	2.5
2220220	19500	245	None	EXP Pot Bearing	N	N	N	0	2.5
3336620	456	42	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
3338480	123	148	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	3
3339020	5730	206	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	1	3
3340620	406	142	EXP Elastomeric	FIX Elastomeric	N	N	N	0	2
1003070	2974	52	FIX Elastomeric	EXP Elastomeric	Y	Y	Y	2	2
1003160	8908	111	None	EXP Elastomeric	Y	N	Y	4	3
1003160	8908	111	None	None	Y	N	Y	4	3
1016671	4194	129	EXP Pot Bearing	FIX Pot Bearing	Y	Y	Y	2	2
1016671	4194	164	None	EXP Pot Bearing	Y	Y	Y	2	2
1016671	4194	100	None	EXP Pot Bearing	Y	Y	Y	2	2
1016672	4194	125	EXP Pot Bearing	FIX Pot Bearing	Y	Y	Y	4	3
1016672	4194	158	None	EXP Pot Bearing	Y	Y	Y	4	3
1016672	4194	117	None	EXP Pot Bearing	Y	Y	Y	4	3
1022349	14755	56	EXP Elastomeric	None	Y	N	Y	5	4
1022349	14755	69	EXP Elastomeric	None	Y	N	Y	5	4
1022349	14755	34	EXP Elastomeric	FIX Elastomeric	Y	N	Y	5	4
1026840	7725	180	FIX Elastomeric	EXP Elastomeric	Y	N	Y	2	3
1034850	4495	58	FIX Elastomeric	FIX Elastomeric	N	N	N	0	1
1037380	17440	46	FIX Elastomeric	EXP Elastomeric	Y	N	Y	2	2
1040801	6925	95	EXP Elastomeric	FIX Elastomeric	Y	N	Y	4	4
1040801	6925	95	None	EXP Elastomeric	Y	N	Y	4	4
1040802	6925	95	EXP Elastomeric	FIX Elastomeric	Y	N	Y	4	4
1040802	6925	95	None	EXP Elastomeric	Y	N	Y	4	4
1041160	3980	115	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	4
1041160	3980	115	None	EXP Pot Bearing	Y	N	Y	2	4
1044839	65775	175	FIX Elastomeric	EXP Elastomeric	Y	N	Y	2	3
1045240	22590	85	EXP Elastomeric	None	Y	N	Y	5	3
1045240	22590	85	EXP Elastomeric	FIX Elastomeric	Y	N	Y	5	3
1046960	9224	81	FIX Elastomeric	EXP Elastomeric	Y	N	Y	2	2
1047010	21703	97	FIX Elastomeric	EXP Elastomeric	Y	N	Y	2	2
1052920	25521	160	EXP Pot Bearing	FIX Pot Bearing	Y	Y	Y	4	2
1052920	25521	200	None	EXP Pot Bearing	Y	Y	Y	4	2
1074590	7171	105	EXP Elastomeric	FIX Elastomeric	N	N	N	0	2
1074600	5400	70	EXP Elastomeric	FIX Elastomeric	Y	N	Y	2	2
1074600	5400	83	FIX Elastomeric	EXP Elastomeric	Y	N	Y	2	2
1074750	43232	96	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1
1077090	12417	182	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	1

1077100	12417	245	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	3	1
1077100	12417	216	FIX Pot Bearing	EXP Pot Bearing	Y	N	Y	3	1
1091321	6925	92	FIX Elastomeric	EXP Elastomeric	Y	N	Y	3	4
1091322	6925	92	FIX Elastomeric	EXP Elastomeric	Y	N	Y	4	4
2262530	800	85	EXP Elastomeric	FIX Pot Bearing	Y	N	Y	4	2
2262530	800	121	None	EXP Elastomeric	Y	N	Y	4	2
2262530	800	75	None	EXP Pot Bearing	Y	N	Y	4	2
2265310	6005	115	EXP Elastomeric	FIX Elastomeric	N	N	N	0	4
3343620	3268	125	EXP Elastomeric	FIX Elastomeric	Y	N	Y	2	2
3346370	700	101	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
3346370	700	102	None	EXP Elastomeric	N	N	N	0	1
3368130	5600	175	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	2
5502121	21777	97	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1
5502301	7850	128	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
5514160	2500	88	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	2
5514160	2500	117	None	EXP Pot Bearing	Y	N	Y	2	2
5523850	37597	150	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1003970	3555	147	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1004080	6923	184	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1004370	1642	161	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1013730	11650	96	EXP Elastomeric	FIX Elastomeric	Y	N	Y	3	1
1013730	11650	113	None	EXP Elastomeric	Y	N	Y	3	1
1017470	4933	127	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1
1017630	3226	107	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1017630	3226	130	None	EXP Elastomeric	N	N	N	0	1
1017640	3226	125	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1017640	3226	180	None	EXP Elastomeric	Y	N	Y	1	1
1018510	5625	125	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1018560	2705	87	FIX Pot Bearing	EXP Pot Bearing	N	N	N	0	2
1019900	2093	85	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1020930	1614	100	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1021360	3828	180	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1024830	1017	136	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1026390	1511	110	None	FIX Elastomeric	N	N	N	0	1
1026390	1511	110	None	None	N	N	N	0	1
1026440	757	75	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1026440	757	95	None	EXP Elastomeric	N	N	N	0	1
1026440	757	75	None	EXP Elastomeric	N	N	N	0	1
1030420	1800	105	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1030710	671	93	None	None	N	N	N	0	1
1030720	1671	123	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1030810	2770	103	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1030810	2770	103	None	EXP Elastomeric	N	N	N	0	1
1030850	1981	122	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1040350	2628	90	None	None	N	N	N	0	1
1040370	2935	174	FIX Pot Bearing	EXP Pot Bearing	N	N	N	0	1
1041690	402	105	None	None	Y	Y	N	1	1
1041700	402	106	EXP Elastomeric	FIX Elastomeric	N	N	N	0	1
1041710	402	102	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1041730	542	118	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1045670	5845	155	FIX Pot Bearing	EXP Pot Bearing	N	N	N	0	1
1046820	6939	113	None	None	N	N	N	0	1
1050220	1363	120	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1054811	2448	107	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1

1054811	2448	104	None	EXP Elastomeric	Y	N	Y	1	1
1054812	2448	107	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
1054812	2448	104	None	EXP Elastomeric	Y	N	Y	1	1
1077160	11972	86	FIX Elastomeric	EXP Elastomeric	N	N	N	0	1
1091690	92	180	EXP Pot Bearing	FIX Pot Bearing	N	N	N	0	1
1091690	92	145	None	EXP Pot Bearing	N	N	N	0	1
1091690	92	96	None	EXP Pot Bearing	N	N	N	0	1
2226190	13405	83	EXP Pot Bearing	FIX Pot Bearing	Y	N	Y	2	1
2226190	13405	134	None	EXP Pot Bearing	Y	N	Y	2	1
2226190	13405	88	None	EXP Pot Bearing	Y	N	Y	2	1
3352030	148	127	EXP Elastomeric	FIX Elastomeric	Y	N	Y	1	1
3352030	148	127	None	EXP Elastomeric	Y	N	Y	1	1
3355450	1242	125	FIX Disc Bearing	EXP Disc Bearing	N	N	N	0	1
3356240	2370	92	FIX Elastomeric	EXP Elastomeric	Y	N	Y	1	1

Note 1: BIN = Bridge Identification Number

APPENDIX B

STATISTICAL ANALYSIS

STATISTICAL ANALYSIS

One-way Analysis of Variance (ANOVA) was performed to assist in determining the correlation between each of the variables (bridge vibration, traffic volume, span length, and bearing type) and deck cracking. The F-test was used to determine if there are any significant differences amongst the means. If there are, the multiple range tests were used to determine which means are significantly different from others. Multi-factor ANOVA was used to examine the effects of two or more factors (i.e. interaction effects) on deck cracking. Data from all 383 bridge spans was used in the analysis. If inspectors rated the bridge vibration or crack ratings with a non-integer, the ratings were rounded to the nearest integer (eg.1.5 was treated as 2 for the analysis).

Effect of Vibration

ANOVA was performed to determine the correlation between vibration severity and observed deck cracking severity (SEV). The results are shown in Tables B1 and B2. Modified vibration ratings (CVIB) shown in Fig. 6 in Section IV along with deck cracking ratings shown in Fig. 4 were used in this analysis.

Table B1. ANOVA table for cracking severity (SEV) by modified vibration ratings (CVIB).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
Between groups	228.262	2	114.131	92.92	0.0000
Within groups	466.751	380	1.22829		
Total (Corr.)	695.013	382			

Table B2. Table of means for cracking severity (SEV) by modified vibration ratings (CVIB) with 95% confidence intervals.

CVIB	COUNT	Mean	Std. Err. (Pooled s)	Lower Limit	Upper Limit
1 (Low)	217	0.617512	0.0752351	0.512909	0.722114
3 (Moderate)	143	1.78322	0.0926793	1.65436	1.91207
5 (High)	23	3.34783	0.231093	3.02653	3.66912
Total	383	1.21671			

Note that the ANOVA table decomposes the variance of SEV into two components: a between-group component and a within-group component. The F-ratio, which in this case equals 92.9187, is a ratio of the between-group estimate to the within-group estimate. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the mean SEV from one level of CVIB to another at the 95.0% confidence level. To determine which means are significantly different from which others, multiple range tests were used.

Table B3. Multiple range tests for cracking severity (SEV) by modified vibration ratings (CVIB).

CVIB	Count	Mean	Homogeneous Groups		
1	217	0.617512	X		
3	143	1.78322		X	
5	23	3.34783			X

Contrast	Difference	+/- Limits
1 - 3	*-1.16571	0.234714
1 - 5	*-2.73031	0.477856
3 - 5	*-1.56461	0.489561

* denotes a statistically significant difference.

Table B3 applies a multiple comparison procedure to determine which means are significantly different from others. The bottom half of the table shows the estimated difference between each pair of means. The asterisks placed next to 3 pairs, indicate that these pairs show statistically significant differences at the 95% confidence level. Three homogenous groups are identified using columns of X's. Within each column, the levels containing X's form a group of means that have no statistically significant differences. Fisher's least significant difference (LSD) procedure was used to discriminate among the means. With this method, there is a 5% risk of calling each pair of means significantly different when the actual difference equals 0.

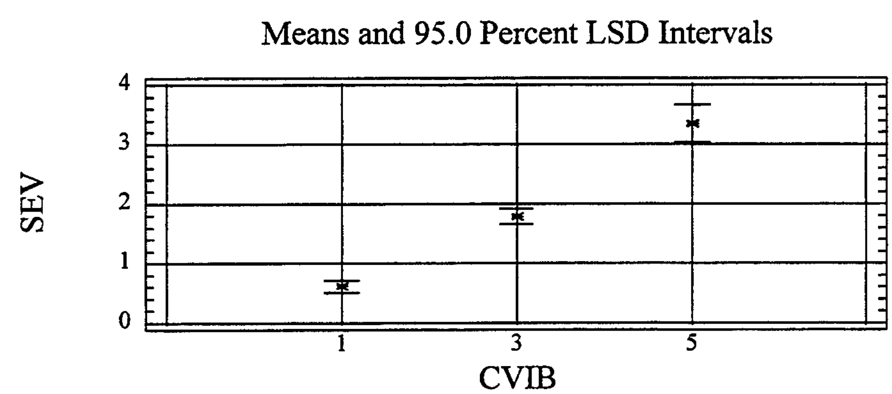

Figure B1. Means plot for cracking severity (SEV) and modified vibration ratings (CVIB).

The means plot (Fig. B1) shows the mean SEV for each level of CVIB. It also shows an interval around each mean. The intervals are based on Fisher's least significant difference (LSD) procedure. They are constructed in such a way that if two means are the same, their intervals will overlap 95%

of the time. Any pair of intervals that do not overlap vertically correspond to a pair of means which have a statistically significant difference. This indicates that there are three significantly different means.

From all the above data, it can be concluded that the vibration severity significantly influences the cracking severity. Similar analysis was performed for other parameters.

Effect of Traffic Volume

For analysis, the traffic volume data , i.e. Average Annual Daily Traffic (AADT), was classified into three groups: low volume (AADT ≤ 1000), medium volume (1000 < AADT ≤ 5000), and high volume (AADT > 5000). The groups were designated 1, 2, and 3 respectively. Analyses similar to those described earlier were conducted and results are given in Tables B4-B6 and Fig. B2.

Table B4. ANOVA table for cracking severity (SEV) by traffic volume (AADT).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
Between groups	36.6719	2	17.3359	9.98	0.0001
Within groups	660.341	380	1.73774		
Total (Corr.)	695.013	382			

Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the mean SEV from one level of AADT to another at the 95% confidence level. Thus, means plot and multiple range tests were conducted for further analysis.

Table B5. Table of means for cracking severity (SEV) by traffic volume (AADT) with 95% confidence intervals.

AADT	COUNT	Mean	Std. Err. (Pooled s)	Lower Limit	Upper Limit
1	89	0.674157	0.139732	0.479882	0.868432
2	124	1.33065	0.118381	1.16606	1.49523
3	170	1.41765	0.101104	1.27708	1.55822
Total	383	1.21671			

Table B6. Multiple range tests for cracking severity (SEV) by traffic volume (AADT).

AADT	Count	Mean	Homogeneous Groups
1	89	0.674157	X
2	124	1.33065	X
3	170	1.41765	X

Contrast	Difference	+/- Limits
1 - 2	*-0.656488	0.36009
1 - 3	*-0.74349	0.339123
2 - 3	-0.0870019	0.306101

* denotes a statistically significant difference

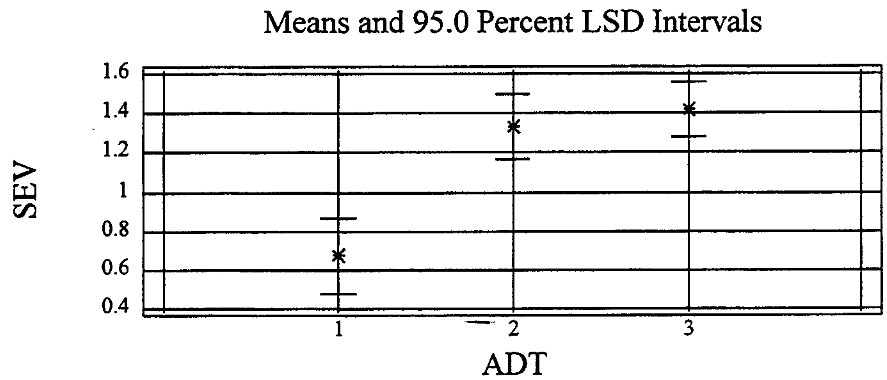

Figure B2. Means plot for traffic volume (AADT) and cracking severity (SEV).

The results shown in Tables B5 and B6, and Fig. B2 indicate that there is no statistically significant differences between cracking of medium and high volume bridges, indicating that they can be combined for further analysis. At the same time, it also indicates that AADT does influence the cracking severity and very low volume bridges exhibit less cracking. This confirms what is expected from practice. Thus, for a multi-factor ANOVA, only two groups will be used, low volume (AADT ≤ 1000) and high volume (AADT>1000).

Effect of Span Length

For analysis, the bridges were classified based on span length into three groups: small spans 30-m or shorter (LEN = 3), medium spans between 30 m and 60 m long (LEN = 2), and long spans which are greater than 60 m (LEN = 1). Analysis results are shown in Tables B7-B9, and Fig. B3. Since the P-value of the F-test is less than 0.05, there is a statistically significant difference between the mean SEV from one level of span length (LEN) to the another at the 95% confidence level. Thus, means plot and multiple range tests were conducted for further analysis.

Table B7. ANOVA table for cracking severity (SEV) by span lengths (LEN).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
Between groups	17.9466	2	8.97331	5.04	0.0069
Within groups	677.066	380	1.78175		
Total (Corr.)	695.013	382			

Table B8. Table of means for cracking severity (SEV) by span lengths (LEN) with 95% confidence intervals.

AADT	COUNT	Mean	Std. Err. (Pooled s)	Lower Limit	Upper Limit
1	22	2.09091	0.284585	1.69524	2.48658
2	258	1.17442	0.0831025	1.05888	1.28996
3	103	1.13592	0.131524	0.95306	1.31878
Total	383	1.21671			

Table 9. Multiple range tests for cracking severity (SEV) by span length.

Len	Count	Mean	Homogeneous Groups
3	103	1.13592	X
2	258	1.17442	X
1	22	2.09091	X

Contrast	Difference	+/- Limits
1 - 2	*0.91649	0.582929
1 - 3	*0.954987	0.616429
2 - 3	0.0384963	0.305903

*denotes a statistically significant difference

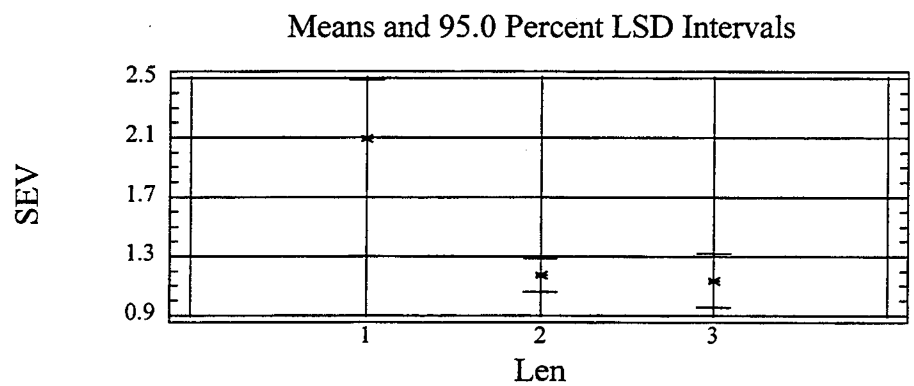

Figure B3. Means plot for span lengths (LEN) and cracking severity (SEV).

The results from Tables B8 and B9, and Fig. B3 indicate that there is no statistically significant differences between cracking of bridges with spans less than 30 m long, and spans between 30 m to 60 m long, indicating that they can be combined. At the same time, it also indicates that span length does influence the cracking severity, with longer spans exhibiting more cracking. Thus, for a multi-factor ANOVA, only two groups will be used, spans 60 m or shorter, and spans longer than 60 m.

Effect of Bearings

Influence of bearings on deck cracking severity was examined. Since there are many different types of bearings, they were classified into 6 groups, as following.

1. Elastomeric Bearing (Free/Expansion)
2. Elastomeric Bearing (Fixed)
3. Pot Bearing (Fixed)
4. Pot Bearing (Free/Expansion)
5. None
6. Others (include discs, rockers, multi-rotational, etc.)

Analysis results are given in Tables B10-B11, and Figs. B4-B5, for beginning (BEGBEAR) and end bearings (ENDBEAR). The results indicate that there is no statistically significant difference between the cracking severity and type of bearing. Thus, type of bearing is not considered in further analysis.

Table B10. ANOVA table for beginning bearing type (BEGBEAR) by cracking severity (SEV).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
Between groups	16.527	2	3.30539	1.84	0.1048
Within groups	678.486	380	1.7997		
Total (Corr.)	695.013	382			

Table B11. ANOVA table for end bearing type (ENDBEAR) by cracking severity (SEV).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
Between groups	7.4899	2	1.49798	0.82	0.5350
Within groups	687.523	380	1.82367		
Total (Corr.)	695.013	382			

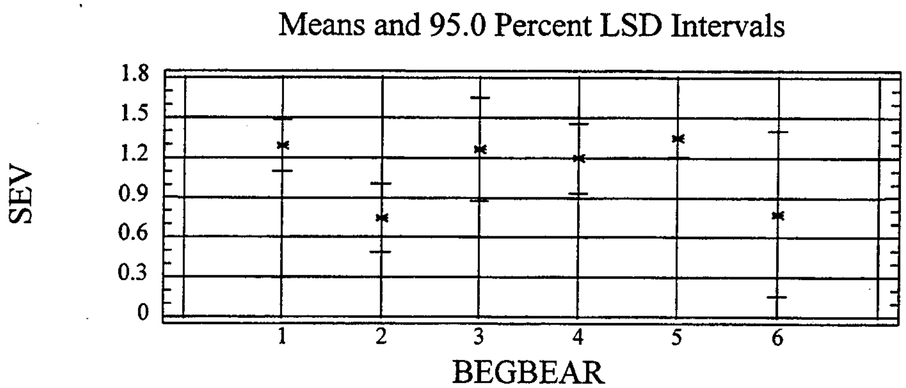

Figure B4. Means plot for beginning bearing type (BEGBEAR) and cracking severity (SEV).

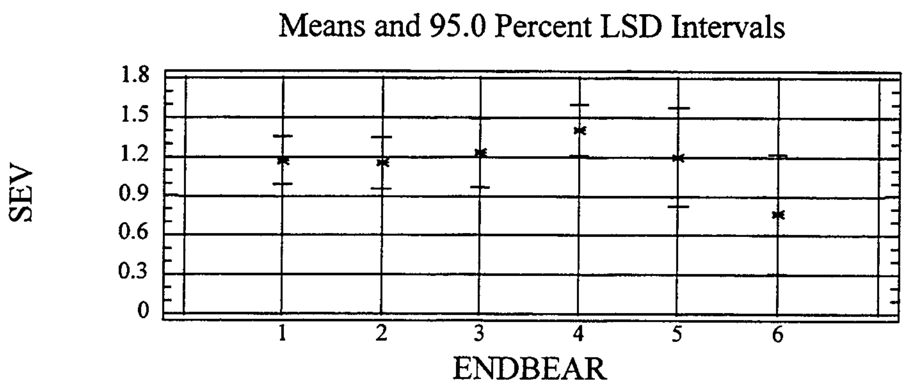

Figure B5. Means plot for end bearing type (ENDBEAR) and cracking severity (SEV).

Multi-factor Analysis of Variance

Multi-factor ANOVA is useful in examining the effects of two or more factors on one variable. Thus, multi-factor ANOVA is used here to examine the effect of bridge vibration, span length, and traffic volume (AADT) on bridge deck cracking. As illustrated in the previous section, bridge vibration is divided into 3 ranges - low (1), medium (3), and noticeable or severe (5). The traffic volume was divided into two categories - low with AADT$\leq$1000 (1), and high with AADT>1000 (3). Similarly, span lengths have been divided in to two categories - short spans of length $\leq$ 60 m (3), and large spans, which are longer than 60 m (1).

This analysis is to determine the factors having a statistically significant effect on deck cracking severity (SEV), and also test for significant interactions amongst the factors. The F-tests in the ANOVA table identify the significant factors. For each significant factor, multiple range tests tell which means are significantly different from others.

Table B12 decomposes the severity of deck cracking (SEV) into contributions by various factors. The contribution of each factor is measured by having the effects of all other factors removed. The P-values test the statistical significance of each factor. Since P-values of vibration severity and span length are less than 0.05, these have a statistically significant effect on bridge deck cracking at the 95% confidence level.

Table B12. ANOVA table for deck cracking severity (SEV).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-Ratio	P-Value
A: CVIB	42.9662	2	21.4831	20.38	0.0000
B: AADT	0.30207	1	0.30207	0.290	0.5928
C: LEN	18.0213	1	18.0213	17.09	0.0000
Interactions					
AB	2.35954	2	1.17977	1.120	0.3277
AC	49.9581	2	24.9717	23.69	0.0000
BC	2.38117	1	2.38117	2.260	0.1337
RESIDUAL	393.262	373	1.05432		
TOTAL (Corrected)	695.013	382			

Note: All F-ratios are based on the residual mean square error.

Figs B6-B8 show the mean deck cracking (SEV) for each level of vibration severity (CVIB), traffic volume (AADT), and span lengths (LEN), along with 95% confidence intervals for each of the means. The bars which do not overlap indicate significant difference between the two means, and bars that overlap indicate no significant difference between the means. The interaction plots are useful for interpreting the interaction between vibration severity, traffic volume, and span length. For example, the two lines drawn on Fig. B9 represent each level of span length. They connect the least squares means for the 3 levels of vibration severity (CVIB). If there was absolutely no interaction, these lines would be parallel. Stronger the interaction, larger the difference in shape of these lines. This plot and the p value of lower than 0.05 for interaction effect (AC) in the means table indicate that interaction exists between vibration severity and span lengths.

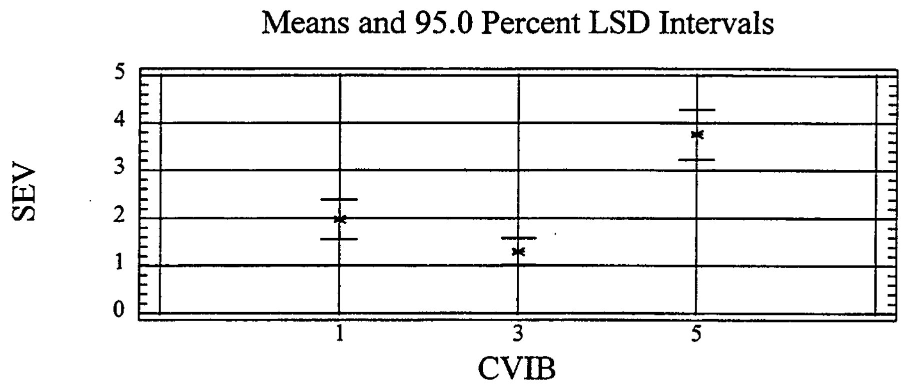

Figure B6. Means plot for deck cracking severity (SEV) and vibration severity (CVIB).

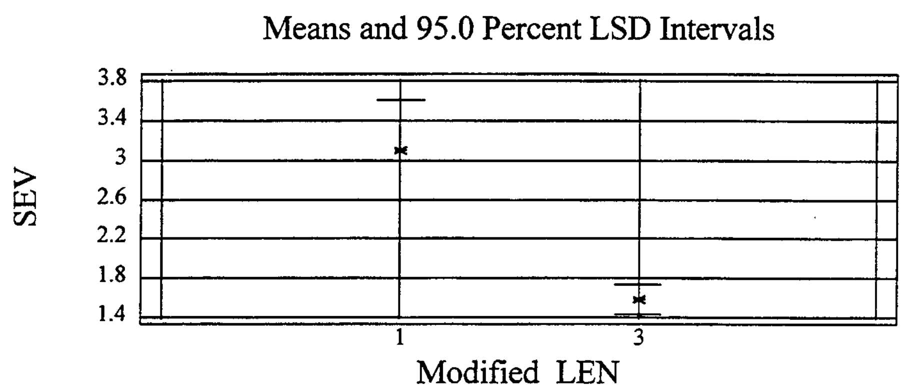

Figure B7. Means plot for deck cracking severity (SEV) and span length (LEN).

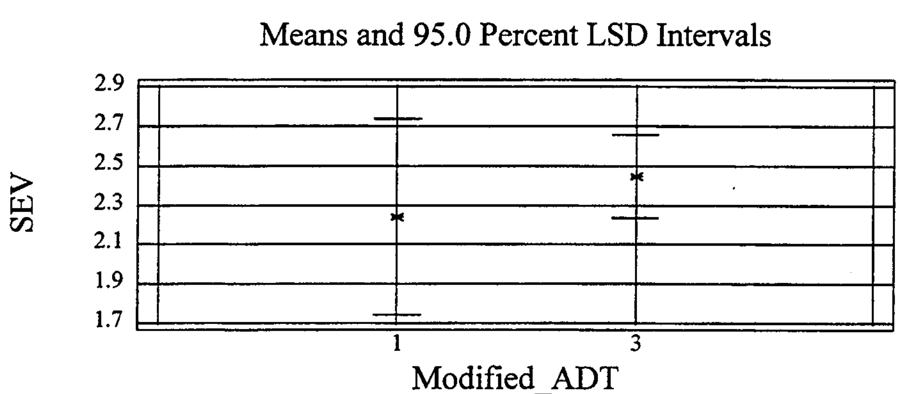

Figure B8. Means plot for deck cracking severity (SEV) and traffic volume (AADT).

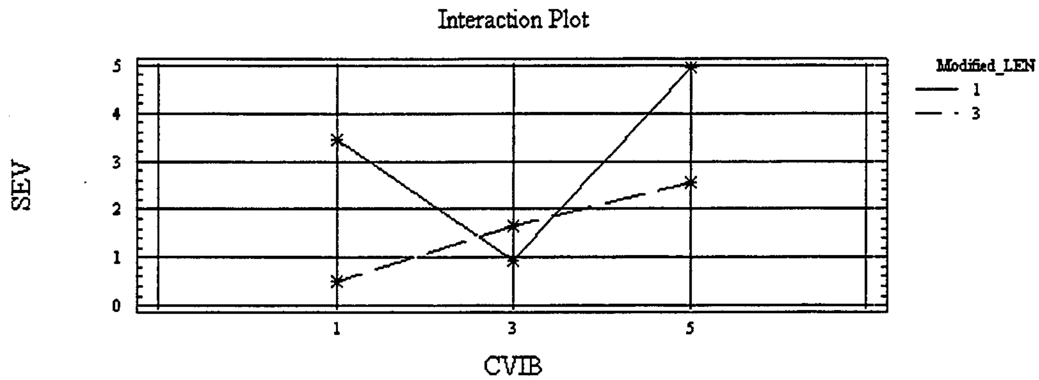

Figure B9. Interaction plot for deck cracking severity (SEV), vibration severity (CVIB), and span length (LEN).