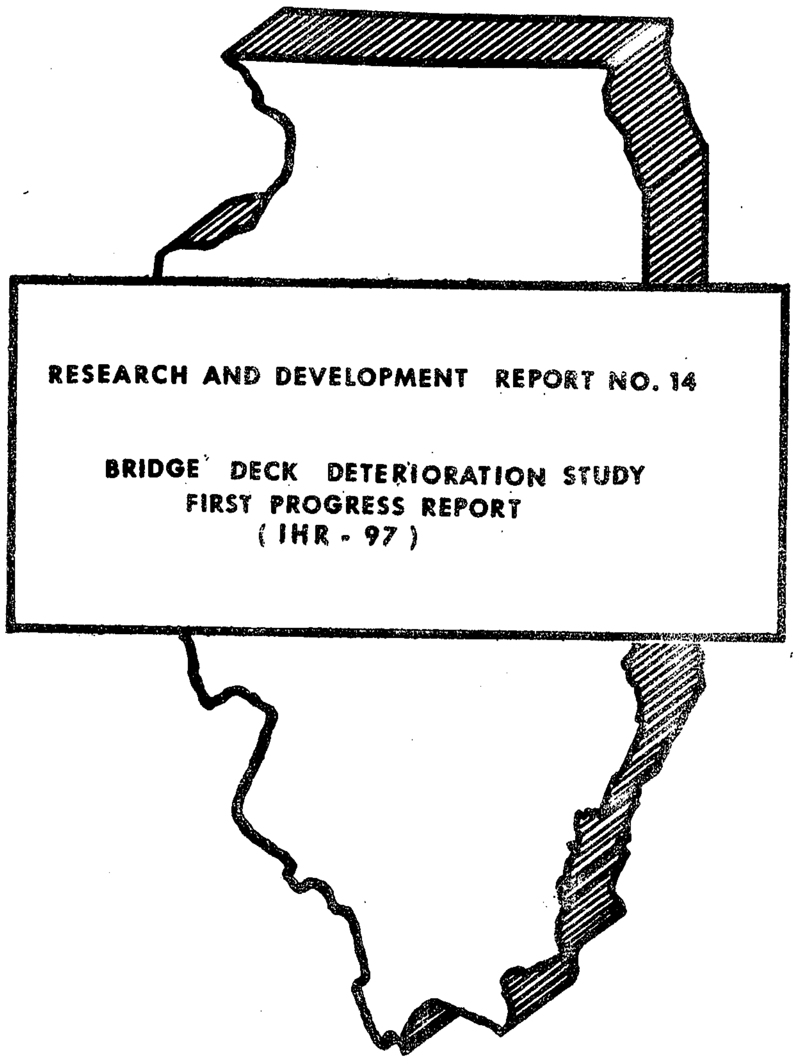
STATE OF ILLINOIS

DEPARTMENT OF PUBLIC WORKS AND BUILDINGS

DIVISION OF HIGHWAYS



RESEARCH AND DEVELOPMENT REPORT NO. 14

BRIDGE DECK DETERIORATION STUDY
FIRST PROGRESS REPORT
(IHR - 97)

Private Communication
Not For Publication

RESEARCH AND DEVELOPMENT
ADMINISTRATIVE REPORT

State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways

RESEARCH AND DEVELOPMENT REPORT NO. 14

BRIDGE DECK DETERIORATION STUDY
FIRST PROGRESS REPORT
(IHR-97)

By
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A Research Study
Conducted by

Illinois Division of Highways
Bureau of Research and Development

July 1967

BRIDGE DECK DETERIORATION STUDY - IHR-97
FIRST PROGRESS REPORT

INTRODUCTION

Premature deterioration of modern reinforced concrete bridge decks in Illinois has been reported with sufficient frequency to make evident a need to establish modifications that will help to avoid the condition in the future. As a first step in a research study directed at this goal, types, extent, and severity of deterioration are being determined by means of a survey of concrete bridge decks that have been constructed in Illinois during and following 1960. This survey was initiated by the Bureau of Research and Development at the request of a Committee on Bridge Deck Deterioration that was formed in the Illinois Division of Highways to investigate the problem. The survey was implemented on March 18, 1966, by the distribution to district offices of a four-page questionnaire (Data Form for Concrete Bridge Decks Constructed During 1960 and Later).

Districts were instructed to survey each of the bridge decks constructed within their boundaries during the period in question and to complete and return a separate questionnaire form for each bridge. A copy of the questionnaire is included as Appendix A.

In the development of the questionnaire form, an attempt was made to include all items that could be conceived possibly to have some influence on deck deterioration. It was anticipated that tabulation and inspection of this data would help to identify the data items most commonly concurrent with deterioration.

The questionnaire survey has furnished detailed information on 1051 bridge decks representing 20 types of superstructure.

The general approach that is planned for the study is one of successive evaluation of data items to determine those most frequently concurrent with reported deterioration. Items which appear to show no marked concurrence will be eliminated from further study.

While the overall study will have but one objective--a determination of what modifications might be made in bridge design, material usage, and construction practice to improve the performance of the bridge deck concrete--it is considered expedient to approach this objective in three successive phases. These three phases are described in the paragraphs that follow, and Phase I results are presented in detail.

Phase I. This is a preliminary study that began with the preparation of a series of tabulations on a district-by-district, regional, and statewide basis, of types of deterioration for which reporting was requested and the number of decks affected by each type of deterioration. The tabulations are limited to the grouping of bridges as to whether or not the various types of deterioration have occurred. The areal extent of the deteriorated areas, and the severity of deterioration, has not been investigated in this phase of the study.

A summary was made of the number of decks affected by each type of deterioration listed on the questionnaire and several apparent trends are demonstrated by means of the relative number of decks affected by more common types of deterioration.

Phase II. This phase of the study will be of a quantitative nature in which further tabulations will be made to summarize the reported areal extent and severity of the various types of deterioration, and to explore the extent to which distribution of values for concrete and construction data may tend to indicate some apparent association with extent and severity of deterioration. It is anticipated that this phase of the study will further assist in determining which additional data items have the greatest apparent association with deck deterioration.

Phase III. This is a supplementary corroborative study in which samples will be obtained from selected bridge decks throughout the state and subjected to laboratory tests. While this phase of the work is described with other parts of the overall study, it is currently planned as a separate research project to be undertaken after the analytical work of the first two phases has been completed.

PHASE I

A preliminary study, consisting of a series of tabulations, was conducted to determine on a statewide, a regional, and a district-by-district basis the types of deterioration displayed by the bridge decks, the number of bridges affected, and the identification of nonconstruction variables that appear to have some effect on deterioration factors and classes.

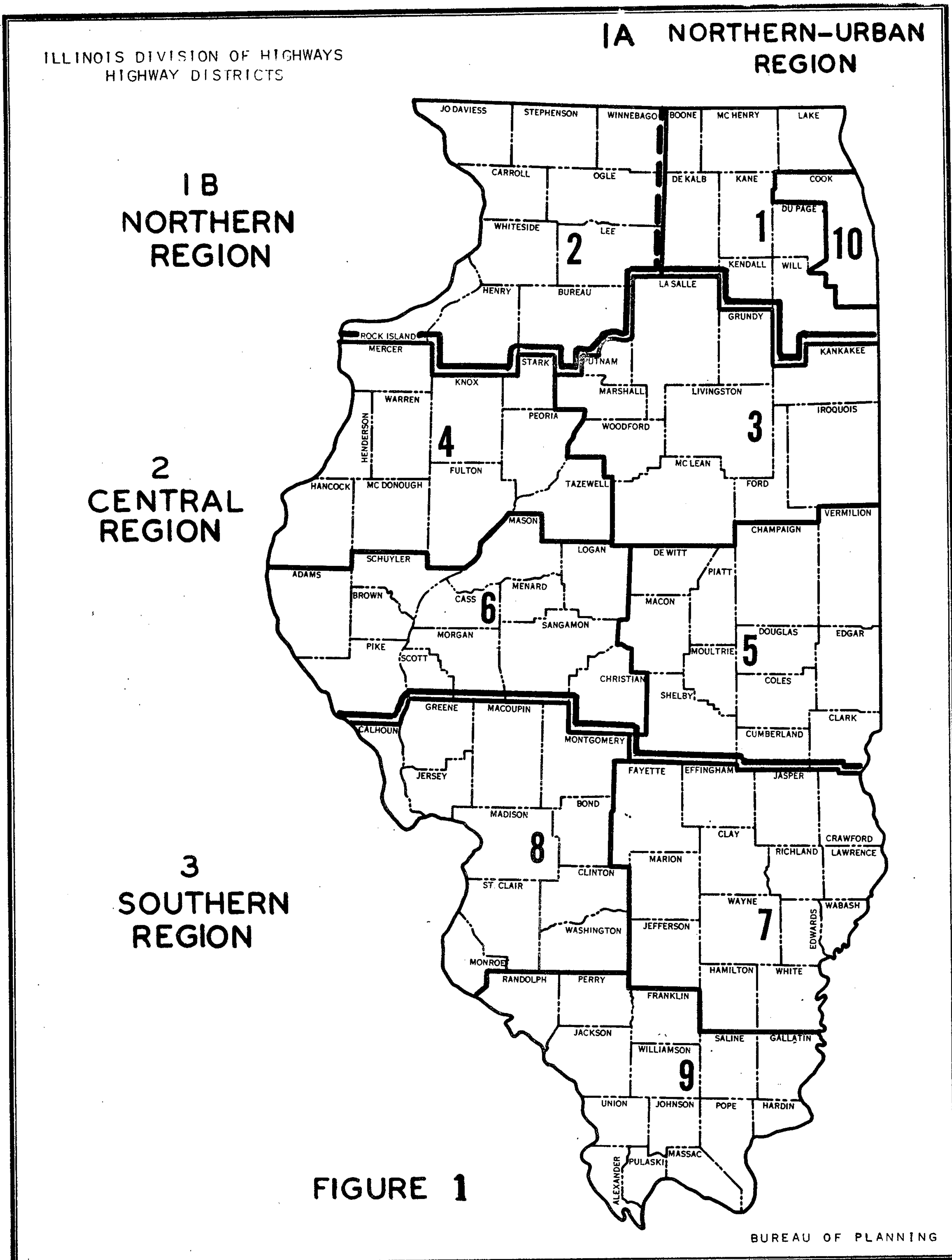
Data were grouped by District to simplify tabulation and to allow for detection of any differences between districts in the reporting of field surveys. This grouping also furnished a basis for the regional grouping shown in Figure 1. This regional grouping was suggested by trends in the data subsequently described. District and region are considered more as classifications than as factors causing deck deterioration.

Factors considered include (1) Type of structure - especially as related to cracking, (2) Year of construction, (3) Traffic Volume, (4) Use of retarder, (5) Use of heavy equipment on structure prior to opening to regular traffic, (6) Season during which deck was constructed, and (7) Skew. Principal types of deterioration included in the study are scaling, spalling and cracking, with patching included as indicating previous deterioration.

The primary emphasis in this phase of the study is on evaluating the extent to which data might show some variation related to District, region, type of structure, year of construction, and traffic volume, but consideration is also given to the effects of other factors.

Some factors appeared unrelated to particular types of deterioration or, if related, unlikely to exert an influence sufficiently conspicuous to permit an evaluation. Relationships investigated between classifications, factors, and reported conditions are indicated in Table 1.

While most data items could be described in a few simple terms, a few items, including type of structure, volume of vehicular traffic and skew, required more extensive description to permit tabulation of all reported classes.



ILLINOIS DIVISION OF HIGHWAYS
HIGHWAY DISTRICTS
1A NORTHERN-URBAN REGION
1 B NORTHERN REGION
2 CENTRAL REGION
3 SOUTHERN REGION
1
2
3
4
5
6
7
8
9
10
JO DAVIESS
STEPHENSON
WINNEBAGO
BOONE
MC HENRY
LAKE
CARROLL
OGLE
DE KALB
KANE
COOK
DU PAGE
WHITESIDE
LEE
KENDALL
WILL
HENRY
BUREAU
LA SALLE
GRUNDY
ROCK ISLAND
MERCER
STARK
PUTNAM
KANKAKEE
KNOX
MARSHALL
LIVINGSTON
WARREN
PEORIA
IROQUOIS
HENDERSON
WOODFORD
FULTON
MC LEAN
HANCOCK
MC DONOUGH
TAZEWELL
FORD
VERMILION
MASON
CHAMPAIGN
LOGAN
DE WITT
SCHUYLER
PIATT
ADAMS
MENARD
BROWN
CASS
MACON
SANGAMON
MORGAN
DOUGLAS
EDGAR
PIKE
SCOTT
MOULTRIE
CHRISTIAN
COLES
SHELBY
GREENE
MACOUPIN
CLARK
CALHOUN
MONTGOMERY
CUMBERLAND
FAYETTE
EFFINGHAM
JASPER
JERSEY
BOND
MADISON
CLAY
CRAWFORD
RICHLAND
LAWRENCE
MARION
CLINTON
ST. CLAIR
WAYNE
WABASH
EDWARDS
JEFFERSON
WASHINGTON
MONROE
HAMILTON
WHITE
RANDOLPH
PERRY
FRANKLIN
JACKSON
SALINE
GALLATIN
WILLIAMSON
UNION
JOHNSON
POPE
HARDIN
ALEXANDER
PULASKI
MASSAC
BUREAU OF PLANNING

FIGURE 1

TABLE 1.

Relationships Investigated Between Classifications, Factors and Reported Conditions

	Reported Conditions			
	Scaling	Spalling	Cracking	Patching
Classifications				
District	x	x	x	x
Region	x	x	x	x
Factors				
Type of Structure		x	x	x
Year of Construction	x	x	x	x
Traffic	x	x	x	
Retarder	x		x	
Heavy Equipment Used on Deck			x	
Season	x		x	
Skew			x	

A listing of 20 types of superstructure was prepared. This list which appears as Table 2, includes 14 types of superstructure more frequently, and 7 types less frequently, used. Based on this listing, each bridge deck reported was given a code number indicating the type of superstructure.

Some 84 bridges included two, and 8 bridges included three, types of superstructure. In tabulations involving deck cracking it was possible to identify the type of structure.

Traffic volume ranges were assigned initially through a preliminary analysis of the data to form groups of closely similar size representative of various levels of service. Initially seven levels were chosen, six covering more usual downstate traffic volumes - generally below 12,500 ADT - and two additional covering higher volumes in the urban region. Very high traffic volumes, approaching 200,000 ADT, were reported for Chicago expressways in a few instances. The number of groupings was reduced to four to permit convenient tabulation of scaling data. Ranges chosen initially and those used in the scaling tabulations are as follow:

Initial Ranges	Ranges Used in Scaling Tabulation
1. Not open	1. Not open
2. 45 - 549	2. 45 - 1999
3. 550 - 1999	3. 2000 - 12,499
4. 2000 - 3499	4. 12,500 up
5. 3500 - 12,499	
6. 12,500 - 34,999	
7. 35,000 up	

Scaling

Flaking of concrete from wearing surfaces has for years presented a problem of concern. Most often this flaking or scaling has been attributed to deleterious

TABLE 2.

A Listing of Types of Superstructures Reported

(1) Continuous Steel Beam Non-Composite
(2) Continuous Steel Beam Composite
(3) Steel Beam Non-Composite
(4) Steel Beam Composite
(5) R. C. Deck Girder (S. S.)
(6) R. C. Deck Girder Continuous
(7) Pretensioned Precast Concrete Beam (S. S.)
(8) Pretensioned Precast Concrete Beam Continuous
(9) Reinforced Concrete Slab (S. S.)
(10) Reinforced Concrete Slab Continuous
(11) Continuous Plate Girder Non-Composite
(12) Continuous Plate Girder Composite
(13) Plate Girder Non-Composite
(14) Plate Girder Composite
(15) Miscellaneous

    (15A) Cantilever Plate Girder with Suspended WF Beam End Spans
    (15B) Truss
    (15C) Simple Span Precast Concrete Slab
    (15D) Reinforced Concrete Rigid Frame
    (15E) Cantilever Beam Span with Suspended End Spans
    (15F) Cantilever Girder with Suspended End Spans
    (15G) Continuous Concrete Box Girder

effects on concrete pavements and wearing surfaces of salts applied during ice and snow removal and control operations.

To alleviate the problem of scaling, two measures are currently used. An agent is added to increase the small air voids in bridge deck concrete, and a linseed oil-petroleum spirits mixture is sprayed on cured upper deck surfaces as a sealant.

Some modification of construction practice which included an increase in specified air-content and use of deck sealant came into practice during the 1962-63 period; thus, an evaluation of the effectiveness in the control of scale of these two measures acting together is perhaps of greatest interest.

Air-content requirements were raised in 1962 from 3-5 to 4-6 percent. The upper limit was later increased to 7 percent. Although a slight decrease in average 14-day modulus of rupture results was noted from 1961 to 1962, 1963 and 1964 average 14-day modulus of rupture results for structure concrete are about the same as the average of 1959 through 1961 results.

Also put into practice during the 1962-63 period was a specification requiring application of two coats of a boiled linseed oil-petroleum spirits mixture to all newly constructed bridge decks.

Several conditions which modify deck performance have become apparent to those familiar with the problem. It was expected that decks carrying greater volumes of vehicular traffic would tend to receive more attention during winter maintenance operations and more often exhibit damage. The most recently cast bridge decks and those not open to traffic were expected to be free of scale. It was anticipated that differences in climate from northern to southern Illinois would result in evidences of deterioration being found more frequently in northern than in southern Illinois. Further, bridge decks cast during late fall and winter were expected to be more susceptible to scaling.

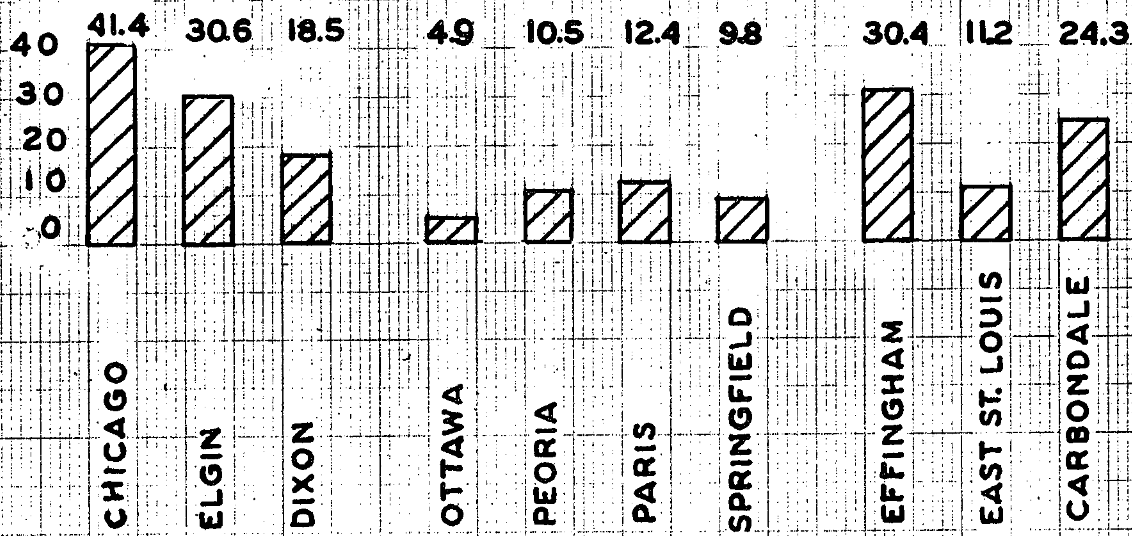
Table 3 and Figure 2 indicate the reported relative prevalence of scaling by District and by Region. In addition to the total number affected by scaling separately in the traffic lanes, gutter sections, and safety curbs, a total is given inclusive of scaling in any of the three locations for each District and Region. The percentages of decks affected by scaling were computed separately on two different sets of bases. The first set included for each District the total number of decks open to traffic, and the second set included for each District the decks built during the period of 1960 to 1964 inclusive which are open to traffic. While the percentages computed on the latter basis are somewhat higher, the relationship between the percentages reported from different Districts appears to be essentially unchanged. The Chicago, Elgin, and Effingham Districts report that 30 per cent or more of the decks inspected show scale. In the Districts comprising the Northern Region, the Northern Urban Region is most severely affected. In the Southern Region, the Effingham and Carbondale Districts report a considerably higher percentage of decks affected than had been expected, and it appears possible that some aggregates used in these Districts may be responsible in part for lower scale resistance.

Factors related in some way to traffic volume are suspected of playing a major role in the Northern Region and to be of lesser significance in the Central Region. In the Southern Region, scaling appears to be independent of factors related to traffic volume as may be seen in Table 4 and Figure 3.

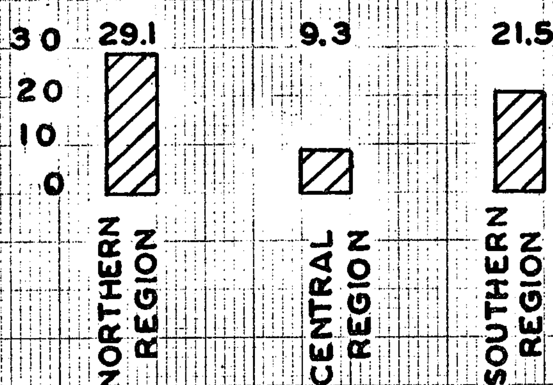
The season during which the deck is constructed appears to be associated with resistance of concrete bridge decks to scaling, with spring-cast and summer-cast traffic lane and gutter sections seemingly being the more vulnerable (Table 5 and Figure 4). At least a part of the scaling appears to be associated in some way with conditions requiring use of retarders as indicated in Table 5 and Figure 5. Whether or not this may be related to the actual use of retarders or to other variables of construction practices associated with higher air temperature requiring the use of retarders has not been determined.

Several of the figures indicate a lower relative frequency of scale for bridges cast in the 1962-63 period. This appears attributable in part to the previously mentioned corrective measures which were then introduced.

FIGURE 2 SCALING OF CONCRETE BRIDGE DECKS CONSTRUCTED 1960 & LATER



RELATIVE NUMBER OF BRIDGE DECKS AFFECTED BY SCALING IN EACH DISTRICT SHOWN AS A PERCENTAGE OF THE TOTAL NUMBER REPORTED OPEN TO TRAFFIC



RELATIVE NUMBER OF BRIDGE DECKS AFFECTED BY SCALING IN EACH REGION SHOWN AS A PERCENTAGE OF THE TOTAL NUMBER REPORTED OPEN TO TRAFFIC

FIGURE 3 TRENDS IN REPORTED SCALING IN TRAFFIC LANES AS AFFECTED BY AGE OF DECK AND TRAFFIC VOLUME GROUPING - BY REGION

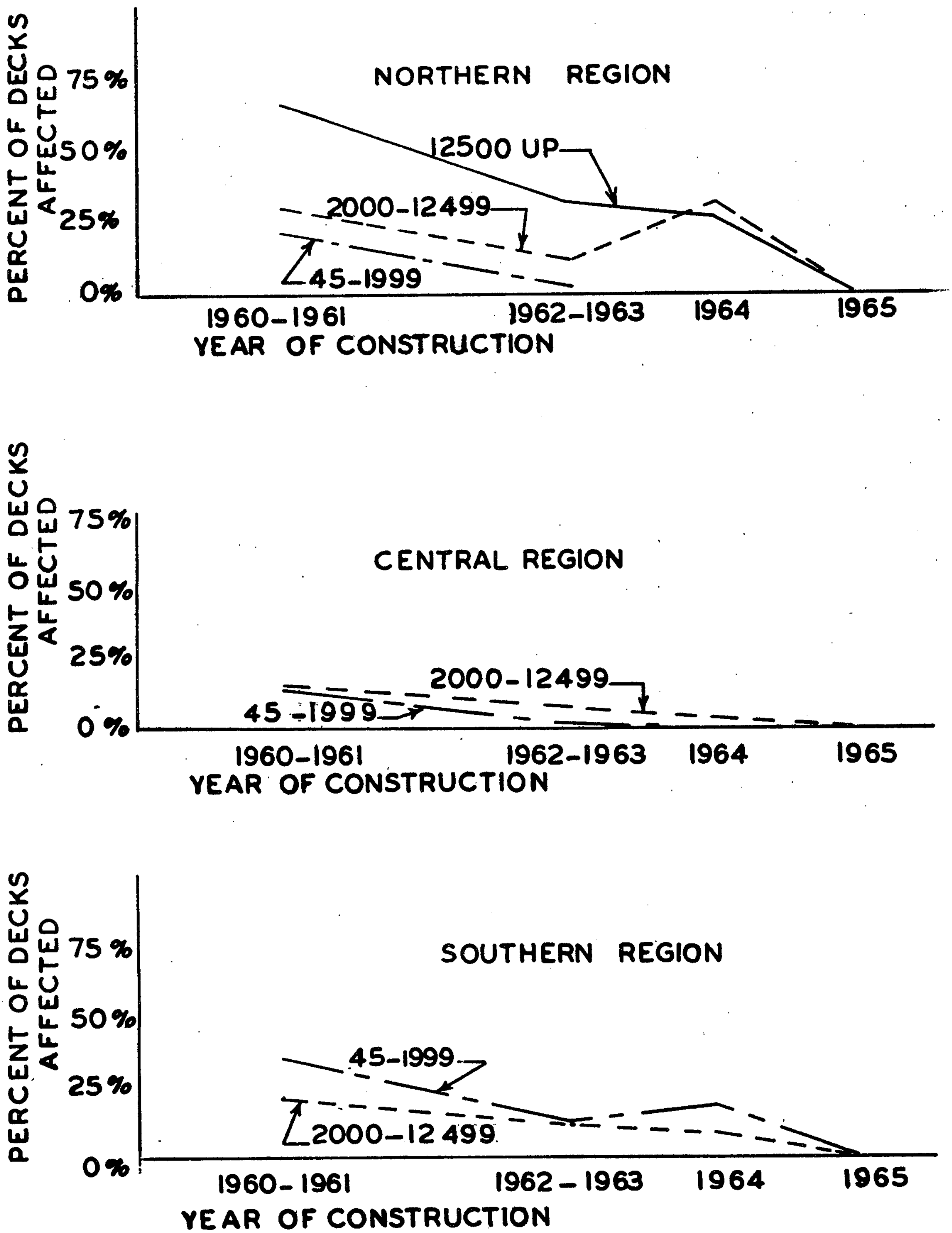


FIGURE 4 TRENDS IN REPORTED SCALING AS AFFECTED BY AGE AND SEASON OF CONSTRUCTION

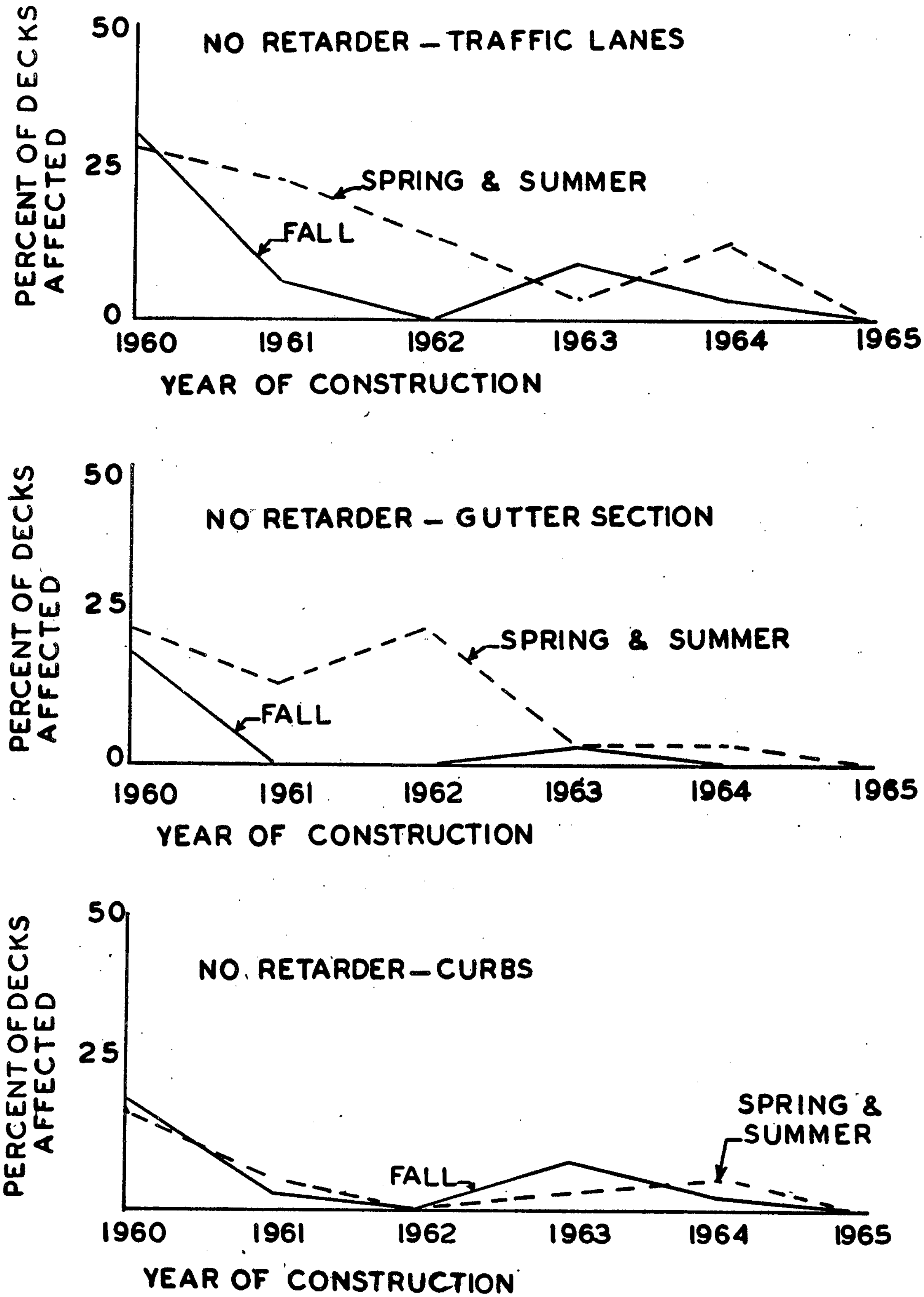


FIGURE 5 TRENDS IN REPORTED SCALING AS AFFECTED BY AGE OF DECK & USE OR NON USE OF RETARDER

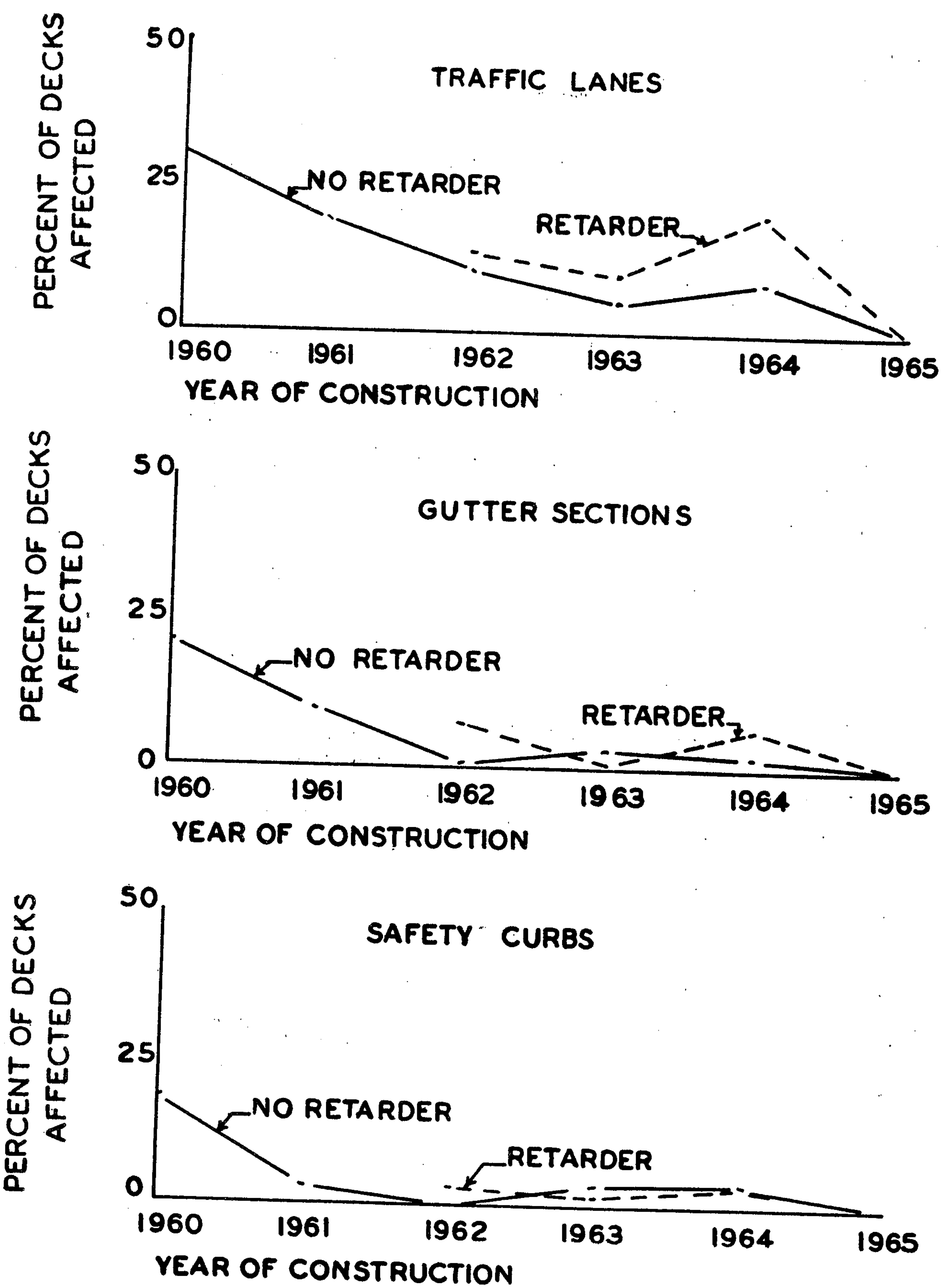


TABLE 3

BRIDGE DECK DETERIORATION IHR-97

SUMMARY OF SCALING DATA FOR CONCRETE BRIDGE DECKS

CONSTRUCTED 1960 AND LATER: DISTRICT AND REGION

		Total Bridge Decks (1)	Decks Open to Traffic (2)	Decks Built in 1965 Open to Traffic (3)	Decks Built 1960 - 1964 Open to Traffic (4)	Decks Affected: Traffic Lanes	Decks Affected: Gutter Sections	Decks Affected: Safety Curbs	Decks Affected: Total With Scale	% of Decks (2)	% of Decks (4)
District	Chicago	128	121	5	116	50	1	0	50	41.4	43.1
	Elgin	110	78	3	75	16	10	12	24	30.6	32.0
	Dixon	190	152	7	145	27	13	1	28	18.5	19.3
	Ottawa	101	101	0	101	2	0	4	5	4.9	4.9
	Peoria	96	95	17	78	9	3	0	10	10.5	12.8
	Paris	1[illegible]9	97	6	91	8	7	2	12	12.4	13.2
	Springfield	43	41	3	38	2	2	2	4	9.8	10.5
	Effingham	88	79	11	68	15	14	16	24	30.4	35.3
	East St.Louis	95	89	11	78	7	3	0	10	11.2	12.8
	Carbondale	91	74	4	70	15	11	13	18	24.3	25.7
Region	Northern	428	351	15	336	93	24	13	102	29.1	30.4
	Central	349	334	26	308	21	12	8	31	9.3	10.1
	Southern	274	242	26	216	37	28	29	52	21.5	24.0
		1051	927	67	860	151	64	50	185		21.5

Decks cast in 1965 were indicated to be free of scale.
Statewide 20% of decks cast between 1960 and 1965 and open to traffic are affected.
Numbers in parenthesis in the last column refer to the colum showing the basis on which percentages are computed.

TABLE 4.
BRIDGE DECK DETERIORATION IHR-97
SUMMARY OF SCALING DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED 1960 AND LATER: YEAR OF CONSTRUCTION AND TRAFFIC VOLUME GROUPS

Year of Construction	1960 - 1961			1962 - 1963		
Traffic Group	45 - 1999	2,000 12,499	12,500 Up	45 - 1999	2,000 12,499	12,500 Up
Number of Bridges						
Northern	26	78	29	30	69	16
Central	48	33	1	75	82	1
Southern	39	47	--	44	39	--
Decks Affected in Traffic Lanes						
Northern	6	24	19	1	8	5
Central	7	6	0	1	6	0
Southern	14	3	--	6	5	--
Percent of Decks Affected in Traffic Lanes						
Northern	23	30.8	65.5	3.3	11.6	31.0
Central	14.6	18.2	0	1.3	7.3	0
Southern	36.0	21.3	--	13.6	12.8	0

TABLE 4. (CONTINUED)
BRIDGE DECK DETERIORATION IHR-97
SUMMARY OF SCALING DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED
1960 AND LATER: YEAR OF CONSTRUCTION AND TRAFFIC VOLUME GROUPS

Year of Construction	1964			1965					
Traffic Group	45 - 1999	2,000 12,499	12,500 Up	45 - 1999	2,000 12,499	12,500 Up	Not Open	Data Not Available	
Number of Bridges									
Northern	9	22	47	3	9	3	77	10	428
Central	23	28	1	20	6	-	15	16	349
Southern	16	24	--	13	13	-	32	7	274
							124		1051
Decks Affected in Traffic Lanes									
Northern	2	7	14	0	0	0	1	6	93
Central	0	1	0	0	0	-	0	0	21
Southern	3	2	-	0	0	-	0	4	37
Percent of Decks Affected in Traffic Lanes									
Northern	?	31.8	29.8	-	-	-	1.3		
Central	0	3.6	0	-	-	-			
Southern	18.7	8.3	-	-	-	-			

TABLE 5.
BRIDGE DECK DETERIORATION IHR-97
SUMMARY OF SCALING DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED
1960 AND LATER: USE OF RETARDER AND SEASON OF CONSTRUCTION

		Spring and Summer Construction								Fall and Winter Construction					
		Retarder				No Retarder				Retarder		No Retarder			
		No Scale		Scale		No Scale		Scale		No Scale	Scale	No Scale		Scale	
1960	Traffic Lanes	2		1		83	71.0	34	29.0	1	3	36	66.6	18	33.3
	Gutter Sections	2		0		90	76.9	27	23.1	4	0	45	80.4	11	19.6
	Safety Curbs	2		1		100	82.6	21	17.4	3	1	45	80.4	11	19.6
1961	Traffic Lanes	5		0		64	75.3	21	24.7	3	1	29	93.5	2	6.4
	Gutter Sections	5		0		72	85.7	12	14.3	3		35	100.0	0	
	Safety Curbs	4		1		80	96.4	3	5.6	2		36	97.3	1	2.7
1962	Traffic Lanes	33	82.5	7	17.5	69	85.2	12	14.8	8	0	34			
	Gutter Sections	30	90.9	3	9.1	83	97.6	2	2.4	6	0	37			
	Safety Curbs	31	96.8	1	3.2	84	100.0	0	0	6	0	39			
1963	Traffic Lanes	72	92.3	6	7.7	58	96.7	2	3.3	18	4	31	90.2	3	9.8
	Gutter Sections	78	98.8	1	1.2	58	96.7	2	3.3	21	1	33	97.1	1	2.9
	Safety Curbs	72	100			64	100.0			18	2	34	91.9	3	8.1
1964	Traffic Lanes	87	78.2	24	21.6	39	86.6	6	13.4	18	3	29	96.7	1	3.3
	Gutter Sections	67	93.1	5	6.9	80	96.4	3	3.6	9	1	42		0	0
	Safety Curbs	59	95.2	3	4.8	87	95.6	5	5.4	7		43	97.7	1	2.3
1965	Traffic Lanes	56				18				5		19			
	Gutter Sections	43				29				1		24			
	Safety Curbs	38				32						24			

IHR-97 Form 6

Although no definite conclusions can yet be drawn, it appears worthwhile to further study the quantitative concrete and construction data as it may relate to the severity of scaling.

Spalls and Potholes

Spalling and potholing are identified as areas where the concrete has broken into small pieces progressing down to about the level of the top reinforcement. The loose pieces of concrete either may be in-place or may have been removed by traffic. With some exceptions, deterioration caused by spalling and potholing is chiefly confined to traffic lanes, and occurs almost entirely on decks open to traffic. The prevalence of these forms of deterioration in the Chicago and Elgin Districts, as may be seen in Table 7, prompted the designation of a Northern Urban Region. Outside of this region, only the Springfield, Effingham, and Carbondale Districts reported as affected more than 7.5 per cent of the decks open to traffic. In these three districts about 20 per cent of the decks were reported as affected. Figure 6 indicates the relative prevalence of spalls and potholes in the districts and regions.

There appears to be a tendency for scaling and spalling to occur on the same decks. Statewide, both occurred on the same decks in 94 of 194 cases (about 43 per cent).

The questionnaire requested information on the presence of four classes of spalls and potholes:

(1) at transverse cracks, steel exposed,

(2) at transverse cracks, no steel exposed,

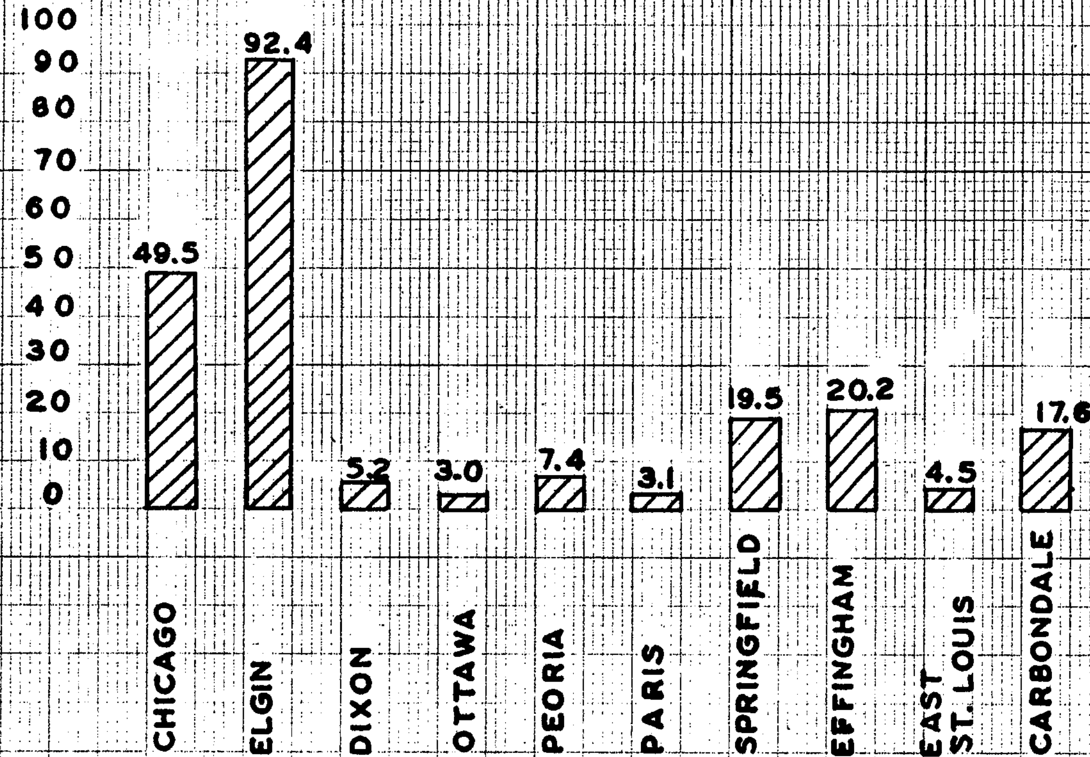
(3) not at transverse cracks, steel exposed, and

(4) not at transverse cracks, no steel exposed.

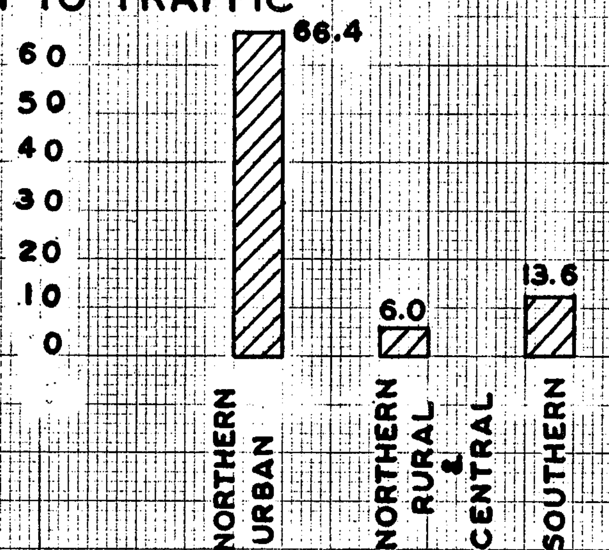
The last class is most numerous and it is likely that the 126 affected decks reported include surface spalls which are not associated with reinforcement. Next most common is the second class.

All four classes are listed, together with the affected location in Tables 7, 8, and 8A. The number of decks reported as affected is given in Table 7 by District and in Table 8 by type of bridge.

FIGURE 6 SUMMARY OF SPALL & POTHOLE DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED 1960 AND LATER



RELATIVE NUMBER OF BRIDGE DECKS IN EACH DISTRICT AFFECTED BY SPALLS & POTHOLES SHOWN AS A PERCENTAGE OF THE TOTAL NUMBER OF BRIDGE DECKS OPEN TO TRAFFIC



RELATIVE NUMBER OF BRIDGE DECKS IN EACH REGION AFFECTED BY SPALLS & POTHOLES SHOWN AS A PERCENTAGE OF THE TOTAL NUMBER OF BRIDGE DECKS OPEN TO TRAFFIC

TABLE 7. BRIDGE DECK DETERIORATION IHR-97
SUMMARY OF DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED 1960 AND LATER
NUMBER OF DECKS WITH SPALLS AND POTHOLES. LOCATION AFFECTED AND
PRESENCE OR ABSENCE OF EXPOSED REINFORCEMENT

		Number of Bridge Decks	Bridge Decks Open to Traffic	SPALLS AND POTHOLES												Total Decks with Spalls & Potholes	Percent of Bridge Decks Open to Traffic with Spalls and Potholes
				At Transverse Cracks						Not At Transverse Cracks							
				Steel Exposed			No Steel Exposed			Steel Exposed			No Steel Exposed				
				Traffic Lanes	Gutter Sections	Safety Curbs	Traffic Lanes	Gutter Sections	Safety Curbs	Traffic Lanes	Gutter Sections	Safety Curbs	Traffic Lanes	Gutter Sections	Safety Curbs		
DISTRICTS	Chicago	128	121	19	0	0	26	0	0	18	0	0	58	1	0	60	49.5
	Elgin	110	78	11	0	2	43	9	14	13	0	2	68	36	42	72	92.4
	Dixon	190	152	0	0	0	1	0	0	0	0	0	7	1	0	8	5.2
	Ottawa	101	101	1	0	0	2	0	0	0	0	0	0	0	0	3	3.0
	Peoria	96	95	1	0	0	7	0	0	0	0	0	0	0	0	7	7.4
	Paris	109	97	0	0	0	1	0	0	1	0	0	3	0	0	3	3.1
	Springfield	43	41	2	0	1	1	0	0	0	0	0	4	0	1	8	19.5
	Effingham	88	79	0	0	0	5	1	4	0	0	0	15	7	8	16	20.2
	East St. Louis	95	89	0	0	0	2	0	0	0	0	0	2	0	0	4	4.5
	Carbondale	91	74	0	0	0	7	0	0	3	0	0	8	0	1	13	17.6
REGION	Northern Urban	238	199	30	0	2	69	9	14	31	0	2	126	37	42	132	66.4
	Northern Rural and Central	539	486	4	0	1	12	0	0	1	0	0	14	1	1	29	6.0
	Southern	274	242	0	0	0	14	1	4	3	0	0	25	7	9	33	13.6
TOTAL		1051	927	34	0	3	95	10	18	35	0	2	165	45	52	194	21.3

TABLE 8.
BRIDGE DECK DETERIORATION IHR-97
SUMMARY OF DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED 1960
AND LATER. SPALLS AND POTHOLES BY BRIDGE TYPE

Type of Bridge	Number of Bridges	Bridges Open to Traffic	SPALLS AND POTHOLES: At Transverse Cracks, Steel Exposed: Yes T	Yes G	Yes C	No T	No G	No C	Not at Transverse Cracks, Steel Exposed: Yes T	Yes G	Yes C	No T	No G	No C
1,000	606	549	16	0	3	47	8	13	13	0	2	70	23	23
2,000	89	72	7	0	0	19	1	4	8	0	0	30	8	11
3,000	21	21	0	0	0	4	0	0	2	0	0	4	1	1
4,000	58	43	2	0	0	6	1	0	3	0	0	13	1	3
5,000	6	4				1						1		
6,000	47	43										3	1	
7,000	40	38	2			4			2			7	1	2
8,000	13	7				3		1	1			4		2
9,000	20	20				1						8	8	8
10,000	44	40							1			1	1	1
11,000	54	44	1			1			1			11		
12,000	14	12	5			5			4			8		
13,000	4	4												
14,000	8	7	1			3						2	1	1
15A000	4											2		
15B000	9	9										1		
15C000	1	1												
15D000	2	2												
15E000	8	4												
15F000	2	2				1								
15G000	1	1												
			34	0	3	95	10	18	35	0	2	165	45	52
Cross Check	1051	927	34	0	3	95	10	18	35	0	2	165	45	52

TABLE 8A.
BRIDGE DECK DETERIORATION IHR-97
SUMMARY OF DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED 1960
AND LATER. SPALLS AND POTHOLES BY BRIDGE TYPE

Type of Bridges Number of Bridges in Parenthesis	SPALLS AND POTHOLES											
	At Transverse Cracks Steel Exposed						Not At Transverse Cracks Steel Exposed					
	Yes			No			Yes			No		
	T	G	C	T	G	C	G	G	C	T	G	C
Continuous Beam) Continuous Girder) Steel (677)	29 4.3%	0	3	72 10.6%	9	17	26 3.9%	0	2	119 17.6%	31	34
Simple Beam) Simple Girder) Cantilever Beam) Steel Cantilever Girder) (85)	3 3.5%	0	0	14 16.5%	1	1	5 5.9%	0	0	21 24.7%	3	5
Concrete (156)	2 1.3%	0	0	9 5.8%	0	0	4 2.6%	0	0	24 15.4%	11	13
9 Truss Bridges Are Not Included												
Total (927)	34	0	3	95	10	18	35	0	2	164	45	52

As indicated in Table 8A, decks of concrete girder and slab bridges appear somewhat more resistant to spalling associated with reinforcement than do decks of steel bridges.

There appears to be a rather evident relationship between the type or development of spalling and potholing in traffic lanes, and resistance to cracking of different types of bridge superstructures. As may be seen in Figure 7 bridges constructed entirely of reinforced concrete are indicated to be more resistant to spalling and potholing than are bridges with steel stringers. Figure 10, included in the following section discussing deck cracking, indicates that reinforced concrete bridges as a group also are more resistant to transverse deck cracking than are bridges with steel stringers.

The percentage of decks on continuous steel structures affected by spalling and potholes does not appear to be sufficiently different from that shown for decks of simple span steel structures and structures with cantilever construction to warrant any special consideration in design.

Age of construction and traffic volume appear to play a major part in the formation of spalls and potholes only in the Northern Urban Region. From Table 9 and Figures 8A and 8B, a comparison may be made between spalling characteristics for structures grouped by age and traffic volume range.

Cores obtained from decks subject to spalling indicate that a system of inclined fractures may develop above the top layer of reinforcement undergoing corrosion.

Normally, a protective cover of 1-1/2 to 2 inches of concrete has been considered adequate to prevent corrosion of embedded steel for the life of the structure under ordinary conditions. For concrete piling exposed to sea water, 3 inches of cover is considered minimum.

With cover of as much as 2 inches, the changes of spalling appear remote although some observations indicate that, given the proper circumstances, spalling can occur with cover of that depth. Such has occurred only rarely on decks constructed in the past, even on those decks subject to heaviest application of salt.

FIGURE 7 INFLUENCE OF BRIDGE TYPE ON LOCATION AND TYPE OF SPALLS AND POTHOLES IN TRAFFIC LANES– STATE WIDE

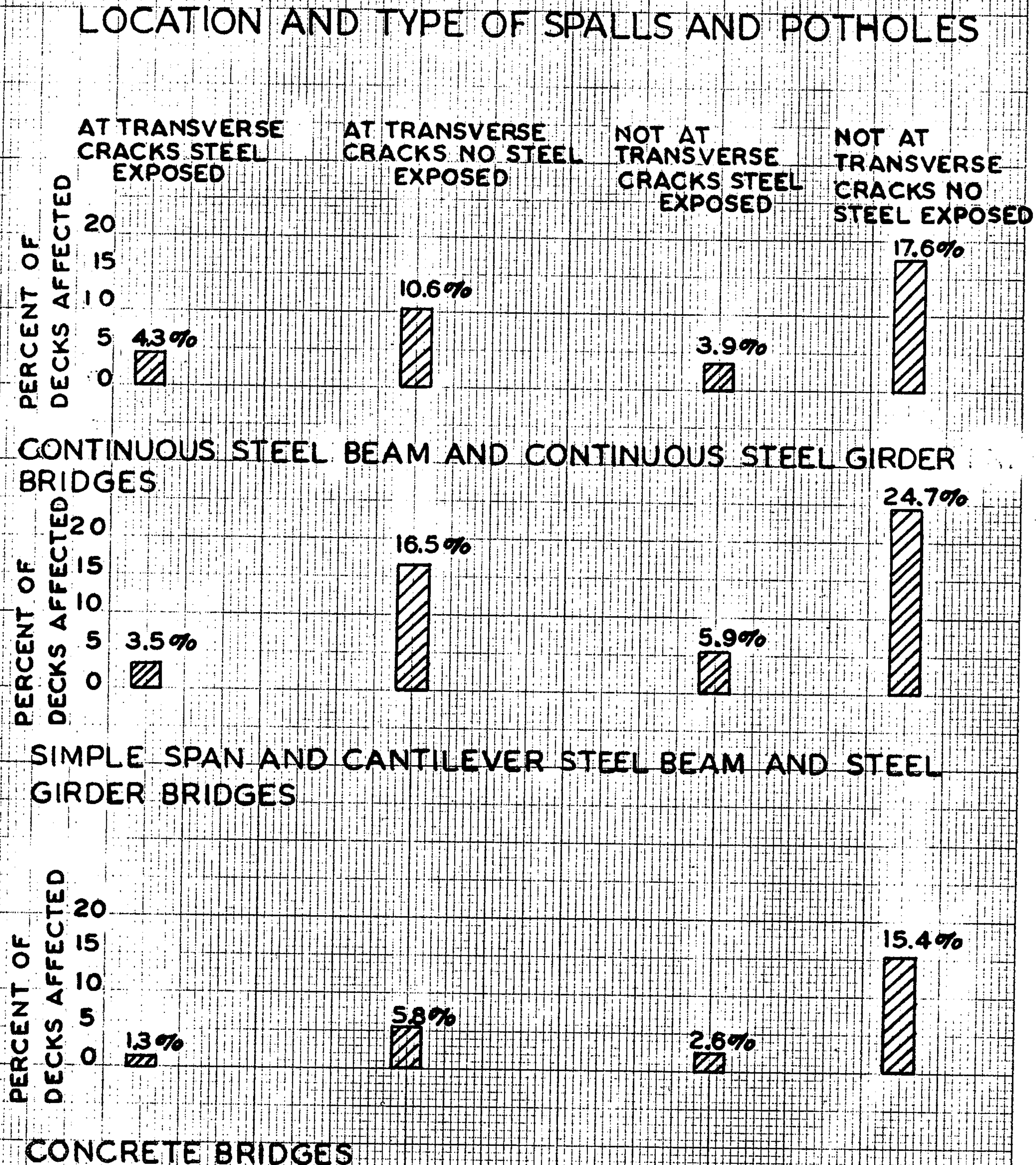


FIGURE 8A GENERAL TRENDS WITH AGE, TRAFFIC VOLUME AND REGION OF THE PERCENTAGE OF BRIDGE DECKS REPORTED TO SHOW SPALLS AND POTHOLES IN TRAFFIC LANES

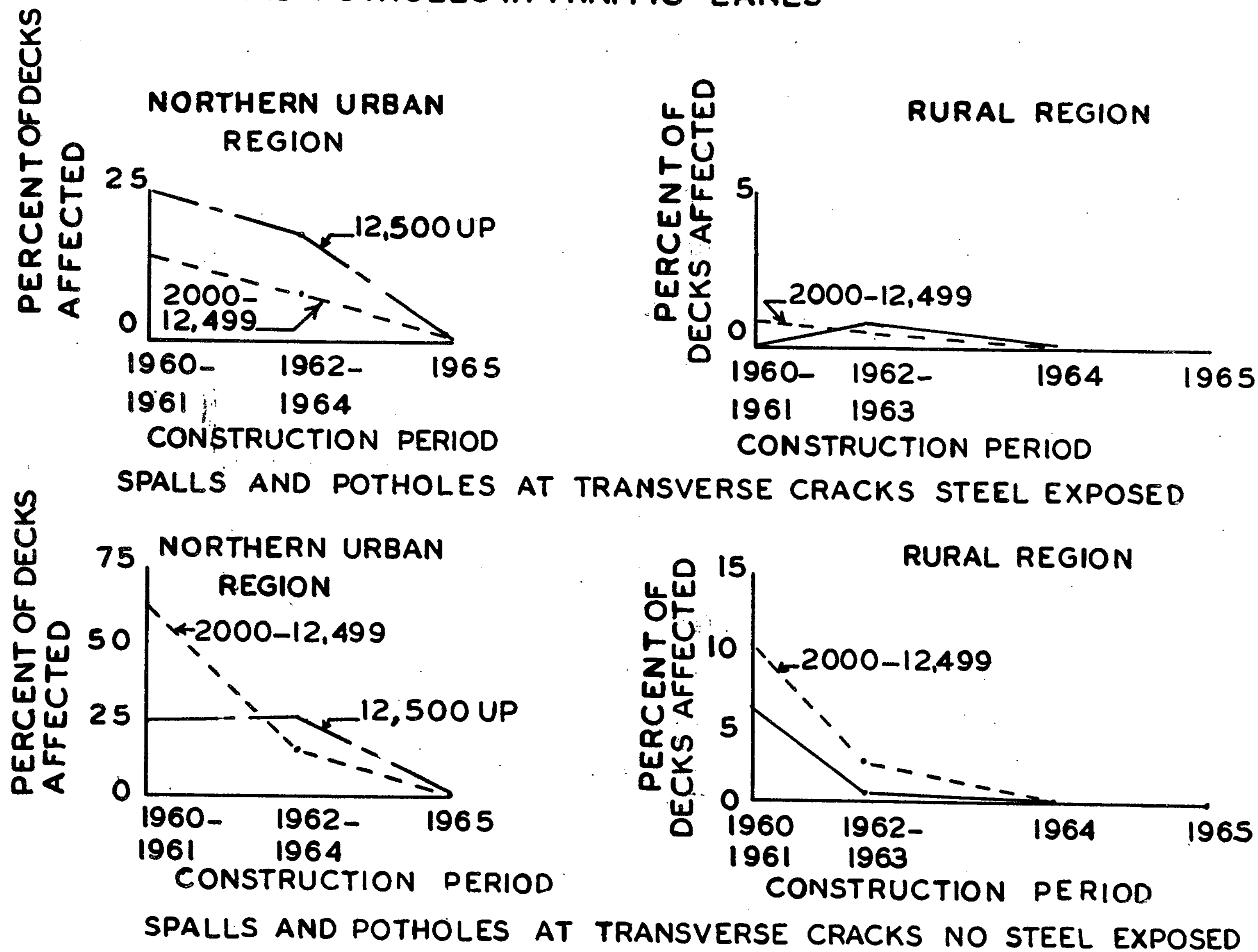
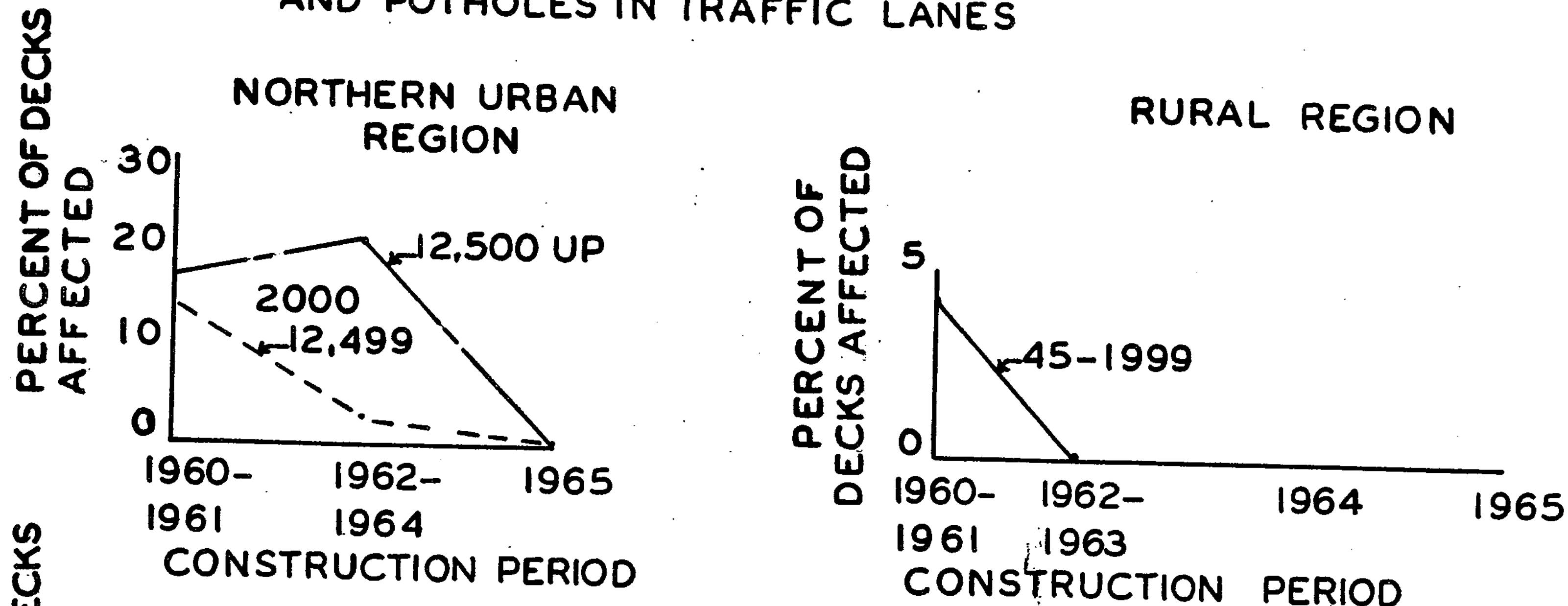
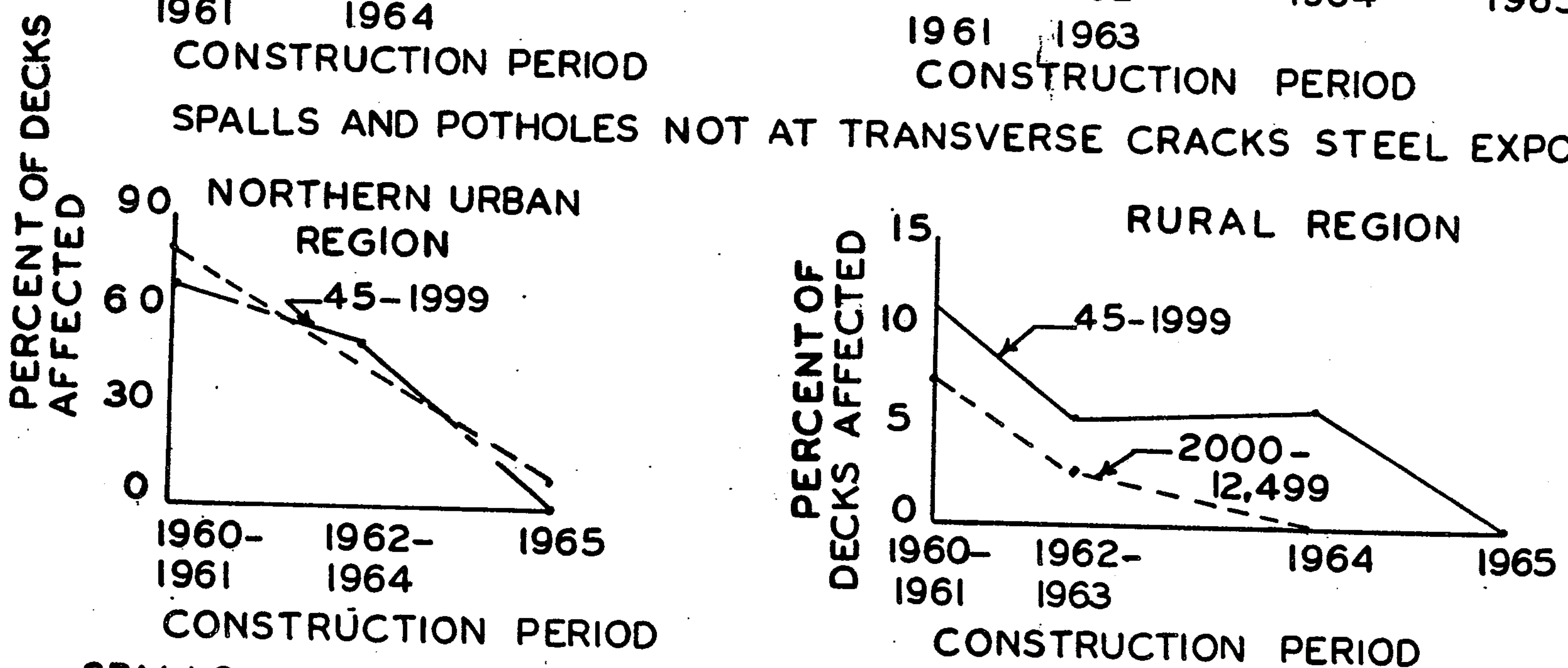


FIGURE 8B GENERAL TRENDS WITH AGE TRAFFIC VOLUME AND REGION OF THE PERCENTAGE OF BRIDGE DECKS REPORTED TO SHOW SPALLS AND POTHOLES IN TRAFFIC LANES



SPALLS AND POTHOLES NOT AT TRANSVERSE CRACKS STEEL EXPOSED



SPALLS AND POTHOLES NOT AT TRANSVERSE CRACKS NO STEEL EXPOSED

TABLE 9.

BRIDGE DECK DETERIORATION IHR-97
SUMMARY OF SPALL AND POTHOLE DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED
1960 AND LATER. YEAR OF CONSTRUCTION AND TRAFFIC VOLUME

NORTHERN URBAN REGION

	1960 - 1961			1962 - 1964			1965					
	45-1999	2,000-12,499	12,500 Up	45-1999	2,000 12,499	12,500 Up	45-1999	2,000 12,499	12,500 Up	Not Open	No Traffic Data	Total
Number of Decks	15	41	28	2	33	62	0	6	2	39	10	238
At Cracks Steel Exposed Percent	0	6 14.6	7 25.0	0	2 6.1	11 17.7	0	0	0	0	4	30
At Cracks No Steel Exposed Percent	6 40	26 63.5	8 29.6	0	5 15.1	19 30.6	0	0	0	1	4	69
Not at Cracks Steel Exposed Percent	1 6.7	6 14.6	5 17.9	0	1 3.0	13 21.0	0	0	0	0	5	31
Not at Cracks No Steel Exposed Percent	11 74.0	34 83	19 67.9	1	15 45.4	32 51.6	0	3	0	4	7	126

TABLE 9. (CONTINUED)

BRIDGE DECK DETERIORATION IHR-97
SUMMARY OF SPALL AND POTHOLE DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED 1960 AND LATER. YEAR OF CONSTRUCTION AND TRAFFIC VOLUME

NORTHERN RURAL, CENTRAL AND SOUTHERN REGIONS

	1960 - 1961			1962 - 1963			1964 - 1965					
	45-1999	2,000-12,499	12,500 Up	45-1999	2,000-12,499	12,500 Up	45-1999	2,000-12,499	12,500 Up	Not Open	No Traffic Data	Total
Number of Decks	98	117	2	148	174	2	83	79	2	85	23	813
At Cracks												
Steel Exposed	0	1	1	1	1	0	0	0	0	0	0	4
Percent		0.9		0.7	0.6							
At Cracks												
No Steel Exposed	6	12	1	1	5	0	0	0	0	1	0	26
Percent	6.1	10.2		0.7	2.9							
Not at Cracks												
Steel Exposed	4	0	0	0	0	0	0	0	0	0	0	4
Percent	4.3											
Not at Cracks												
No Steel Exposed	11	9	1	8	5	0	3	0	0	0	2	39
Percent	11.2	7.7		5.3	2.9		6.4					

Deck Cracking

Counts of cracks of observable width in the top and bottom surfaces of each span inspected were reported in three groupings: transverse cracks part way across, transverse cracks completely across, and longitudinal cracks. The number of deck units(a single span or groups of spans from a single bridge representative of one type of superstructure) affected by each type of cracking is tabulated by district in Table 10, by region in Table 11, and by bridge type in Tables 12 and 13. A tabulation by year of construction, type of structure and traffic volume is available but is considered of too great length for inclusion in this report.

It may be noticed in Tables 10 through 13 that cracks in the under surface are present in many of the deck units affected by top surface cracking, and that the numbers of units affected by top and bottom transverse cracking part way across is closely similar. In the case of transverse cracks completely across, and of longitudinal cracks, more units are reported as affected by top surface cracks. Adverse illumination and difficulty of easy access limit close inspection of slab undersurfaces and may explain a part of the differences, but a comparison of the relative number of top and bottom surface cracks will be of interest because of indications given as to the influence of average tensile strength - representative of average quality of the concrete - in the total amount of cracking experienced.

The percentages of decks affected by one of the three types of cracking shown in Figure 9 and Table 10 do not indicate any very evident regional differences. Observed differences between districts may be accounted for in part by differences in age and type of superstructure, length and severity of service.

The type of superstructure influences the relative number of deck units affected by transverse cracking to a greater degree than do other factors considered. Under this factor are considered the following: (1) continuous length of deck, (2) type of support, i. e., steel beam or girders, concrete girders or concrete slab,

TABLE 10.

CONCRETE BRIDGE DECKS CONSTRUCTED DURING 1960 AND LATER
INITIAL SUMMARY 1966

SUMMARY BY DISTRICT OF THE NUMBER OF BRIDGE DECK UNITS
AFFECTED BY VARIOUS TYPES OF DECK CRACKING

DISTRICT	Number of Deck Units	TRANSVERSE CRACKS				LONGITUDINAL CRACKS	
		Across		Part Way Across			
		Top Side	Underside	Top Side	Underside	Top Side	Underside
Elgin	127	37 (29.1)	24 (18.9)	79 (61.6)	83 (65.5)	12 (9.45)	5 (3.94)
Dixon	204	23 (11.3)	20 (9.8)	95 (46.5)	99 (48.5)	11 (5.49)	3 (1.46)
Ottawa	105	23 (21.9)	9 (8.56)	79 (75.0)	80 (76.1)	23 (21.9)	4 (3.81)
Peoria	101	36 (35.6)	30 (29.6)	76 (75.1)	74 (73.2)	1 (0.98)	0 (0)
Paris	114	17 (14.9)	23 (20.2)	53 (46.5)	67 (58.8)	5 (4.38)	5 (4.38)
Springfield	51	13 (25.4)	3 (5.88)	38 (74.5)	32 (62.8)	8 (1.57)	0 (0)
Effingham	103	8 (7.76)	9 (8.75)	65 (63.1)	68 (66.0)	6 (5.82)	6 (5.82)
East St. Louis	113	1 (8.85)	1 (8.85)	46 (40.7)	34 (30.1)	12 (10.6)	1 (8.85)
Carbondale	93	8 (8.6)	6 (6.45)	42 (45.1)	44 (47.4)	3 (3.23)	0 (0)
Chicago	140	22 (15.7)	7 (5.0)	123 (87.9)	100 (71.5)	2 (1.43)	1 (0.71)
TOTAL	1151	188 (16.3)	132 (11.42)	696 (60.5)	681 (59.0)	83 (7.20)	23 (2.0)

Numbers in parenthesis are the percentage of decks affected in each district.

TABLE 11.

CONCRETE BRIDGE DECKS CONSTRUCTED DURING 1960 AND LATER
INITIAL SUMMARY 1966

SUMMARY BY REGION OF THE NUMBER OF BRIDGE DECK UNITS
AFFECTED BY VARIOUS TYPES OF DECK CRACKING

REGION	Number of Deck Units	TRANSVERSE CRACKS				LONGITUDINAL CRACKS	
		Across		Part Way Across			
		Top Side	Underside	Top Side	Underside	Top Side	Underside
Northern Urban	267	59 (22.1)	31 (11.6)	202 (75.6)	183 (68.6)	14 (5.25)	6 (2.24)
Northern	204	23 (11.3)	20 (9.79)	95 (46.5)	99 (48.5)	11 (5.39)	3 (1.47)
Central	371	89 (24.0)	65 (17.5)	246 (66.4)	253 (68.2)	37 (10.0)	7 (1.89)
Southern	309	17 (5.50)	16 (5.18)	153 (49.5)	146 (47.3)	21 (6.8)	7 (2.16)
TOTALS	1151	188	132	696	681	83	23

Numbers in parenthesis are the percentage of decks affected in each region.

TABLE 12.

BRIDGE DECK DETERIORATION STUDY IHR-97
SUMMARY OF CRACKING DATA BY BRIDGE TYPE FOR CONCRETE BRIDGE DECKS
CONSTRUCTED DURING 1960 AND LATER

TYPE OF BRIDGE	Number of Deck Units	Number of Decks Affected						Percent of Decks Affected					
		TRANSVERSE CRACKS				LONGITUDINAL CRACKS		TRANSVERSE CRACKS				LONGITUDINAL CRACKS	
		Across		Part Way Across				Across		Part Way Across			
		Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side
Continuous Steel Beam Non-Composite	611	133	113	426	449	43	13	21.8	18.5	69.6	73.2	7.3	2.1
Continuous Steel Beam Composite	98	12	9	71	73	4	2	12.2	9.2	72.5	74.5	4.1	2.0
Steel Beam Non-Composite	53	2	0	25	18	7	2	3.8	0	47.2	34.0	13.2	3.8
Steel Beam Composite	76	5	2	39	40	5	1	6.6	2.6	51.4	52.6	6.6	1.3
R. C. Deck Girder (S.S.)	6			3	2								
R. C. Deck Girder Continuous	47	2		24	26	5		4.3	0	51.0	55.3	10.6	0
Pretensioned Precast Concrete Beam (S.S.)	43	5		13	13	4	2	11.6	0	30.2	30.2	9.3	7.65
Pretensioned Precast Concrete Beam Continuous	13			2	2	1	0						
Reinforced Concrete Slab (S.S.)	24	1		1	1	2	1						
Reinforced Concrete Slab Continuous	47			7	1	4		0	0	14.9	21.2	8.5	0
Continuous Plate Girder Non-Composite	61	15	2	41	27	3	1	24.6	3.2	67.2	44.3	4.9	1.6
Continuous Plate Girder Composite	20	3	1	16	15	1							
Plate Girder Non-Composite	10	3		5	2								
Plate Girder Composite	12	1	1	8	4								

TABLE 12. (CONTINUED)

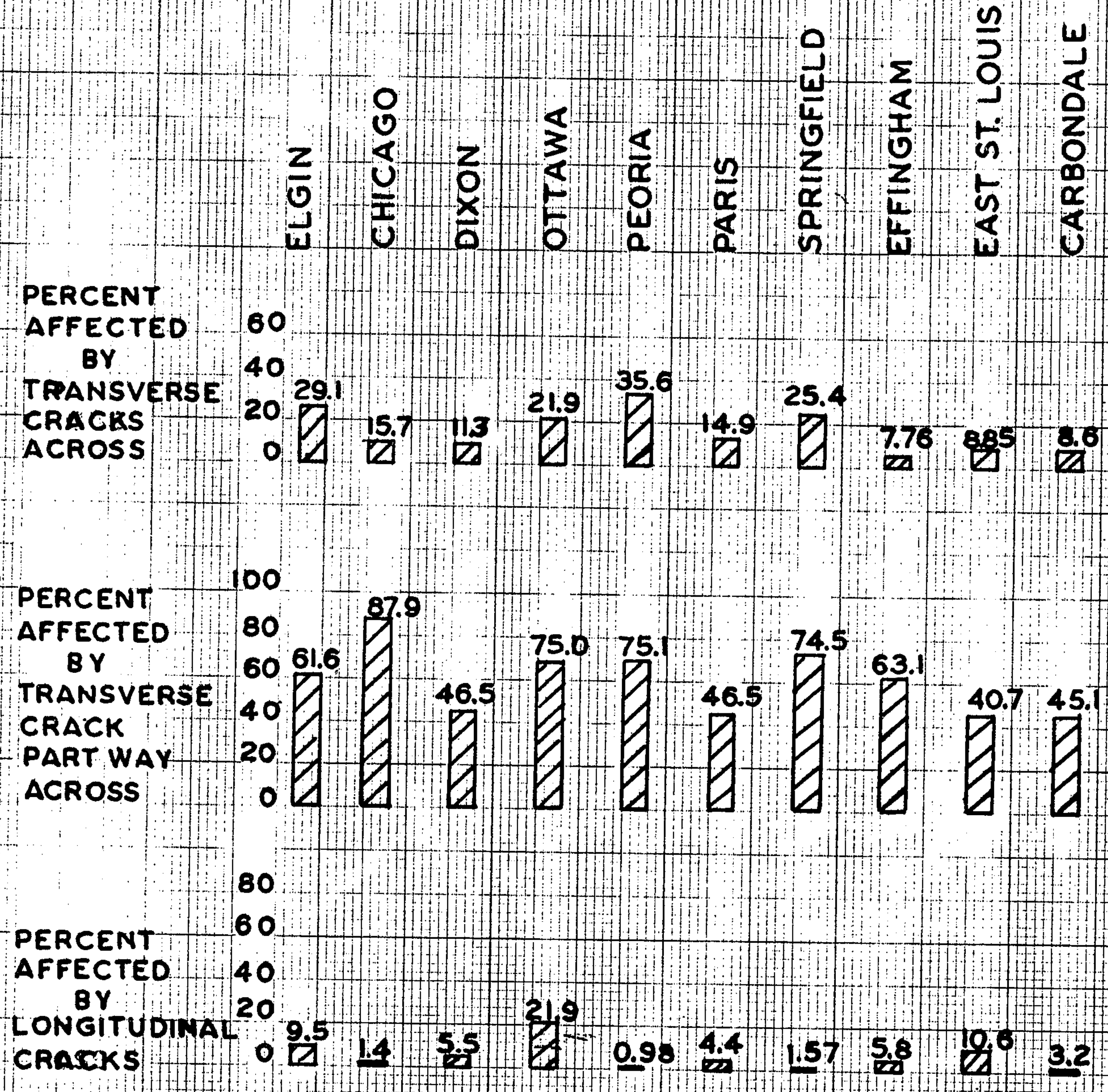
TYPE OF BRIDGE	Number of Deck Units	Number of Decks Affected						Percent of Decks Affected					
		TRANSVERSE CRACKS				LONGITUDINAL CRACKS		TRANSVERSE CRACKS				LONGITUDINAL CRACKS	
		Across		Part Way Across				Across		Part Way Across			
		Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side
Cantilever Plate Girder with Suspended WF Beam End Spans	4			2	2								
Truss	12	4	3	8	2	2	1						
Simple Span Precast Concrete Slab	1				1								
Reinforced Concrete Rigid Frame	2												
Cantilever Beam Span with Suspended End Spans	8	2	1	3	5	1							
Cantilever Girder with Suspended End Spans	2			2		1							
Continuous Concrete Box Girder	1												
	1151	188	132	696	682	83	23						

TABLE 13.

BRIDGE DECK DETERIORATION STUDY IHR-97
DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED DURING 1960 AND LATER
SUMMARY OF DECK CRACKING BY MAJOR TYPE OF SUPERSTRUCTURE

TYPE OF BRIDGE		Number of Decks Affected						Percent of Decks Affected					
		TRANSVERSE CRACKS				LONGITUDINAL CRACKS		TRANSVERSE CRACKS				LONGITUDINAL CRACKS	
		Across		Part Way Across				Across		Part Way Across			
		Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side	Top Side	Under Side
Steel:													
Continuous:													
Non Composite	672	148	115	467	476	46	14	22.0	17.1	69.5	71.0	6.8	2.1
Composite	118	15	10	87	88	5	2	12.7	8.5	73.8	73.6	4.2	1.7
Simple:													
Non Composite	63	5	0	30	20	7	2	8.0	0	47.6	31.8	11.1	3.1
Composite	88	6	3	47	44	5	1	6.7	3.4	53.4	50.0	5.7	1.1
Concrete:													
Beam Type:													
Simple Span	49	5	0	16	15	4	2	10.2	0	32.6	30.6	8.1	4.1
Continuous	60	2	0	26	28	6	0	3.3	0	43.3	46.6	10.0	0
Slab	71	1	0	8	2	6	1	1.4	0	11.2	2.8	8.4	1.4

FIGURE 9 PERCENTAGE OF BRIDGE DECK UNITS AFFECTED BY VARIOUS TYPES OF DECK CRACKING IN THE UPPER SURFACE



and (3) composite action in the case of steel superstructures. These effects may be deduced from inspection of Tables 12 and 13 and Figure 10.

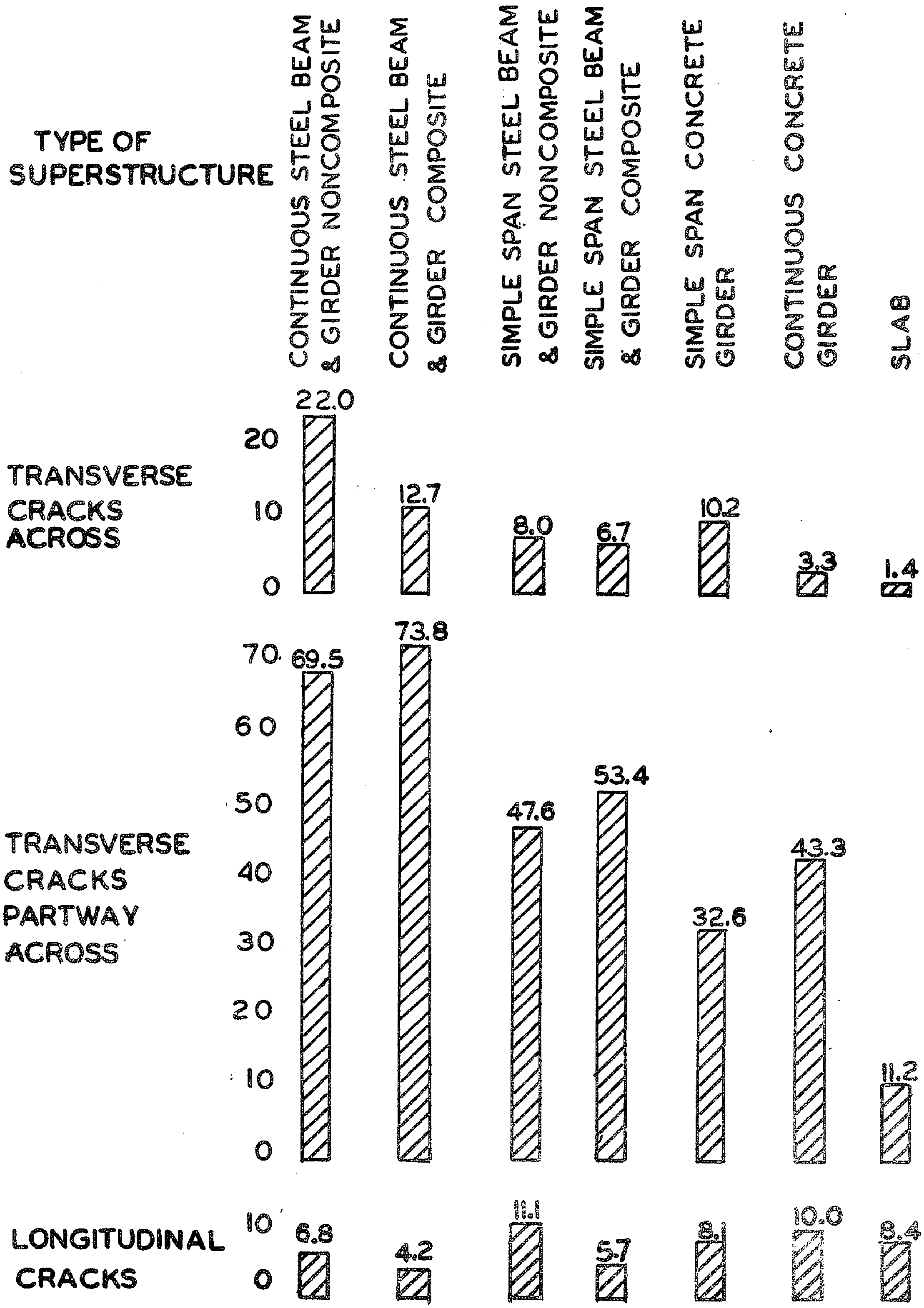
Transverse cracking part way across is more prevalent in deck units of continuous than in deck units of simple span structures. Deck units composite with steel stringers or girders are affected in slightly greater number than are non-composite deck units. Except for continuous concrete girder bridges which approach simple-span steel beam bridges in the relative number of deck units affected by transverse cracking part way across, deck units of concrete bridges are much more resistant to partial width transverse cracking. Units representative of slab bridges are most resistant. Such transverse cracks as may be observed usually occur over the supports of continuous slabs.

Transverse cracks across and longitudinal cracks affect smaller numbers of composite than non-composite deck units. Transverse cracks across appear to affect a substantially larger relative number of simple span than of continuous concrete girder deck units. Longitudinal cracks appear to affect a more consistent fraction of deck units representative of concrete than deck units of steel bridges. In the case of slab bridges, such longitudinal cracks as do occur are likely to occur over top longitudinal bars of large size.

These indications appear to show that deck length, type of support, and presence of shear connectors are of influence in transverse cracking part way across in the order listed. All three factors point to shrinkage as being of prime importance in deck cracking.

The presence of spalls and potholes at transverse cracks with steel exposed is influenced to some degree by the resistance of the deck to transverse cracking. Influence of structure type on spalls and potholes at transverse cracks with no steel exposed is less definite; a greater percentage of simple-span decks are shown as affected.

FIGURE 10 PERCENTAGE OF BRIDGE DECK UNITS AFFECTED BY VARIOUS TYPES OF DECK CRACKING IN THE UPPER SURFACE FOR SEVEN MAJOR TYPES OF SUPERSTRUCTUR



The percentage of decks in each district affected by spalls and potholes is also roughly correlated with the percentage of deck units affected by transverse cracks, as may be seen in the correlation shown in Figure 11.

Patching

The relative numbers of decks which have been patched are included as an indication of earlier deterioration. As might be expected, patching has generally been most frequently reported from those districts and regions having largest percentage of bridge decks affected by scaling, by spalls and by potholes.

Table 14 presents data on patching. The number of decks constructed during the 1960-1964 period and open to traffic are given, together with the number and percentage affected for each District and Region. The number and percentage affected is also given by period of construction and length or severity of service.

Table 15 indicates that the type of structure has little or no apparent influence on patching.

Retarder and Early Loading

Addition of certain retardants to the concrete mixture and use of heavy equipment on decks during construction and before they were opened to regular traffic were both expected to affect the possibility of cracking.

Since bridges with steel superstructures are noticeably more subject to deck cracking, 121 such deck units not open to traffic were grouped according to reported presence or absence of cracks, use or non-use of retardant, and use or non-use of heavy equipment on the deck. This grouping appears in Figure 12.

The use of heavy equipment on the deck during construction and before the deck is opened to regular traffic is not shown to exert a pronounced influence. If the use of heavy equipment is alone considered, it appears that the chances of deck cracking are about even.

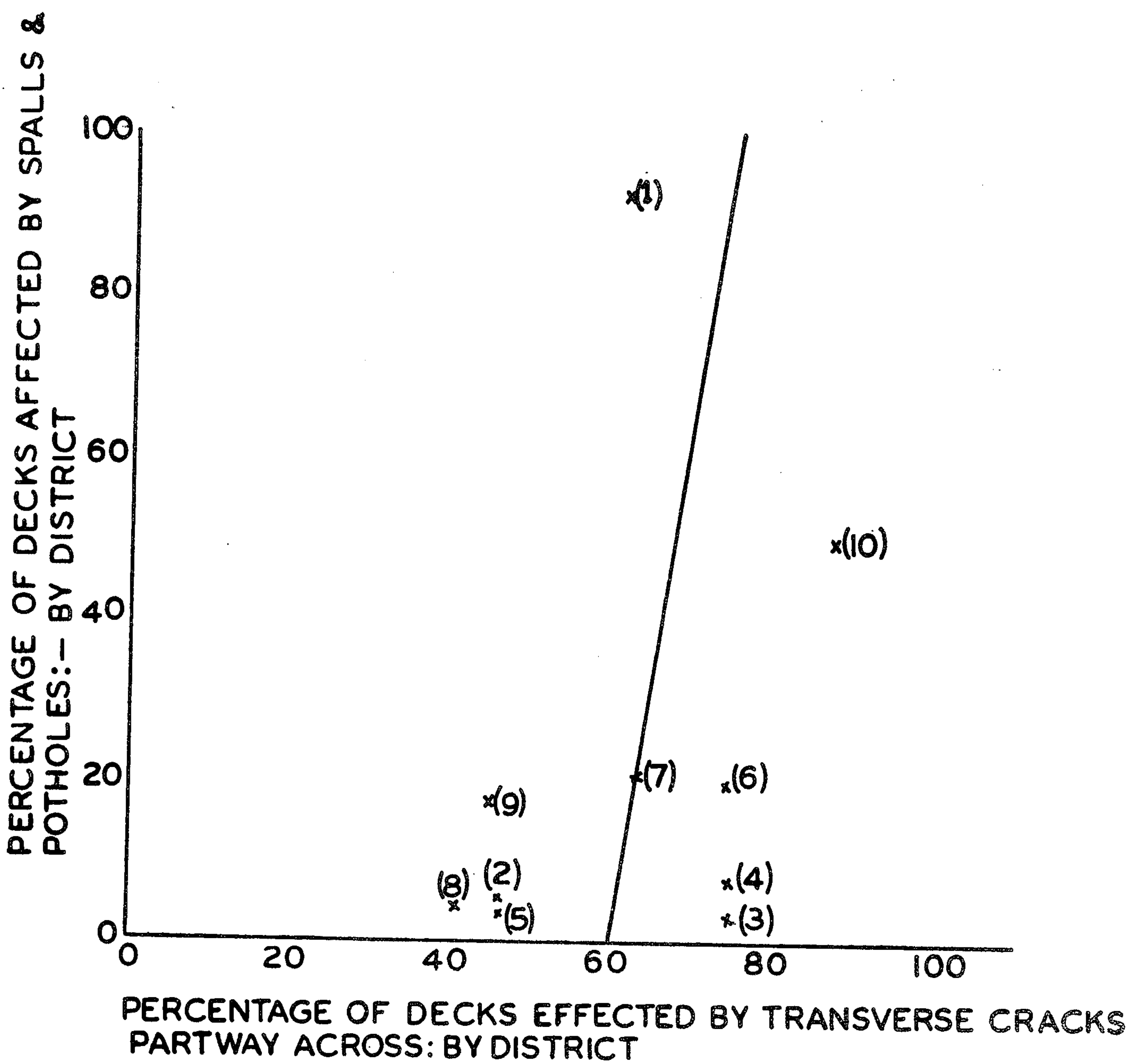


FIGURE 11 CORRELATION OF THE PERCENTAGE OF BRIDGE DECKS AFFECTED BY SPALLS & POTHOLES WITH THE PERCENTAGE OF BRIDGE DECKS AFFECTED BY TRANSVERSE CRACKS

TABLE 14.

BRIDGE DECK DETERIORATION STUDY IHR-97
SUMMARY OF PATCHING DATA BY DISTRICT, REGION AND YEAR OF CONSTRUCTION
FOR CONCRETE BRIDGE DECKS CONSTRUCTED 1960 AND LATER

DISTRICT	Decks Built 1960 - 1964 Open to Traffic	Number Affected	% of Decks Affected
Chicago	116	12	10.3
Elgin	75	4	5.33
Dixon	145	1	0.69
Ottawa	101	3	2.97
Peoria	78	0	---
Paris	91	0	---
Springfield	38	1	2.63
Effingham	68	2	2.94
East St. Louis	78	6	7.69
Carbondale	70	3	4.28
REGION			
Northern Urban	191	16	8.38
Northern (Total)	336	17	5.07
Central	308	4	1.3
Southern	216	11	5.1
Total	860	32	

Construction Period	Number Constructed Open to Traffic	Number Affected	Percent Affected
1960-61	301	20	6.64
1962-63	356	8	2.25
1964	170	4	2.35
1965	67	0	--
	894		
Not Open	124		
Not Reported	33		
	1051	32	

TABLE 15.

BRIDGE DECK DETERIORATION STUDY IHR-97
SUMMARY OF PATCHING DATA FOR CONCRETE BRIDGE DECKS CONSTRUCTED
1960 AND LATER: TYPE OF SUPERSTRUCTURE

STRUCTURE TYPE	Number Affected	Deck Units Open to Traffic	Percent Affected
Continuous Steel Beam Non-Composite	13	549	2.4
Continuous Steel Beam Composite	3	72	4.1
Steel Beam Non-Composite	1	21	4.8
Steel Beam Composite	2	43	4.7
Pretensioned Precast Concrete Beam (SS)	3	38	7.9
Pretensioned Precast Concrete Beam Continuous	1	43	2.3
Reinforced Concrete Slab Continuous	1	40	2.5
Continuous Plate Girder Composite	3	12)	
Plate Girder Composite	1	4)	
Cantilever Plate Girder with Suspended WF Beam	2	4)	Note
End Spans		)	(1)
Truss	1	9)	

Note (1) Percentages are omitted because of small size of sample.

FIGURE 12 EFFECT OF RETARDER AND USE OF HEAVY EQUIPMENT ON DECK DURING CONSTRUCTION ON CRACKING OF BRIDGE DECKS NOT OPEN TO TRAFFIC-STEEL BRIDGES

	CRACKS REPORTED	NO CRACKS REPORTED
NO RETARDER HEAVY EQUIPMENT	6	12
RETARDER HEAVY EQUIPMENT	12	6
NO RETARDER NO HEAVY EQUIPMENT	15	15
RETARDER NO HEAVY EQUIPMENT	34	21

NUMBER OF DECKS OF STEEL BRIDGES NOT OPEN TO TRAFFIC GROUPED BY USE OF RETARDER AND USE OF HEAVY EQUIPMENT ON DECK

NO RETARDER	21 43.7%	27 56.3%
RETARDER	46 63%	27 37%

NUMBER AND PERCENTAGE OF DECKS OF STEEL BRIDGES NOT OPEN TO TRAFFIC GROUPED BY USE OF RETARDER

These data indicate as shown in Figure 12 that the use of retarder may increase the tendency for deck cracking to occur.

Before final conclusions are drawn, however, it will be necessary to consider the effects of durability characteristics of coarse aggregate, casting and curing temperatures, water-cement ratio, and other quantitative variables which may well have an influence on deck cracking.

Summary

Scaling was most frequently reported from the Northern Urban Region and more common in the Southern than in the Central Region. Based on 860 decks constructed during the years 1960 to 1964 and open to traffic, and inclusive of all bridge decks showing scale, the following percentages of reported decks were affected: 39 per cent in the Northern Urban Region, 19 per cent elsewhere in the Northern Region, 10 per cent in the Central Region, and 24 per cent in the Southern Region.

Bridge decks constructed during the spring and summer months appear to be more susceptible to scaling than those constructed during the fall and winter months. Also, chances of early development of scaling appear to be greatest when the decks are castunder conditions of hot weather requiring the use of retarders.

A comparison of this current survey with one conducted in 1960 is of interest.(1) From among the group of 860 bridges currently under study, scaling was reported as present on 151 or 17.5 per cent in traffic lanes, 64 or 7.5 per cent in gutter sections and 50 or 5.8 per cent in safety curbs. The 1960 survey included 503 bridges which had not been modified since construction during the period of 1947 to 1959. Scaling in varying degree was found in 6 to 13 per cent of these in the deck, gutter, hub-guard and sidewalk. Further, about the same percentage of bridges constructed between 1954 and 1959 had suffered scaling damage as had those constructed between 1948 and 1953. Allowing for some differences between the two surveys in the basis for

(1) A survey of Air-Entrained Structures in Illinois, J. D. Lindsay, HRB Bulletin 323, page 13.

computation of percentages, no general decrease is indicated in the relative number of decks subject to scaling after only a few years service.

Spalling and potholing of bridge decks associated with corrosion of reinforcement in the top mat have become a major maintenance problem in recent years. Of 927 bridge decks open to traffic, 194 or 21 percent displayed spalling and potholing, inclusive of 49 decks or 5.3 percent with steel exposed, most of which were reported from the northern urban region.

The length of service and to a lesser degree the severity of service appear to influence the relative frequency with which both scaling and spalls and potholes were reported. Spalls and potholes associated with transverse cracks were more common on decks of steel beam or steel girder bridges.

Transverse cracking extending part way across the deck was most notably influenced by the type of stringer or beams supporting the deck (i.e., steel or concrete), continuous length of the deck and, in the case of decks of steel beam or steel girder bridges, the presence of shear connectors. Decks of concrete girder and more notably concrete slab bridges showed better resistance to transverse cracking than did decks supported by steel members.

Approximately 60 percent of all bridges included in the study were reported to display transverse cracks of observable width extending part way across the deck slab. Closely comparable numbers were observed in top and bottom surfaces. Transverse cracks extending across the entire deck affect a smaller percentage (16.3) of the total number of decks reported as do longitudinal cracks which affect only 7.2 percent of the total.

Use of retarder or conditions which accompany its use appear to exert a greater influence on early transverse cracking part way across than does use of heavy construction equipment on decks prior to opening decks to regular traffic.

The association of different kinds of cracking on individual decks of non-composite steel beam bridges was most notably influenced by the year of construction and influenced to some degree by traffic volume, but of less than evident influence were skew, use or non-use of retarder, season of construction, or use of heavy equipment on deck.

The degree to which factors discussed in this report appear to be of influence on major types of deterioration is indicated in Table 16.

PHASE II

This phase is to be a quantitative study consisting of further tabulations of data to determine the severity of the various types of deterioration, and to determine possible relationships between the various types of deterioration and specific variables of construction and materials as well as those variables which were not eliminated from further study during Phase I.

Discussion of Factors

It is intended that further study consider only factors likely to exert an evident influence on deterioration. Some factors yet to be studied are expressed as numerical values. These include slump, water-cement ratio, air content, cement factor, casting temperatures, and curing temperatures. Factors expressed numerically should meet three requirements. First, reported values should represent to some scale influence of the factor on observed condition. Concrete data does not completely fulfill this requirement because deterioration most frequently is local in nature and does not, except for cracking, affect the entire deck. Further, values for concrete data are more representative of overall average quality of deck concrete than representative of quality of concrete in locations affected. Second, the range of values for the factor should allow some grouping of data; and third, the groups so formed should include data from enough decks to be indicative of average rather

TABLE 16 CONCRETE BRIDGE DECKS CONSTRUCTED DURING 1960 AND LATER — INITIAL SUMMARY 1966

FACTOR	SCALING	SPALLS & POTHOLES	CRACKING	PATCHING
1 DISTRICT	NOTE (3)	NOTE (3)	NOTE (1)	NOTE (3)
2 REGION	NOTE (3)	NOTE (3)	NOTE (1)	NOTE (3)
3 TYPE OF STRUCTURE		NOTE (2)	NOTE (3)	NOTE (1)
4 YEAR OF CONSTRUCTION	NOTE (3)	NOTE (3)		NOTE (3)
5 TRAFFIC	NOTE (3)	NOTE (3)		
6 USE OF RETARDER	NOTE (2)		NOTE (2)	
7 USE OF HEAVY EQUIPMENT ON STRUCTURE BEFORE IT WAS OPENED TO REGULAR TRAFFIC			NOTE (1)	
8 SEASON DURING WHICH DECK WAS CONSTRUCTED	NOTE (2)			

NOTES

(1) PRELIMINARY EVALUATION INDICATES THIS FACTOR IS NOT OF CONSPICUOUSLY EVIDENT INFLUENCE

(2) PRELIMINARY EVALUATION INDICATES THIS FACTOR MAY HAVE SOME INFLUENCE

(3) PRELIMINARY EVALUATION INDICATES THIS FACTOR HAS EVIDENT INFLUENCE

than special conditions. For example, although the cement factor is of importance, for purposes of analysis it does not meet these requirements either by the range - a value of 1.5 is most frequently reported with values from 1.6 to 1.75 reported occasionally - or by the small size of the group of decks representative of cement factors greater than 1.63.

Other factors are expressed qualitatively. These include source of aggregate, method of curing, brand of cement, brand of air entraining agent, and brand of retarding agent. Factors expressed qualitatively should satisfy two requirements. They should consist of more than one subdivision, and subdivisions should include data from enough decks to represent average conditions when considered as a group.

Most qualitative factors permit grouping of data. The factor "method of curing" is an exception since curing cover is most frequently wetted burlap. In the case of individual subclasses of some other factors, the limited number of reported examples reduce the possibility of assessment of their influence.

Although generally considered to be of importance, of less than evident influence through uniformity of application are cement factor, method of curing concrete, and linseed oil treatments. Additional factors are either not generally suspected or more successfully of identifiable influence on deterioration in laboratory studies or carefully controlled field exposure tests. These include brand and amount of air entraining agent, source of fine aggregate, and source of cement.

Length and severity of service seem to have some influence on deterioration only where traffic is very heavy. Even with very heavy traffic, the influence of severity of service on deck cracking appears indirect and contingent on other factors including: type of structure, length of span, presence of shear connectors in the case of decks on steel stringers, depth of concrete cover above uppermost reinforcement, and possibly type of coarse aggregate and water-cement ratio.

Proposed Further Study

Including factors presented in Table 15 which exhibit some evident influence on deterioration, and additional factors which appear to warrant further consideration, the following factors and levels are proposed for evaluation with respect to the severity of deterioration.

Factor		Levels
Region	(3)	Northern Central Southern
Year of Construction	(3)	(60-61) (62-63) (64-65)
Traffic	(4)	Not open, 45-1999, 2000-12,499, 12,500 up
Curing Temperatures	(2)	Minimum below 45°, Maximum above 80°.
Source of Coarse Aggregate	(4)	Gravel Sources - present in decks with little or no deterioration. Gravel Sources - present in decks with moderate deterioration. Crushed Stone Sources - present in decks with little or no deterioration. Crushed Stone Sources - present in decks with moderate deterioration.
Air Content	(3)	Below 4.6 4.7-5.2 5.3 and up
Water-cement Ratio	(2)	Below 4.6 Above 4.7
Type of Structure	(4)	Simple Span Steel Beam Noncomposite Simple Span Steel Beam Composite Continuous Steel Beam Noncomposite Continuous Steel Beam Composite

Cumulative distributions of air content are prepared for low end of the range, average and high end of the range representing decks in each district reported as free of scaling and decks in each region reported as affected by scaling, spalls and potholes.

Cumulative distributions are also prepared for theoretical and actual values reported for water-cement ratio. These also represent decks in each district reported as free of scaling and decks in each region reported as affected by scaling, spalls and potholes.

It has been observed that an occasional deck in the southern region constructed using dark grey limestone aggregate will exhibit scaling or flaking of mortar from deck surfaces, that fragments of coarse aggregate are sometimes found embedded in these flakes. Data relating to the comparative durability of coarse aggregates used in the southern region and throughout Illinois will be secured and the influence of coarse aggregate source on deck condition will be evaluated.

It is anticipated that additional explorations or modifications of the proposed work will develop as the work on this phase of the study progresses.

APPENDIX A

DATA FORM FOR CONCRETE BRIDGE DECKS CONSTRUCTED DURING 1960 AND LATER

District ______________
______Rte. ______________
Section______________
Project ______________
County______________

1. Type of bridge: ____

2. Composite ________; Non-composite ____________

3. Right angle _________; Skewed _________; Angle of Skew _________

4. Number and length of spans ________________________________

5. Date concrete was cast (day, month, and year):

   Traffic lanes, from ______________ to ______________
   Gutter sections, from ______________ to ______________
   Safety curbs, from ______________ to ______________

6. Sequence of casting concrete:______________________________
____
____

7. Ambient temperatures:

   During placing concrete, from ______________ to ______________
   During next seven days, from ______________ to ______________

8. Concrete data:

	Traffic Lanes	Gutter Sections	Safety Curb
Cement factor, bbls./cu.yd.	________	________	________
Water/cement ratio, gals./sack:			
Theoretical	________	________	________
Actual	________	________	________
Slump:			
Average	________	________	________
Range	________	________	________
Air-entraining agent:			
Brand Name	________	________	________
fl.ozs./cu.yd.	________	________	________

ADDITION TO

DATA FORM FOR CONCRETE BRIDGE DECKS CONSTRUCTED DURING 1960 AND LATER

8. Concrete data:		Traffic Lanes	Gutter Sections	Safety Curbs
Air content:				
	Average	____________	____________	____________
	Range	____________	____________	____________

8. (CONTINUED)

	Traffic Lanes	Gutter Sections	Safety Curbs
Retarding admixture:			
Brand Name	______	______	______
fl. ozs./sack cement	______	______	______
Source of materials:			
Coarse aggregate	______	______	______
Fine aggregate	______	______	______
Cement	______	______	______

9. Method of curing concrete:______________________________

____

10. Linseed oil treatments:

First treatment: Date__________, No. of applications ______, Tot.Gal/Sq.Yd.____

Second treatment: Date__________, No. of applications ______, Tot.Gal/Sq.Yd.____

11. Date bridge opened to traffic ______________________________

12. Vehicles per day using bridge: Total __________ Commercial __________

13. Was heavy equipment permitted to use the bridge during construction and before it was opened to traffic? Yes _____, No __________

14. Field inspection data:

a. Date inspection was made: ______________________________

b. Amount of scaling present:

		Traffic Lanes	Gutter Sections	Safety Curbs
(1) Number of locations of scaling	S_1	______	______	______
	S_2	______	______	______
	S_3	______	______	______
	S_4	______	______	______
(2) Total area of scaling, sq. ft.	S_1	______	______	______
	S_2	______	______	______
	S_3	______	______	______
	S_4	______	______	______

14. (CONTINUED)

	Traffic Lanes	Gutter Sections	Safety Curbs
(3) Per cent of total	S_1 ______	______	______
	S_2 ______	______	______
	S_3 ______	______	______
	S_4 ______	______	______

c. Spalling and pot holing:

	Traffic Lanes	Gutter Sections	Safety Curbs
(1) Number at transverse cracks:			
with steel exposed	______	______	______
no steel exposed	______	______	______
(2) Number not at transverse cracks:			
with steel exposed	______	______	______
no steel exposed	______	______	______
(3) Total number of spalls and pot holes	______	______	______

d. Number of transverse cracks extending across bridge floor:

Top-side:		Under-side:	
Span 1	______	Span 1	______
Span 2	______	Span 2	______
Span 3	______	Span 3	______
Span 4	______	Span 4	______

e. Number of transverse cracks extending part way across bridge floor:

Top-side:		Under-side:	
Span 1	______	Span 1	______
Span 2	______	Span 2	______
Span 3	______	Span 3	______
Span 4	______	Span 4	______

f. Number of longitudinal cracks in bridge floor:

Top-side:		Under-side:	
Span 1	______	Span 1	______
Span 2	______	Span 2	______
Span 3	______	Span 3	______
Span 4	______	Span 4	______

14. (CONTINUED)

g. Length of longitudinal cracks in bridge floor, ft.

		Avg.	Max.	Min.
Top-side:	Span 1	________	________	________
	Span 2	________	________	________
	Span 3	________	________	________
	Span 4	________	________	________
Under-side:	Span 1	________	________	________
	Span 2	________	________	________
	Span 3	________	________	________
	Span 4	________	________	________

h. Amount of patching that has been performed:

Number of locations ______________, Total sq. ft. ________________

j. Remarks (note any unusual conditions of bridge deck deterioration):

____

____

____

____

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