1811

BRIDGE DECK PERFORMANCE IN VIRGINIA

Based on the PCA-BPR Cooperative Study Conducted in 1961 and a Resurvey Conducted in 1970 as a Part of a Virginia Study of Bridge Finishing Methods.

by

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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1813

SUMMARY

One of the most comprehensive programs for the evaluation and definition of the performance of concrete in bridge decks was that undertaken cooperatively by the Portland Cement Association, the Bureau of Public Roads and eight states distributed throughout the United States. Detailed studies of a few bridges were made in four states and surveys were made on from 100 to 150 bridges in each of eight states including Virginia. These bridges were randomly selected to represent all bridges within the state. The results of the detailed and random surveys have been reported.

The Research Council's special study of bridge deck concrete included observation of construction and sampling on 17 structures distributed throughout the state with the exception of the easternmost (Suffolk) and westernmost (Bristol) highway construction districts. These decks were constructed during the spring and summer of 1963 under specifications, subsequently upgraded, which are now adjudged to produce concrete of "borderline" performance in bridge decks. These decks have been under traffic for six winters. Because of the similarity of the objectives of the two studies it was deemed desirable to include during the survey of the 17 bridges of the Research Council's project a resurvey of the structures included in the PCA — BPR survey last inspected in 1961.

The purpose of the resurvey was twofold:

1. To assess the condition of the randomly selected group of bridges included in the PCA — BPR study and the change in their condition during the period 1961-1970 (the change will serve as a basis against which to compare the performance of the 17 bridges in the Council's research study during approximately the same time span), and
2. To establish the change in condition of the decks, particularly with regard to the further development of surface spalling to provide information which might allow a better understanding of the mechanics of this phenomenon.

The bridges were resurveyed in 1970 using the same techniques utilized in the original survey. Based upon analyses of the results the following conclusions and recommendations are drawn:

Conclusions

(1) Listed in order of decreasing frequency, the defects observed during the 1970 resurvey were scaling, cracking, popouts, spalling, and rusting. This is the same order as was reported for the initial survey in 1961.

(2) The percentage of spans affected by each of the defects increased between surveys. Considering all defects except those in the lowest severity category of each classification, scaling increased from 13 to 31 percent, cracking from 3 to 13 percent, and spalling from 0 to 6 percent. Changes in the other defects were insignificant. These changes are believed to be reasonable in view of the environmental factors and the specification requirements, subsequently upgraded, which existed at the time of construction.

(3) The types of cracking observed in 1970 in decreasing order of frequency were transverse, random, pattern, longitudinal, and diagonal. No "D" cracking has been found in either of the Virginia surveys, or nationwide.

(4) The order of frequency of defects from the sample in the random survey as well as from the smaller sample included in the Council's study of finishing methods on bridges exposed for about the same period as those in the random survey was approximately the same and the percentages of spans affected by each type of defect agreed closely. The percentages of spans showing the various types of cracking also agreed closely.

(5) Because the details concerning the construction of the decks included in the random survey are not available, correlations of the materials and construction characteristics with performance is not possible. The close agreement between the performance of the decks in the random survey and those in the Council's finishing study, for which detailed observations were made during construction, indicates that causative relations developed from that study can be extrapolated to the performance of the larger sample.

(6) Analyses of weather data developed in connection with this survey indicate the wide variety of environments to which Virginia's bridge decks are subjected concomitant with the variation in locally available materials, and emphasize the difficulties of meeting these variable conditions with a single specification applied statewide.

(7) The agreement among the results from surveys conducted at different times and on different samples validates the survey methodology and sampling plan developed for the original survey.

(8) Action taken in 1966 to upgrade specifications for bridge deck concrete (see Table VII) included upgraded requirements for entrained air content, and water-cement ratio, both of which should greatly reduce the incidence of the most prevalent defect observed in the survey, namely scaling.

(9) Although not documentable, the comparatively low frequency of surface spalling when compared with performance in the other states included in the survey is probably related to the provision of 1-11/16" clear cover reinforcement. Adequate cover, per se, is not a complete solution to the problem of surface spalling since the quality of concrete is also important, but there is no evidence to support the belief that the concrete quality was significantly better in Virginia than in other states.

Recommendations

(1) In view of the changes in specification requirements and construction techniques initiated in 1965, it would be of value to assess the performance of decks constructed under the new requirements. The concurring results from the random study and finishing study suggest that the approach used in either study would be valid.

(2) The variety of physical and climatological characteristics confronting the state suggest that efforts be made toward a modular and regional specification, not only for bridge decks but for other applications as well. One phase of this would be to refine the characterization of the environments to which concrete is exposed under field conditions.

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INTRODUCTION

In responding to a questionnaire survey made in 1955 by the Highway Research Board, bridge maintenance engineers rated concrete deterioration fourth in order of importance among the problems requiring their attention and expenditures for correction. In 1967 responses to a similar survey indicated that deck deterioration was rated first. The accelerated deck deterioration during this period has generally been attributed to the greatly increased use of deicing chemicals to maintain bare pavements as well as to increased traffic frequencies and loads. The severe work load placed on inspection forces by rapidly expanding construction volumes associated with the advent of the interstate system has also been blamed for materials and construction deficiencies.

Concomitant with the increased awareness of the "deck problems", numerous research efforts were initiated to define causes and to suggest corrective measures. Among these efforts was the Research Council's study to compare the properties of fresh concrete with those after hardening (Newlon 1963). Partial results from this project have been reported (Hilton, Newlon, and Shelburne 1965) and drafting of a final report is in progress.

One of the most comprehensive programs for evaluation and definition of the "deck problems" was that undertaken cooperatively by the Portland Cement Association, the Bureau of Public Roads and eight states distributed throughout the United States. Detailed studies of a few bridges were made in four states and these have been reported (Kansas 1965; Michigan 1965; California 1967; Missouri 1968). As a part of this program, surveys were made on from 100 to 150 bridges in each of eight states including Virginia. These bridges were randomly selected to represent all bridges within a state. The results of these random surveys have been reported (BPR — PCA 1969) and the entire project summarized (BPR — PCA 1970).

The data from this research are voluminous but some important results are summarized in Table I.

TABLE I

FREQUENCY OF OCCURRENCE IN PERCENT OF THREE MOST COMMON DEFECTS OBSERVED IN THE PCA — BPR STUDY

Defect	7 States	Virginia
Cracking (all types)	69.7	33.2
Spalling	8.1	0.4
Scaling	22.9	43.1

As compared with those in the other states, the bridges in Virginia showed less cracking, substantially less spalling, and significantly more scaling. The lower incidence of cracking was attributed to a greater proportion of simple spans in the Virginia sample. It was also concluded that the higher frequency of scaling was due to the comparatively late adoption of air entrainment in the state. It is interesting to note that the other southern state, Texas, which did not use air entrained concrete, also showed a high incidence of scaling, while Minnesota, with a much more severe climate but also a longer utilization of air entrainment, showed the lowest incidence of scaling of any of the states (excluding California).

While spalling was the least common of the three major defects, it was in the words of the final report "without doubt — the most serious and troublesome kind of bridge deck distress". No reasons for the very low incidence of spalling in the Virginia decks were offered. In the nine years since the field surveys were conducted, concerns have been expressed nationally that spalling is becoming more prevalent, and several significant cases in Virginia have required major repairs. Unpublished reports from California indicate that spalling, which was not a significant problem in 1961, now is one.

The Research Council's special study of bridge deck concrete included observation of construction and sampling on 17 structures distributed throughout the state with the exception of the easternmost (Suffolk) and westernmost (Bristol) highway construction districts. These decks were constructed during the spring and summer of 1963 under specifications, subsequently upgraded, which are now adjudged to produce concrete of "borderline" performance in bridge decks. These decks have been under traffic for six winters. Because of the similarity of the objectives of the two studies it was deemed desirable to include during the survey of the 17 bridges of the Research Council's project a resurvey of the structures included in the PCA-BPR survey last inspected in 1961.

PURPOSE AND SCOPE

The purpose of the resurvey was twofold:

1. To assess the condition of the randomly selected group of bridges included in the PCA — BPR study and the change in their condition during the period 1961 - 1970 (the change will serve as a basis against which to compare the performance of the 17 bridges in the Council's research study during approximately the same time span), and

2. To establish the change in condition of the decks, particularly with regard to the further development of surface spalling to provide information which might allow a better understanding of the mechanics of this phenomenon.

PROCEDURE

Each state cooperating in the PCA — BPR survey used a standard investigation procedure. A copy of the survey form and definitions utilized are given in the Appendix.

The PCA — BPR Method of Inspection was utilized throughout the resurvey. Data were collected in a manner which permitted evaluation of the deterioration on each span of each bridge as well as for the bridge deck as a whole. In this procedure, scaling, spalling, cracking, rusting, and popouts are the types of deterioration emphasized.

Scaling is reported as a percentage of the span's deck area for the average scaled condition and simultaneously the most severe scaling condition on each span is noted. Surface abrasion is included in scaling where a mixture of the two occurs. Scaling is defined as light, medium, heavy, or severe. Surface spalling is recorded as the number of large or small spalls on the span. Generally, any spall smaller than a foot in length or diameter is considered small.

The cracking is recorded by type and severity. A few cracks per span is classified as light. A large amount of cracking is considered heavy, and an intermediate condition is defined as medium cracking. The types of cracking are transverse, longitudinal, diagonal, pattern or map, random, and "D" cracking. When the bridge span inspected has a skew, cracking parallel to the direction of the skew is classified as transverse.

Joint spalls were recorded as to their position on the bridge deck and their size or length along the joint. Rusting was noted as the number of rust spots, while popouts were listed as few or many in accordance with the inspector's opinion of how numerous they appeared on the bridge span deck.

Before the bridges were inspected for evidences of deterioration, several highway research engineers, laboratory technicians, and the authors performed preliminary practice inspections on local bridge decks. The object of this was to try to achieve the most uniform and accurate rating of the deterioration by each person individually analyzing the bridge deck and then comparing respective estimates of the amounts and types of deterioration. Differences in interpretation were reconciled and observation techniques refined. In this way, a consistent definition of the several types of deterioration could be obtained.

Following these preliminary practice inspections, the junior authors performed all of the field inspections of these bridge decks. On the first inspection trip, an experienced concrete technician accompanied them to aid in the initial inspections and to refine the observation techniques.

In the 1961 PCA — BPR survey in Virginia 140 bridges comprising 452 spans were randomly chosen for inspection. In 1970 sixty-six bridges comprising 206 uncovered spans were available for the resurvey. The important characteristics of these bridges are given in Table II.

TABLE II

SPAN CHARACTERISTICS

Characteristics		Number of Occurrences	
		1961	1970
Bridges	Covered	56	14
	Uncovered	84	66
	Total	140	80*
Spans	Covered	190	42
	Uncovered	262	206
	Total	452	248*
Year Built*	1940-1947	8	7
	1948-1955	112	87
	1956-1961	142	112
Traffic Volume**	1 - 750 ADTC	115	113
	751 - 7500 ADTC	114	66
	> 7500 ADTC	33	27
Span Length**	< 45 ft.	139	111
	45 to 90 ft.	118	90
	> 90 ft.	5	5
Air Entrainment**	Specified	134	96
	Not Specified	126	108
	Unknown	2	2

*Four bridges comprising 14 spans were demolished for relocation between the two surveys.

**Uncovered spans only.

After all data had been collected, a computer program was written in the algol language for the Burroughs 5500 computer at the University of Virginia. Prior to analyzing the resurvey data, the program was applied to those obtained for the 1961 survey published in the PCA — BPR Random Survey Report (BPR — PCA 1969). The original field data sheets were available so that reproduction of the published results was used as a check on both the computer program and the data analysis. After this check was obtained, the new data from the resurvey was inserted into the program and new results obtained by the same procedure as was utilized in 1961.

RESULTS

General

The results are summarized in Table III. The format is the same as that used in Table 2B of the PCA — BPR report (BPR — PCA 1969) so that comparisons can be easily made. In Table IV, the same data are presented but spans with defects classified in the least severe category have been combined with those showing no defects. It is believed that this grouping permits a more realistic comparison between the results of the two surveys and minimizes the differences attributable to judgments of the individuals conducting the surveys. For example, the classifications "light scaling" and "light pattern cracking" depend strongly on the orientation of the inspectors. It is reasoned that a defect of sufficient magnitude to be classified above the minimum level would have been recorded by both groups of inspectors and that valid comparisons could thus be made.

As would be expected, the observed deterioration increased in frequency and severity on all of the bridges. As reflected in Tables III and IV by far the most prevalent defects were scaling and cracking. The relative order of the three most prevalent defects (i.e., scaling, cracking and popouts) remained the same between 1961 and 1970. In 1970 surface spalling was the fourth most prevalent whereas in 1961 it was of the same order as rusting, joint spalling, etc. In 1970, only 5 percent of the decks were free of scaling and only 25 percent were free of cracking in some form. It should be noted, however, that much of this distress would be classified as light. Eighty-seven percent of the spans were free of medium or heavy cracking, while about two-thirds of the spans were free of the more serious forms of scaling.

1822

TABLE III

OCCURRENCE OF DEFECTS ON SPANS

Span Defects	1961 Condition		Condition in 1961 of Spans not surveyed in 1970 (i.e. covered)*		Condition in 1961 of Spans Surveyed in 1970*		1970 Condition	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
No Scaling	149	57	19	45	125	61	11	5
Scaling	113	43	23	55	81	39	195	95
No Cracking	175	67	23	55	143	70	51	25
Cracking	87	33	19	45	63	30	155	75
Transverse	66	25	15	36	47	23	121	59
Longitudinal	12	5	4	10	7	3	30	15
Diagonal	7	3	2	5	4	2	9	4
Pattern	19	7	5	12	12	6	47	23
"D"	0		0		0	0	0	0
Random	13	5	4	10	9	4	105	51
No Rusting	261	>99	41	98	206	100	206	100
Rusting	1	<1	1	2	0	0	0	0
No Surface Spalling	260	99	41	98	205	>99	186	90
Surface Spalling	2**	1	1	2	1	< 1	20	10
No Joint Spalling	260	99	40	95	206	100	200	97
Joint Spalling	2	1	2	5	0	0	6	3
No Popouts	233	89	35	83	184	89	169	82
Popouts	29	11	7	17	22	11	37	18

*Four bridges comprising 14 spans were not available for the 1970 survey due to relocation and/or replacement.

**Data published in PCA — BPR Report 5 (1969) erroneously listed 1 rather than 2 spalled spans.

TABLE IV

OCCURRENCE OF MORE SEVERE DEFECTS ON SPANS

Span Defects	1961 Condition		Condition in 1961 of Spans Not Surveyed in 1970 (i.e. covered)		Condition in 1961 of Spans Surveyed in 1970		1970 Condition	
	Number	Percentage	Number	Percentage	Number	Percentage	Number	Percentage
No Scaling — Light Scaling	215	82	35	83	183	87	143	69
Medium Heavy and Severe Scaling	47	18	7	17	23	13	63	31
No or Light Cracking	252	96	39	93	199	97	180	87
Medium or Heavy Cracking	10	4	3	7	7	3	26	13
Transverse	6	2	2	5	4	2	13	6
Longitudinal	0	0	0	0	0	0	1	<1
Diagonal	2	<1	0	0	2	1	1	<1
Pattern	0	0	0	0	0	0	4	2
"D"	0	0	0	0	0	0	0	0
Random	2	<1	1	2	1	<1	7	3
No Rusting	261	>99	41	98	206	100	206	100
Rusting	1	< 1	1	2	0	0	0	0
No or Small Surface Spalls	261	>99	42	100	205	>99	193	94
Large Surface Spalls	1	< 1	0	0	1	< 1	13	6
No Joint Spalls	262	100	42	100	206	100	200	97
Joint Spalls	0	0	0	0	0	0	6	3
No or few Popouts	262	100	42	100	206	100	199	97
Many Popouts	0	0	0	0	0	0	7	3

Surface spalling has progressed to the point where 10 percent of the spans are affected, 6 percent in the more severe classification. While this increase is substantial, it is interesting to note that the current frequency of spalling on the Virginia sample is equal to or less than that reported from three of the seven other states in 1961.

No rusting was observed in 1970. Apparently the rusting or the conditions leading to the rusting were the basis for resurfacing of the one span observed in 1961.

In general the performance of these bridge decks is not alarming and would be considered adequate or above average when compared with other published information on performance of decks in other areas of the country.

In analyzing the data from the 1970 survey, a primary concern was to determine and report the increase of concrete deterioration on the bridge decks during the interval between surveys. It must not be overlooked that decks on 14 of the 80 bridges which were inspected had been resurfaced with a bituminous surface. Forty-two spans were thus covered. Since deck resurfacing is often made necessary because of concrete deterioration, the inspectors tried to discover if this was the reason for the placement of the bituminous concrete on the bridges. The district bridge engineers were requested to convey any information pertaining to the conditions of these deck slabs prior to the placement of the overlays.

Typical of the results received are those from one district which had four resurfaced bridges.

> "Bridge A — We have checked and we find no material or correspondence pertaining to the condition of the deck slabs for this bridge prior to the placement of the bituminous concrete surface.
>
> Bridge B — The bituminous concrete surface was placed on this deck to cover up the irregularities of the deck slabs.
>
> Bridge C — We have checked and found that the condition of the deck slab was very good prior to being covered with the bituminous concrete surface.
>
> Bridge D — We have checked and found that the condition of the deck slab was very good prior to being covered with the bituminous surface."

It would seem that for the most part these resurfacings were for reasons other than concrete distress. This is consistent with the data in Table IV (columns 3 and 4) which show that the condition of these spans in 1961 was close to the average for the entire sample.

As judged by the data from Table IV, it appears that the performance of the decks has been adequate with the possible exception of the resistance to surface scaling. The increase in spalling, while limited to a few spans, should be viewed with concern because of the difficulty associated with its correction.

Specific Defects

The classes of defects will now be discussed individually in more detail, using comparisons in Figures 1 - 14. The data designated as "1961 — all uncovered spans" are the same data as appear in the PCA — BPR report (BPR — PCA 1969).

Scaling

The progression of scaling is evident in Figures 1 and 2, as is the fact that the predominant mode is light. No severe scaling was observed in 1970. The one example of severe recorded in 1961 had been resurfaced.

The frequency of scaling increases with age and traffic volumes as seen in Figures 3 and 4. It is likely that these increases represent the combined effects of several factors including (1) more applications of deicing chemicals on roads with high traffic volumes; (2) greater numbers of freezing and thawing cycles with age; and (3) difficulties of separating abrasion from light scaling. In any event the differences due to age and traffic are not particularly significant.

The influence of air entrainment is shown in Figure 5. In 1970, this influence was less obvious than was true in 1961. The reason is at least twofold. One is the difficulty in distinguishing between light scaling and abrasion. While reduction of scaling is attributed to entrained air, at the same time slight reductions in strength accompanying its use might be associated with increased abrasion. It is much more likely that the lack of significant reduction in scaling from air entrainment reflects the fact that the amount of air specified was not sufficient to provide resistance to scaling. The specifications in force at the time of construction required 3 - 6 percent of air. Based upon the previously reported observations from the Council's special study of deck construction (Hilton, Newlon, and Shelburne 1965), there was a strong tendency to work to the lower limit rather than to the center of the range. It is thus probable that the majority of the spans do not contain what is currently deemed as adequate air entrainment. The Virginia specifications were revised in 1965 to require an air content of $6\frac{1}{2} \pm 1\frac{1}{2}$ percent.

It is significant to note that the eleven spans that were free from scaling are all air-entrained. At the same time, the average daily traffic counts of all of these unscaled spans is less than 7,500 and more than half have an average daily traffic count less than 750. Spans on low volume roads would be expected to have received few if any applications of deicing chemicals.

The combined influences of air entrainment and age are reflected in Figure 6. During the period 1956 — 1961 only two spans were specified as non air-entrained, both of which have scaled but the number is too small to warrant a comparison.

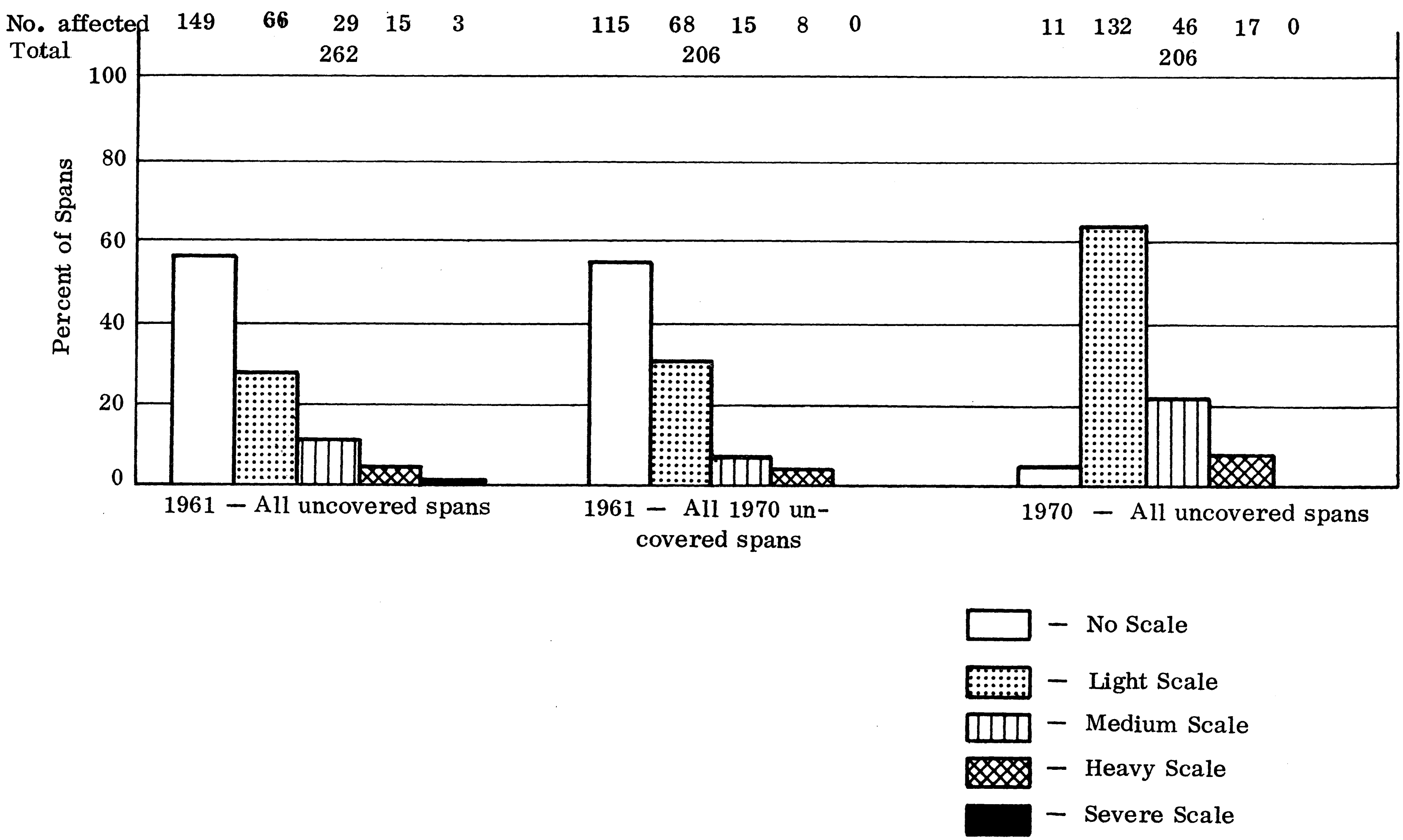

Figure 1. Occurrence of scaling (maximum scaling condition).

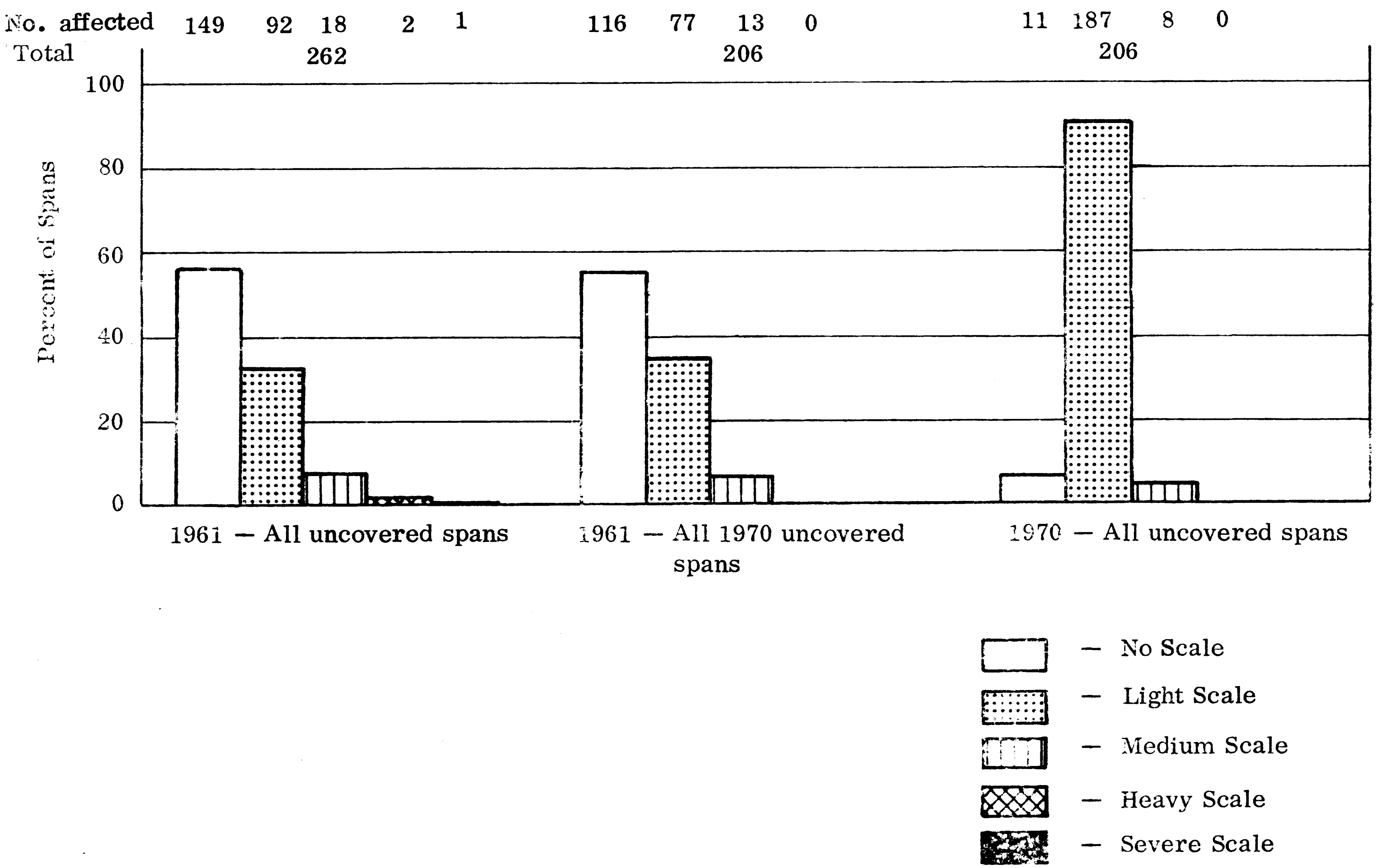

Figure 2. Occurrence of scaling (average scaling condition).

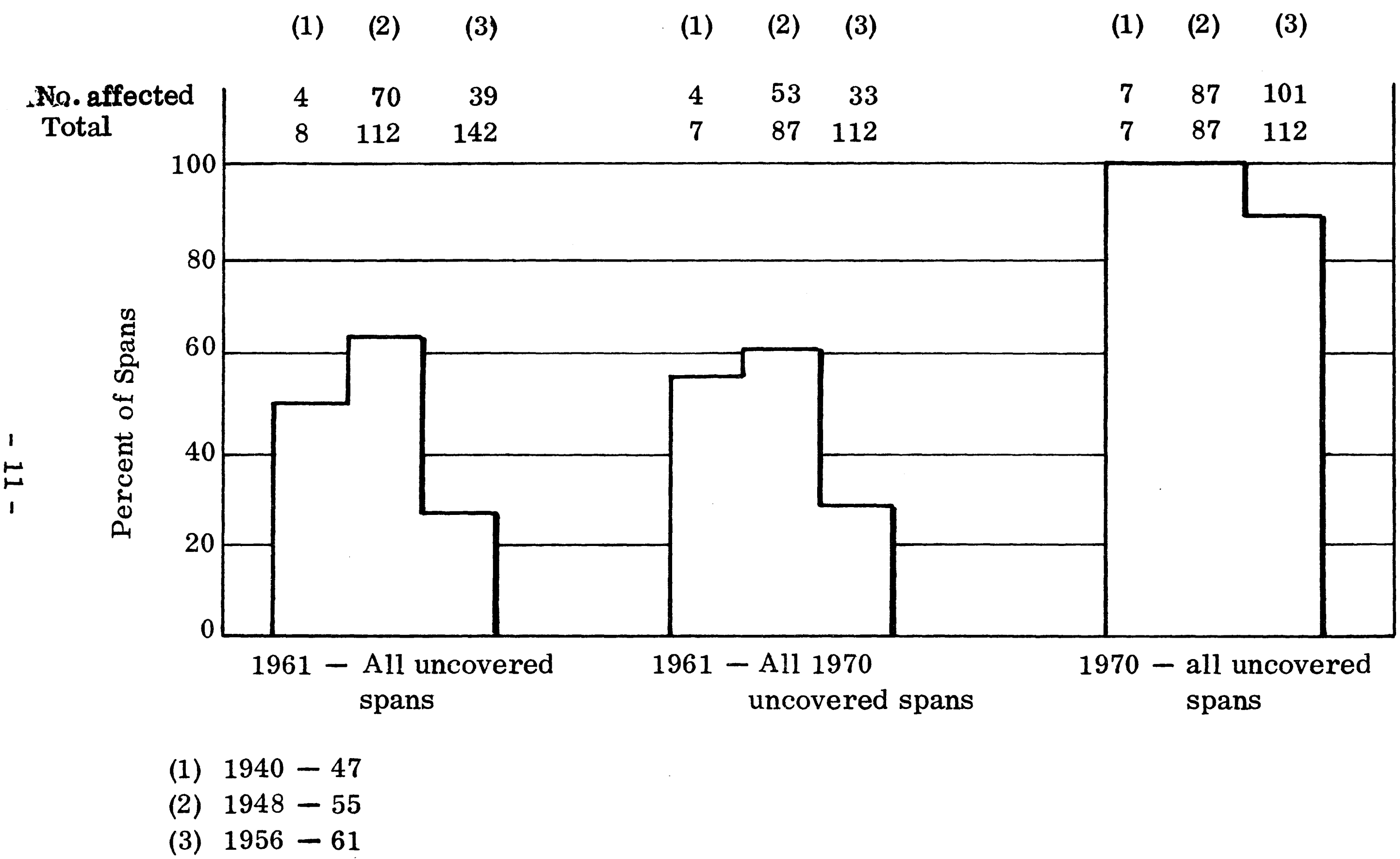

Figure 3. Influence of age on occurrence of scaling.

1828

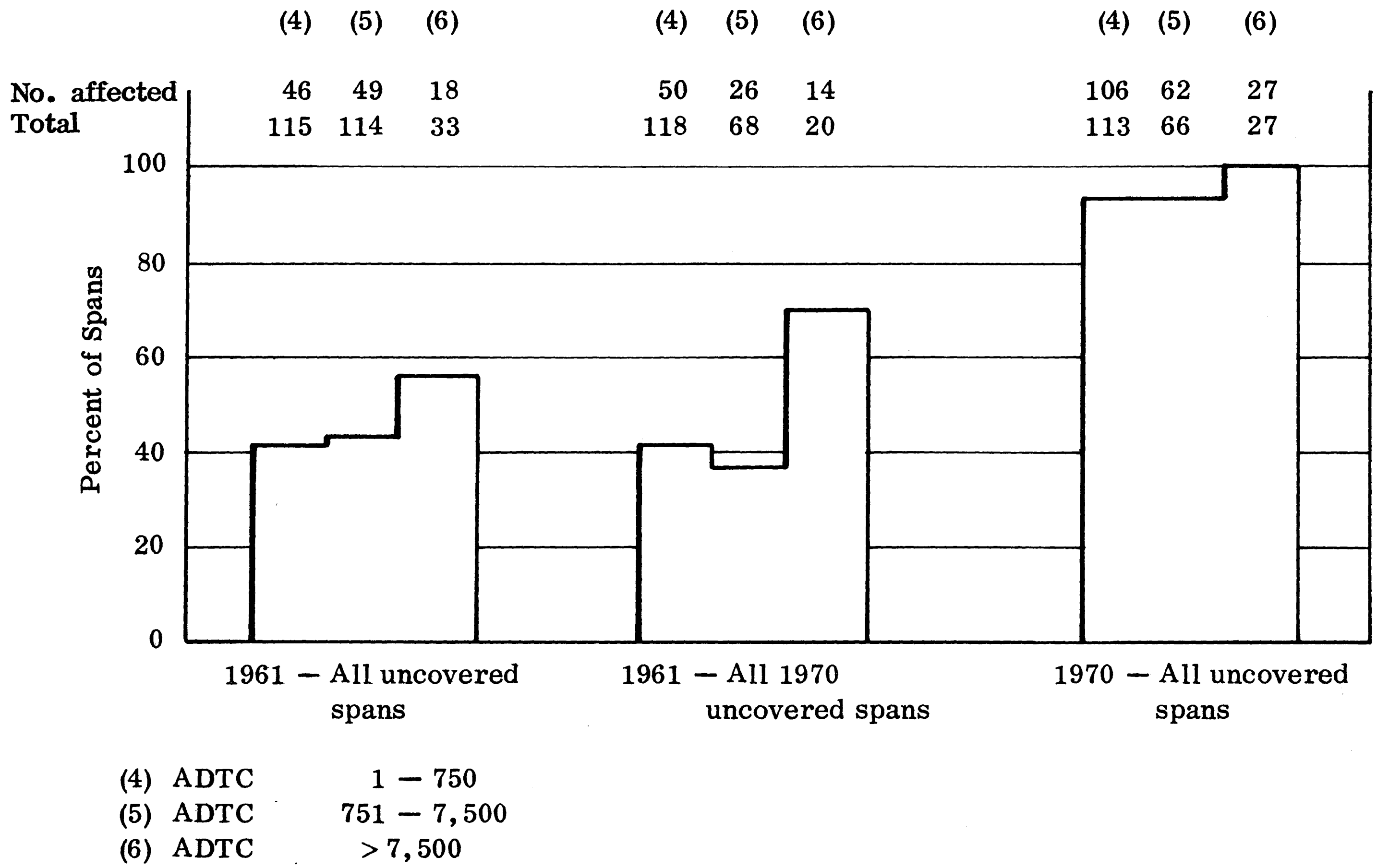

Figure 4. Influence of traffic volume on occurrence of scaling.

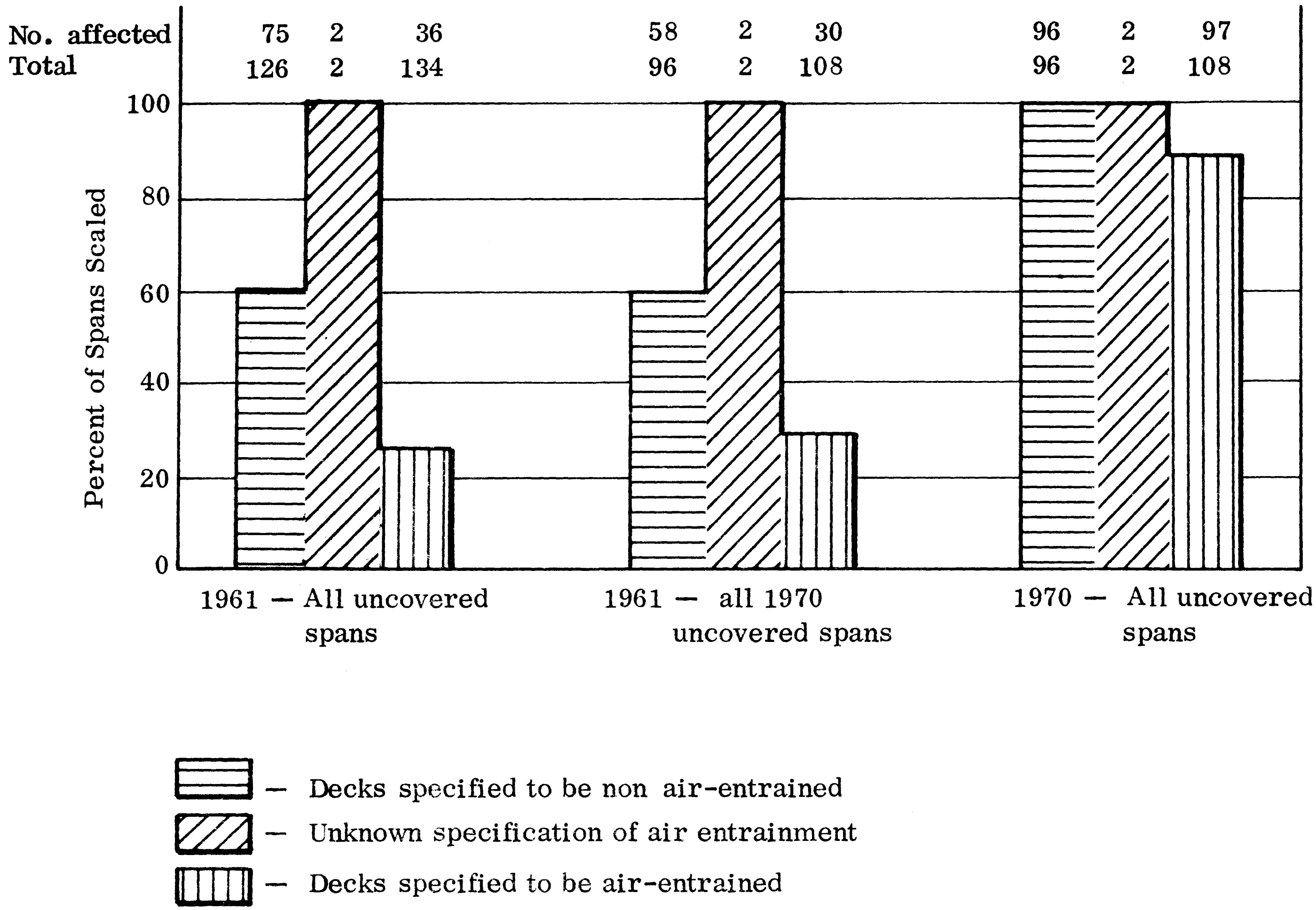

Figure 5. Influence of air entrainment on occurrence of scaling.

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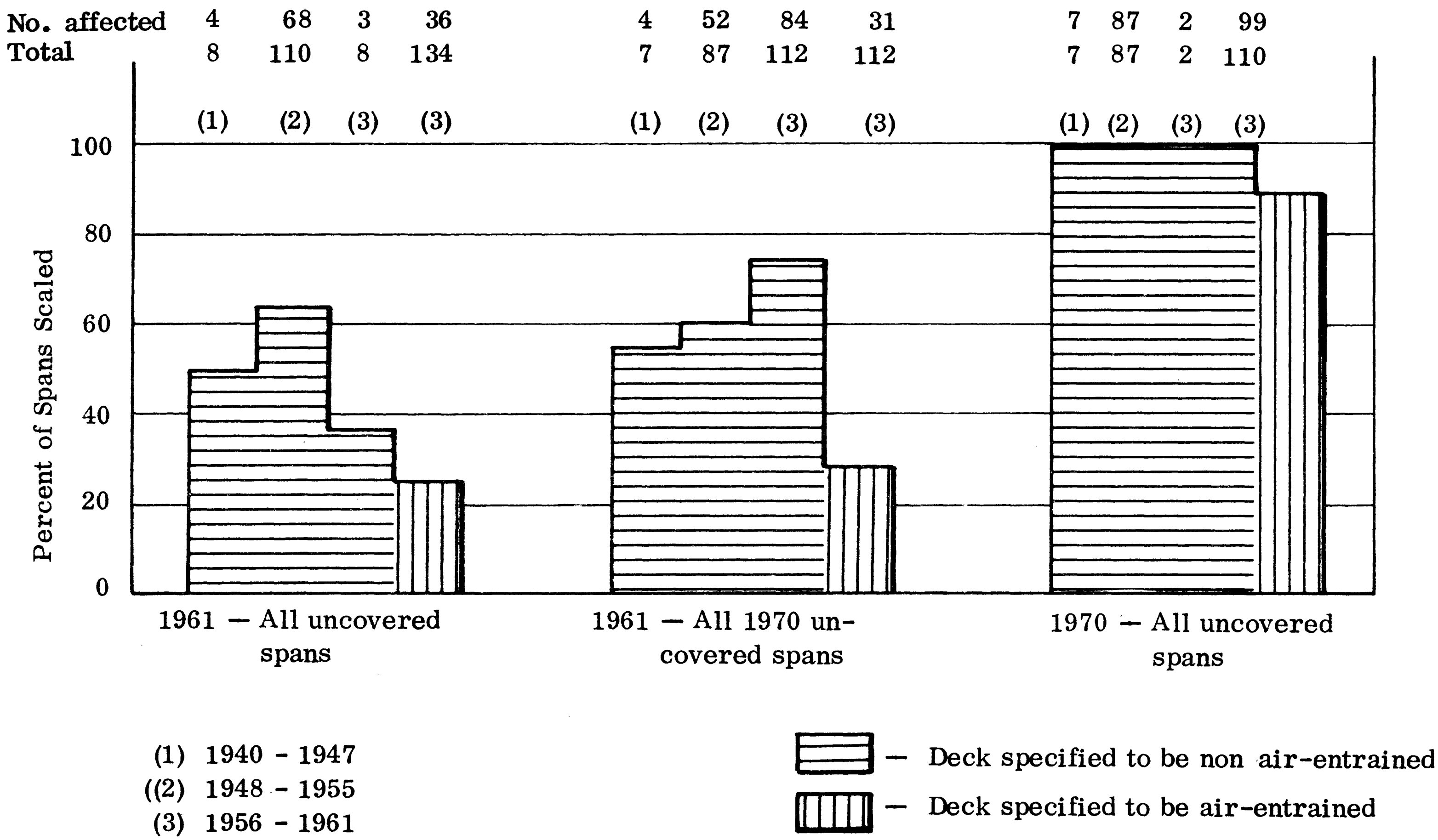


Figure 6. Influence of air entrainment and age on occurrence of scaling.

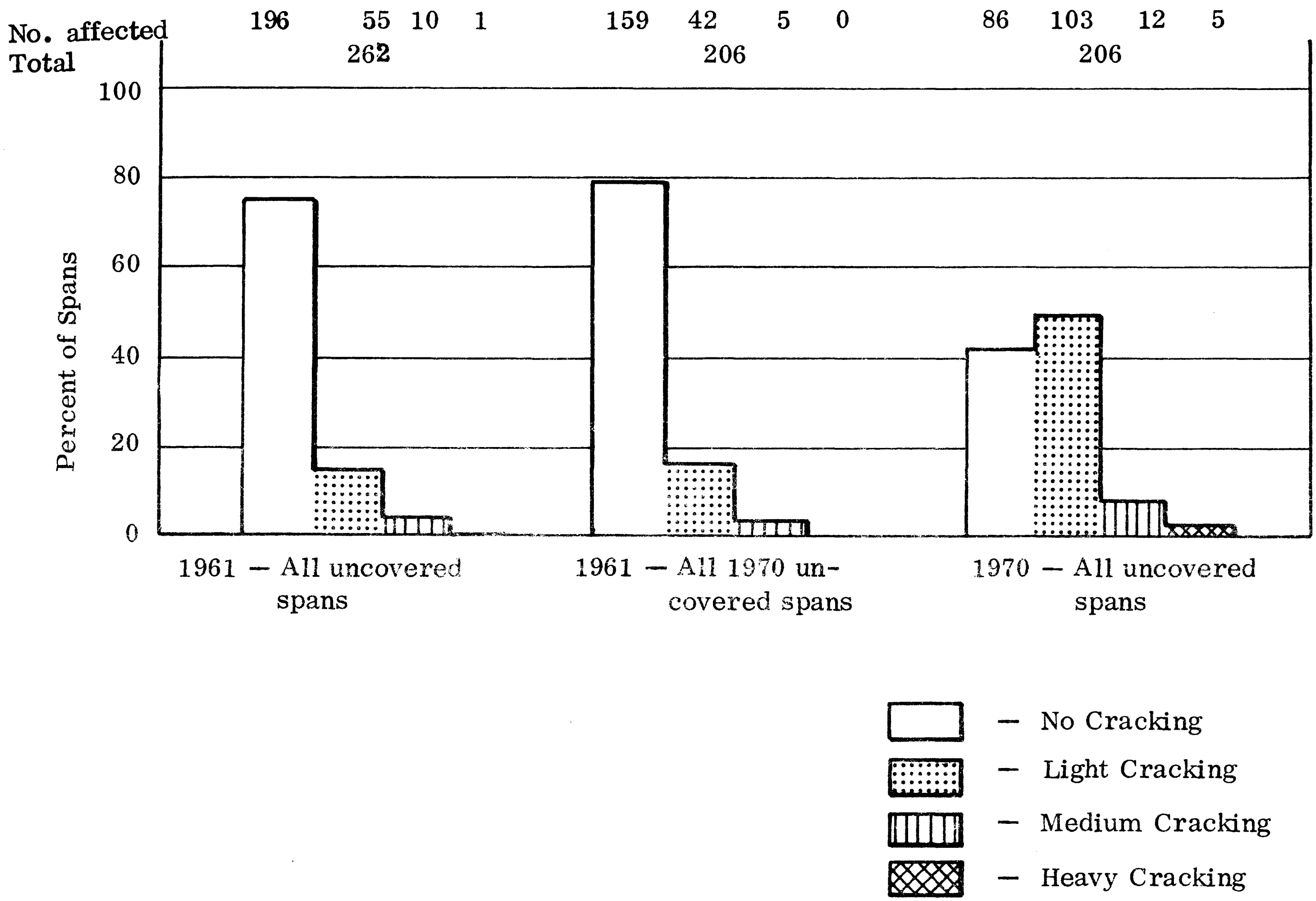
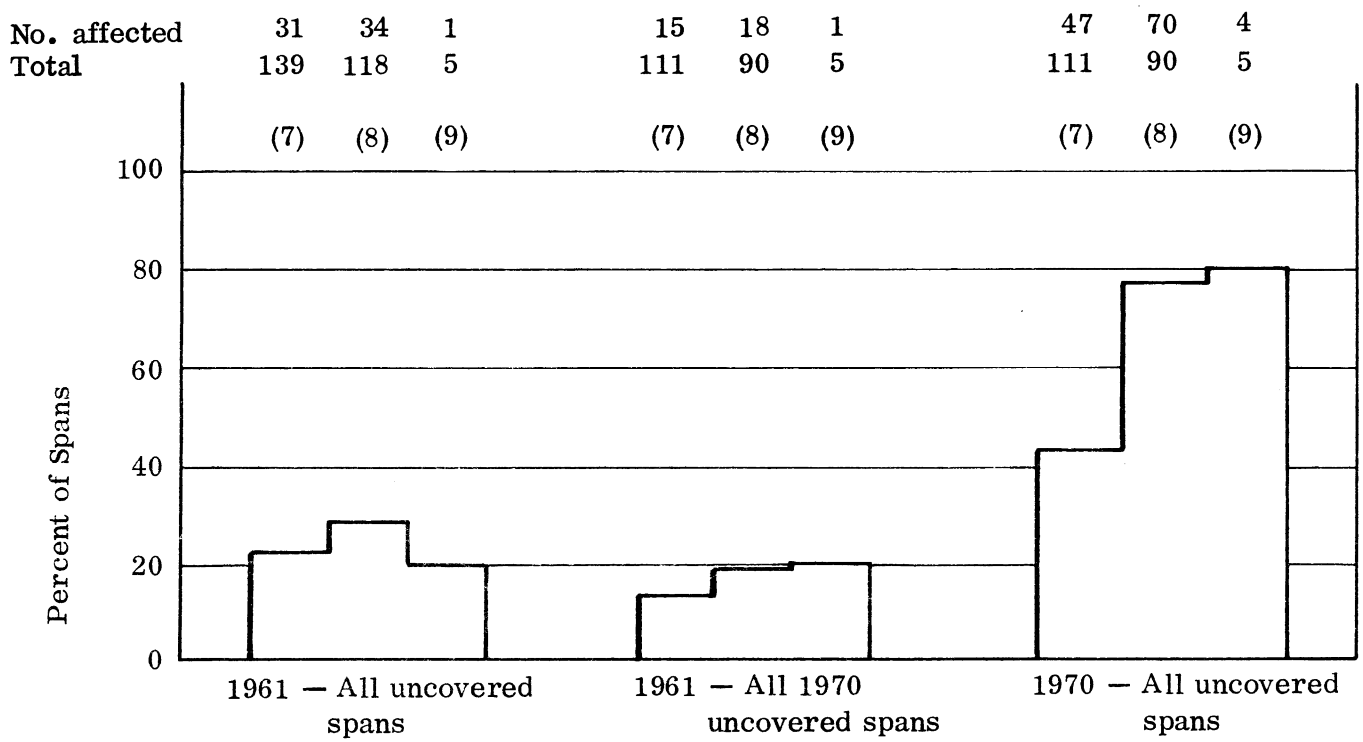
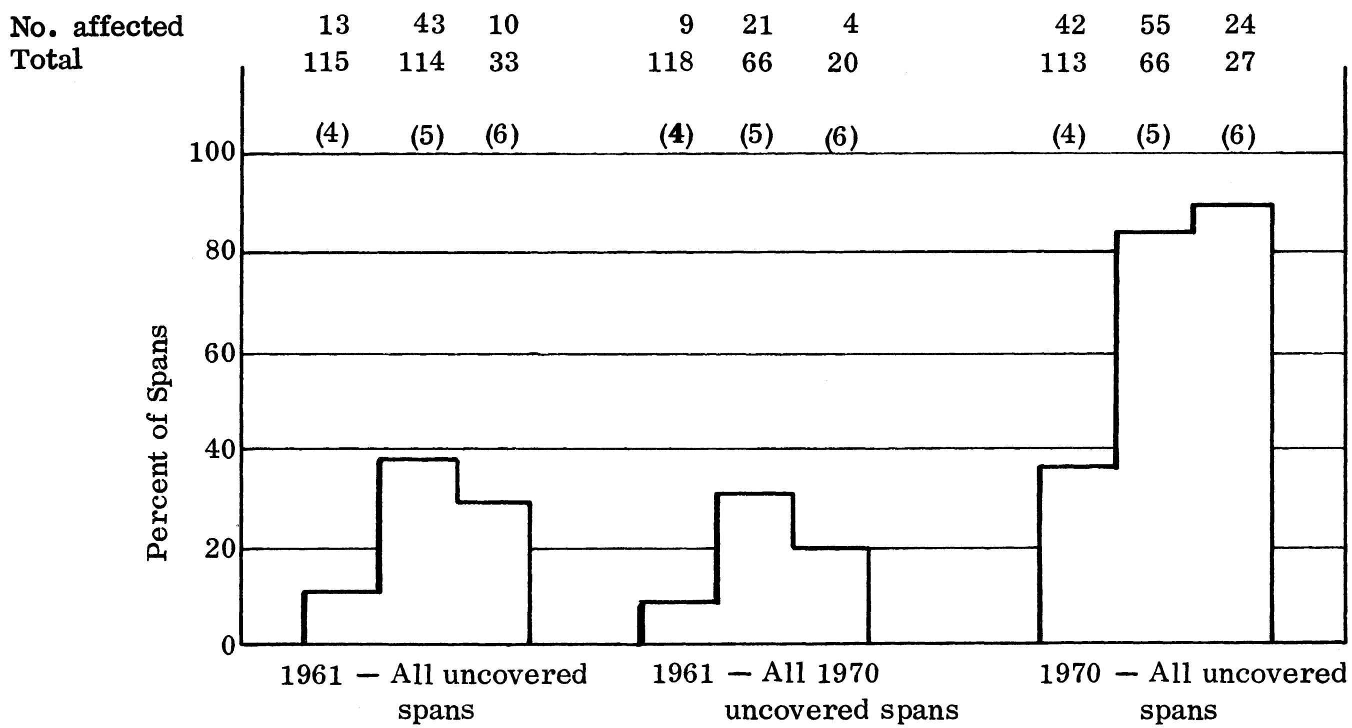


Figure 7. Occurrence of transverse cracking.



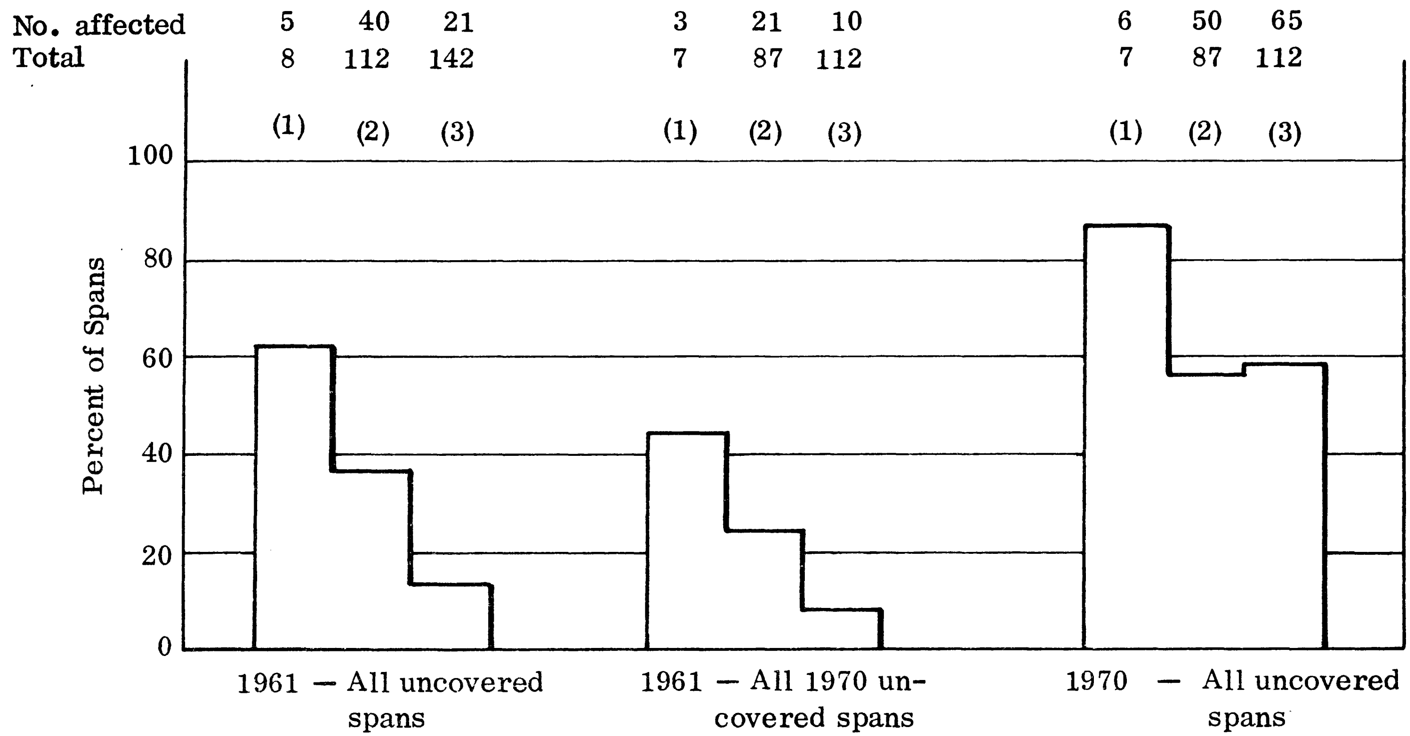
(7) < 45 ft.
(8) 45 ft. - 90 ft.
(9) > 90 ft.

Figure 8. **Influence of span length on occurrence of transverse cracking.**



(4) ADTC — 1 - 750
(5) ADTC — 750 - 7500
(6) ADTC — >7500

Figure 9. Influence of traffic volume on occurrence of transverse cracking.



(1) 1940 — 1947
(2) 1948 — 1955
(3) 1956 — 1961

Figure 10. Influence of age on occurrence of transverse cracking.

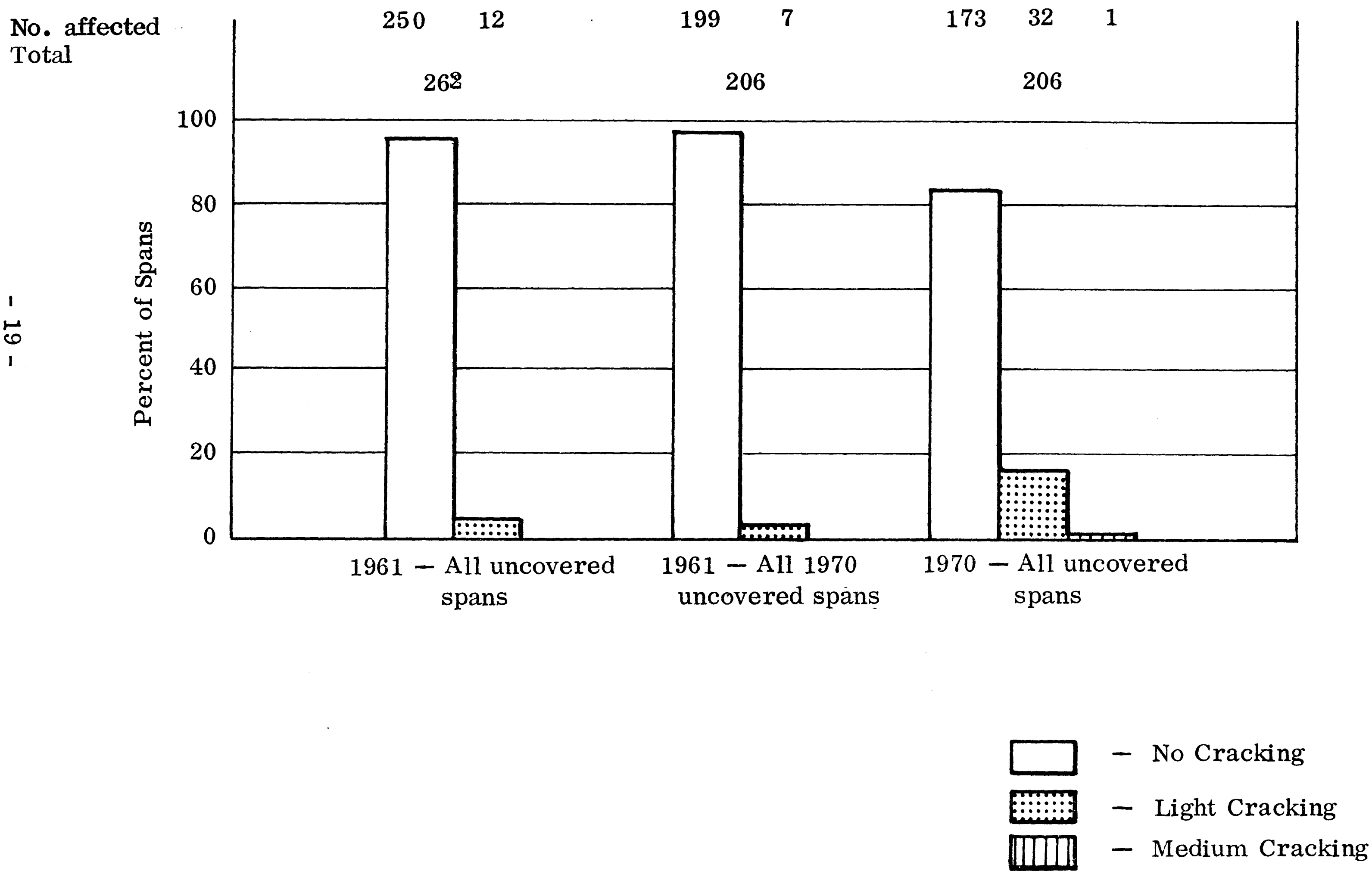


Figure 11. Occurrence of longitudinal cracking.

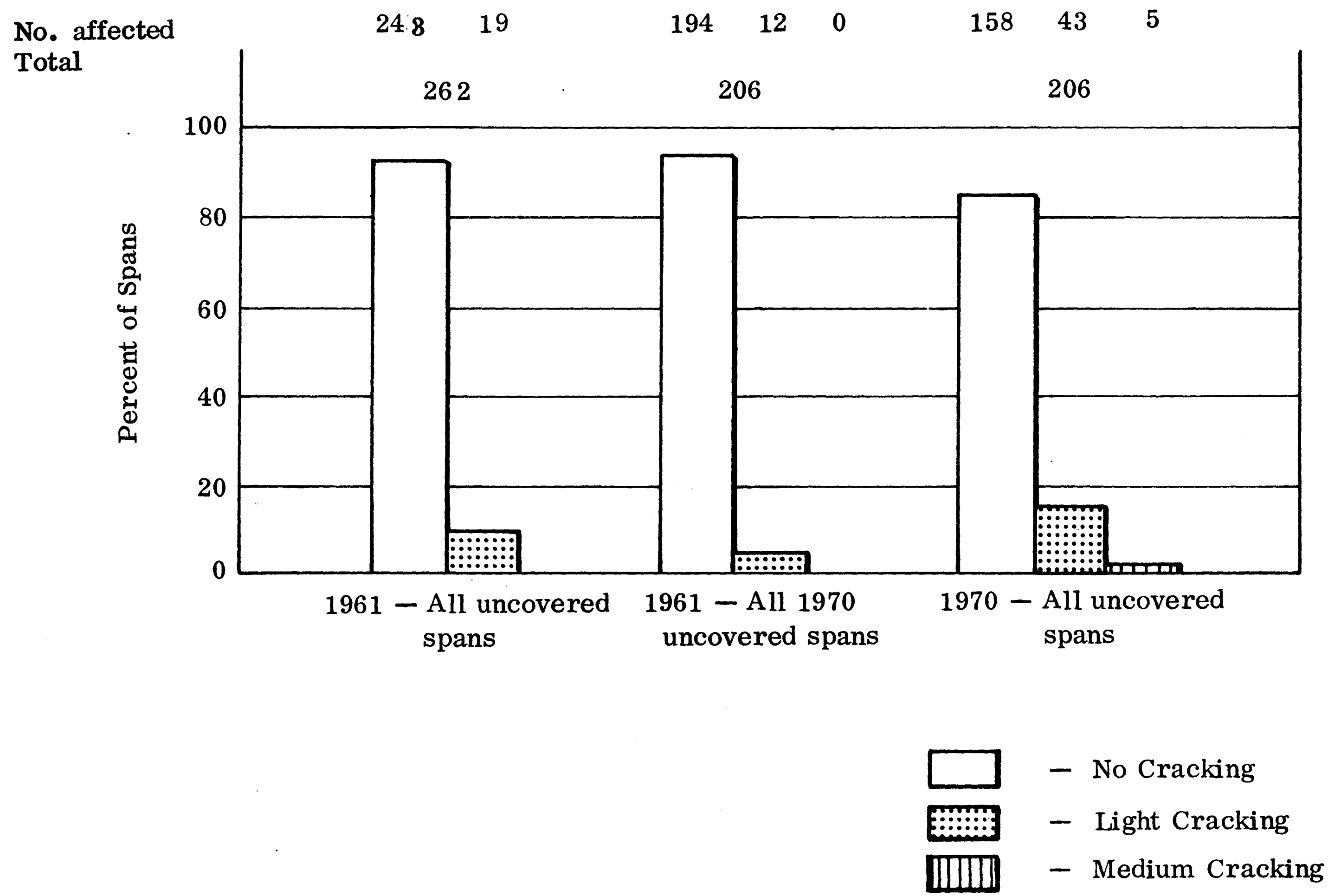


Figure 12. Occurrence of pattern cracking.

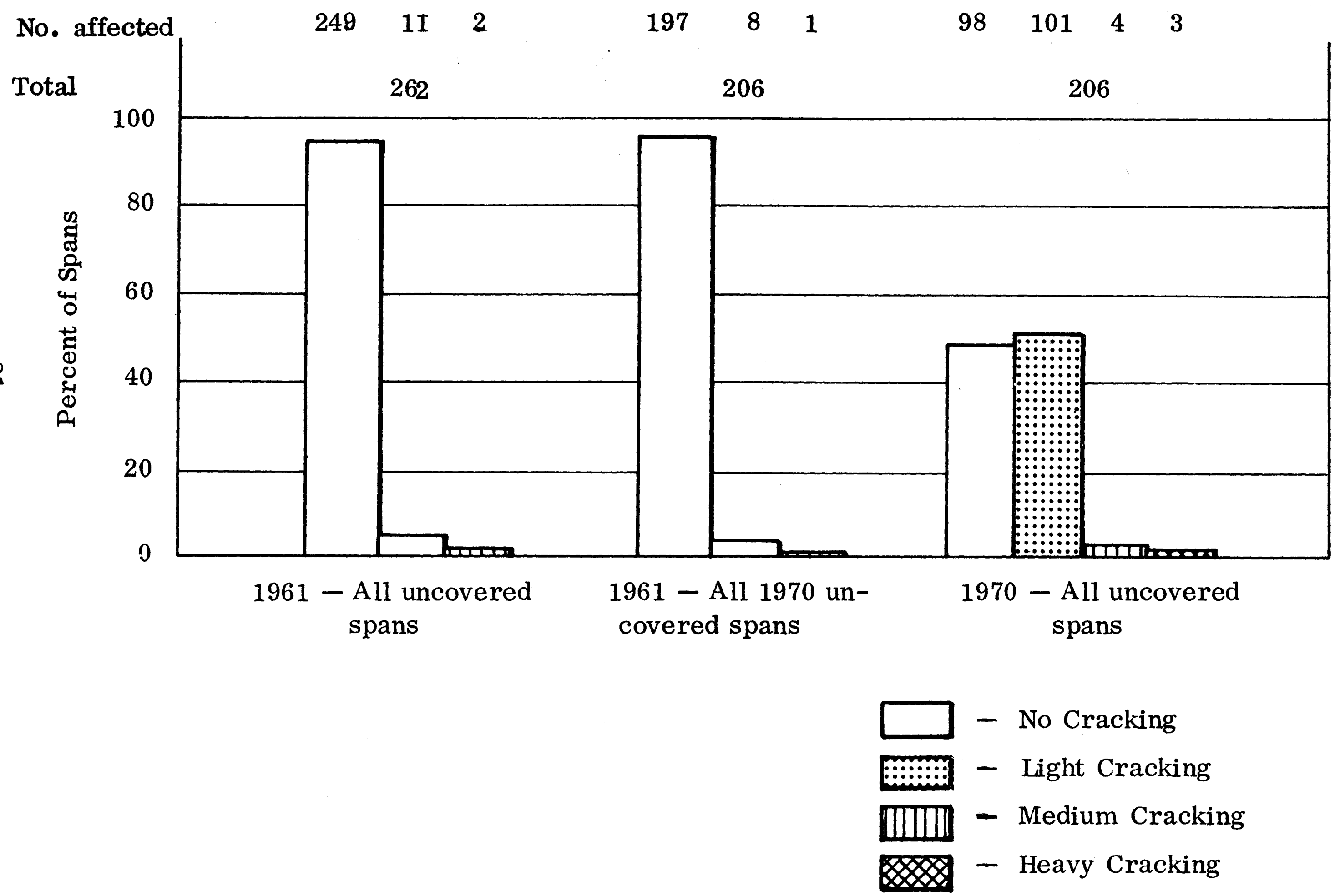


Figure 13. Occurrence of random cracking.

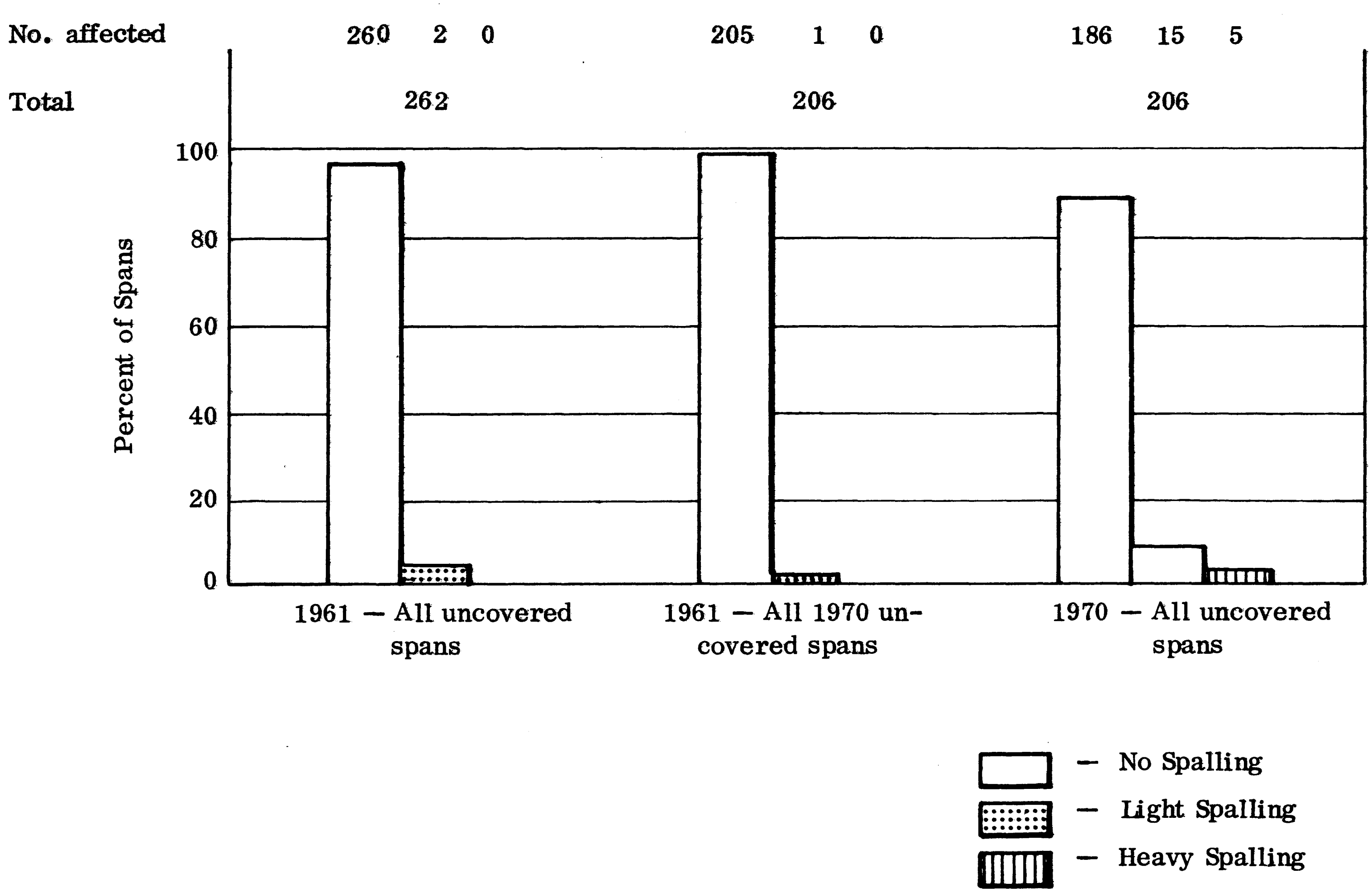


Figure 14. Occurrence of spalling.

Cracking

Cracking was the second most prevalent defect in both 1961 and 1970. Most of the cracking is light and of little consequence, as was seen in Table IV. The largest increase was in the category of random cracking, which showed a tenfold increase. Most of this was light and is believed to reflect differences between the ratings of the inspection teams rather than in actual performance. This probability is discussed later in the section on "Reliability and Reproducibility of the Surveys".

The most prevalent mode of cracking was transverse and its occurrence is shown in Figure 7. In 13 spans (6 percent) the severity is classified as medium or heavy. Approximately three times as many spans showed this level of cracking in 1970 as compared with their condition in 1961.

The influence of span length on cracking is shown in Figure 8. The effect of traffic volumes on the occurrence of transverse cracking is shown in Figure 9. Both reflect the expected trends; namely, an increase with span length and traffic volume. In 1961 these trends were not evident because the longer spans and heaviest traveled bridges were also the youngest. In 1970 there was little difference between the two highest classifications of either volumes or span lengths but spans less than 45 ft. and carrying fewer than 750 vpd showed significantly less transverse cracking than did the other two classes. Transverse cracking can result from either loads or long time volume changes; both of which are time dependent. The effect of age on the occurrence of transverse cracking is shown in Figure 10. These trends are also as expected although there is little difference in the occurrence on the spans in the two youngest categories.

Because cracking and surface spalling are often related phenomena, the relationship between these two defects was evaluated and is discussed later. The occurrences of longitudinal, pattern, and random cracking are shown in Figures 11 - 13. As discussed earlier only random cracking showed a substantial change or a significant amount. In all cases the severity was not alarming. No "D" cracking was observed in either survey. "D" cracking is a serious problem in pavements placed in some areas of the country but the conditions necessary for its occurrence are not operative except in slabs-on-grade.

In general, cracking is not a serious problem and is believed to be within expected limits.

Spalling

Because of the recent nationwide concern over the development of surface spalling, particular attention was given to this defect. Its occurrence is shown in Figure 14. As noted earlier, spalling was more prevalent in 1970 than in 1961 and has shown proportionally a great increase than other defects. The number of spans increased from one to twenty. At the same time spalling is still much less of a problem on the bridges comprising the Virginia sample than on those in many of the other states included in the random survey. On 13 spans (6 percent), spalling was

1840

recorded as large. One bridge contained 33 spalls, another had 24, one had 17 and the remainder had less than 10. Thus only 3 bridges were significantly affected.

The magnitude of the problem did not warrant and the scope of this project did not permit an extensive evaluation for incipient spalls, "hollow areas", etc. but the comparative absence of spalls suggests that a further, more intensive study might shed some light as to why some decks spall and others do not. Suggestions for such a study are included in the "Recommendations" section.

The data were studied for relationships between the simultaneous presence of spalling and transverse cracking. The formative mechanism of spalls is such that transverse cracking could be expected to precede the appearance of spalls. As noted earlier, 121 of the 206 spans (75 percent) contained transverse cracks. Of these 121 spans, 107 (89 percent) had no spalling while 14 (11 percent) did. Twenty spans had spalls and 6 of the 20 spalled spans had no transverse cracking while 14 had both.

These occurrences are summarized in Table V, in which the bridges are listed in decreasing order of spalling severity.

There seems to be no particularly consistent relationship between spalling and transverse cracking, although the two defects often occur simultaneously.

TABLE V

SPALLING VERSUS TRANSVERSE CRACKING

Bridge Number	Number of Spalls	Number of Spans on which Transverse Cracking Appears with Spalling	Number of Spans With Spalling Only
1	18 L* 15 S	2	2
106	17 L 7 S	3	-
127	3 L 14 S	2	-
126	4 L 1 S	-	2
27	2 L 6 S	2	-
14	1 L 5 S	2	-
47	1 L 1 S	-	1
90	6 S	2	-
37 (NBL)	1 S	1	-
138	1 S	-	1

*L = Large, S = Small

Popouts

The number of spans containing popouts did not increase substantially. It was observed, however, that the occurrence of popouts was largely confined to the Northern Virginia area. This is explained by the occurrence of lightweight chert in the locally available coarse aggregate. This occurrence has been extensively studied in a previous Council project (Newlon, Ozol, and McGhee 1965).

Comparison of Performance for Bridges in PCA — BPR Sample and the Council's Special Study

As noted previously, one purpose of the resurvey was to establish a basis against which to compare the performance of the 17 bridges in the Council's research study of finishing and other construction procedures. On each of these 17 structures, one span was studied in detail during construction. The 17 bridges contained 78 spans. Two of the structures were much larger than the others, containing 8 and 13 spans respectively. The remaining 15 bridges, containing 60 spans, were more representative of the "typical" bridge used in Virginia. The detailed evaluation of these decks will be discussed in a subsequent report. Here a comparison will be made of the changes in condition during the period since the initial surveys. These comparisons are shown in Table VI.

TABLE VI

PERFORMANCE OF BRIDGES IN RANDOM SURVEY SAMPLE AND BRIDGE FINISHING SAMPLE

Defect	Occurrence of Defect by Spans		
	PCA-BPR Sample 1961-1970, % of Spans Affected	Finishing Study Sample 1963-1970, % of Spans Affected	Number of Structures Affected in Finishing Study Sample
Covered	17	23	2
Uncovered	83	77	15
No Scaling	5	18	3
Scaling	95	82	12
No Cracking	25	10	1
Cracking	75	90	14
Transverse	59	63	12
Longitudinal	15	30	7
Diagonal	4	8	3
Pattern	23	38	8
"D"	0	0	0
Random	51	55	13
No Rusting	100	100	15
Rusting	0	0	0
No Surface Spalling	90	91	13
Surface Spalling	10	9	2
No Joint Spalling	97	71	14
Joint Spalling	3	29	1
No Popouts	82	82	11
Popouts	18	18	4

The agreement is unusually good. Several of the categories (popouts, surface spalling, and rusting) are in exact agreement. Joint spalling shows the largest disparity. Scaling and cracking show slight differences. In both samples the relative order of severity for the six different types of cracking is the same, and the individual values are in good agreement.

Factors Influencing Performance

The variety of conditions and the long time periods for construction and performance of the structures comprising the Virginia sample do not lend themselves to a detailed cause-effect analysis. Several factors known to affect deck performance are worthy of mention as a general backdrop against which to view the results. Four will be discussed. These are: (1) Specification requirements for concrete used in decks, (2) required cover over upper reinforcing steel, (3) policy on deicing, and (4) climatological characteristics.

The degree to which compliance with the requirements for factors (1) and (2) was obtained is obviously an important but non-documentable factor. Many problems can be traced to failure to fulfill completely the requirements specified for concrete quality and cover. Assuming a relatively constant degree of quality control, the requirements specified furnish a basis for comparison, particularly with performance in the other states included in the nationwide survey.

Concrete Quality

The significant specification requirements for concrete are summarized in Table VII. It can be seen that during the time period spanning the construction of the bridges in the sample (1940-1961), the requirements were essentially the same. The most significant change was the introduction of air entrainment in 1954. The oldest group of bridges (1940-1947) in the survey may have contained concrete of a slightly higher water-cement ratio than those covered by the later specifications. The number of bridges in the oldest class was small compared with the total. Significant upgrading of the requirements did not occur until 1966. Prior to that time the concrete specified would have had "borderline" resistance to weathering when judged in the light of subsequently developed knowledge.

TABLE VII

CONCRETE REQUIREMENTS 1938 - 1970

	Cement Content, sk/cy	Water-Cement Ratio, gal/sk	Air Content, %	Slump, In.	Max. Agg. Size, In.	28-Day Strength, psi	Aggregate Quality Requirements Maximum Losses, % — L. A. Abrasion Coarse Aggregate, 100 rev.	L. A. Abrasion Coarse Aggregate, 500 rev.	Sulfate Soundness Loss* coarse aggregate / fine aggregate	F & T**
1938	6¼	6	-	2-5	1	3,000	10	40		10(15)
1947	6¼	6	-**	2-5	1	3,000	9	35	8(5) / 8(5)	5(15) / 5(15)
1954	6¼	5½	3-6**	0-5	1	3,000	9	35	8(5) / 8(5)	5(15) / 5(15)
1958	6¼	5½	3-6	0-5	1	3,000	9	35	8(5) / 8(5)	5(15) / 8(15)
1966	6¾	5¼	6½ ± 1½	2-4	1	4,000	9	40	12(5) / 12(5)	5(20) / 5(20)
1970	7¼	5¼	6½ ± 1½	2-4	1	4,000	9	40	12(5) / 18(5)	5(20) / 8(20)

*Values in parentheses are specified numbers of cycles.

**Air entrainment was used in pavements beginning in 1948. It was used experimentally in several bridge decks prior to incorporation into specifications.

Cover

Insufficient cover of the upper reinforcing steel has been widely identified as a primary cause of surface spalling. Research in Kansas (Crumpton, Pattengill, and Badgley 1969) showed a very high tendency for deterioration at covers of 1.5" or less and very little deterioration for covers of 2" or more. Spellman and Stratful (1970) have developed an empirical relationship to relate the chloride content per inch depth below the surface. This equation is of the form:

$$C = 9.60\ (0.441)^{S}$$

where

C = chloride content (lb./cy) of a 1-in. thick disk; and

S = maximum depth (in.) below surface for 1-in. thick disk, with a depth limit of 4 in.

A minimum of 2" of clear cover is widely recommended by various agencies prominent in concrete technology (NCHRP 1970).

During the period of construction of the bridges included in the sample, the requirements for location of the uppermost steel was 2" to the center of the uppermost bar. This would be approximately 1-11/16 of clear cover. This cover requirement is adequate with respect to protection from spalling but is close to the "breaking point" of the data developed in Kansas (Crumpton et al 1969). The requirement was increased in 1966 to provide $2\frac{1}{4}$" to center of the uppermost bar, which is approximately 1-15/16" of clear cover. This is very close to the 2" value now judged to be necessary.

Deicing Policy

Prior to World War II there was little use of deicing chemicals. This use was limited to very heavily traveled routes, with the remainder of the roads being cleared by plowing. The "bare pavement" policy developed in the midforties, essentially after World War II, and resulted in the widespread use of chemicals for deicing. For concrete pavement surfaces calcium chloride, rather than sodium chloride, was required until about 1960. Since then either sodium or calcium chloride has been used on concrete pavements.

In the early days of chemical deicers, spreaders were required to be shut down 1000' on either side of a bridge deck, and the remaining snow was removed mechanically. As this policy became impractical, the practice of "sanding" decks evolved. The sand abrasive contained varying amounts of calcium chloride used to prevent freezing of the stockpiled materials. In recent years the sand abrasive has been supplemented by application of calcium chloride. Raw sodium chloride is not permitted on bridge decks although it is used on adjacent pavements. In general, isolated secondary bridges are not treated with chlorides except in certain critical situations.

1844 Some idea of the progressive increase in the use of chlorides is given in Figure 15, which covers the period 1953-54 to 1969-70 inclusive. While there are yearly variations relating to the severity of specific winters, the progressive increase in the use of chlorides is evident. Of the totals shown, between 1,000 and 2,000 tons are used on the secondary system, the remainder being applied to the interstate and primary. The weight of abrasives used is approximately three times the weight of the chlorides.

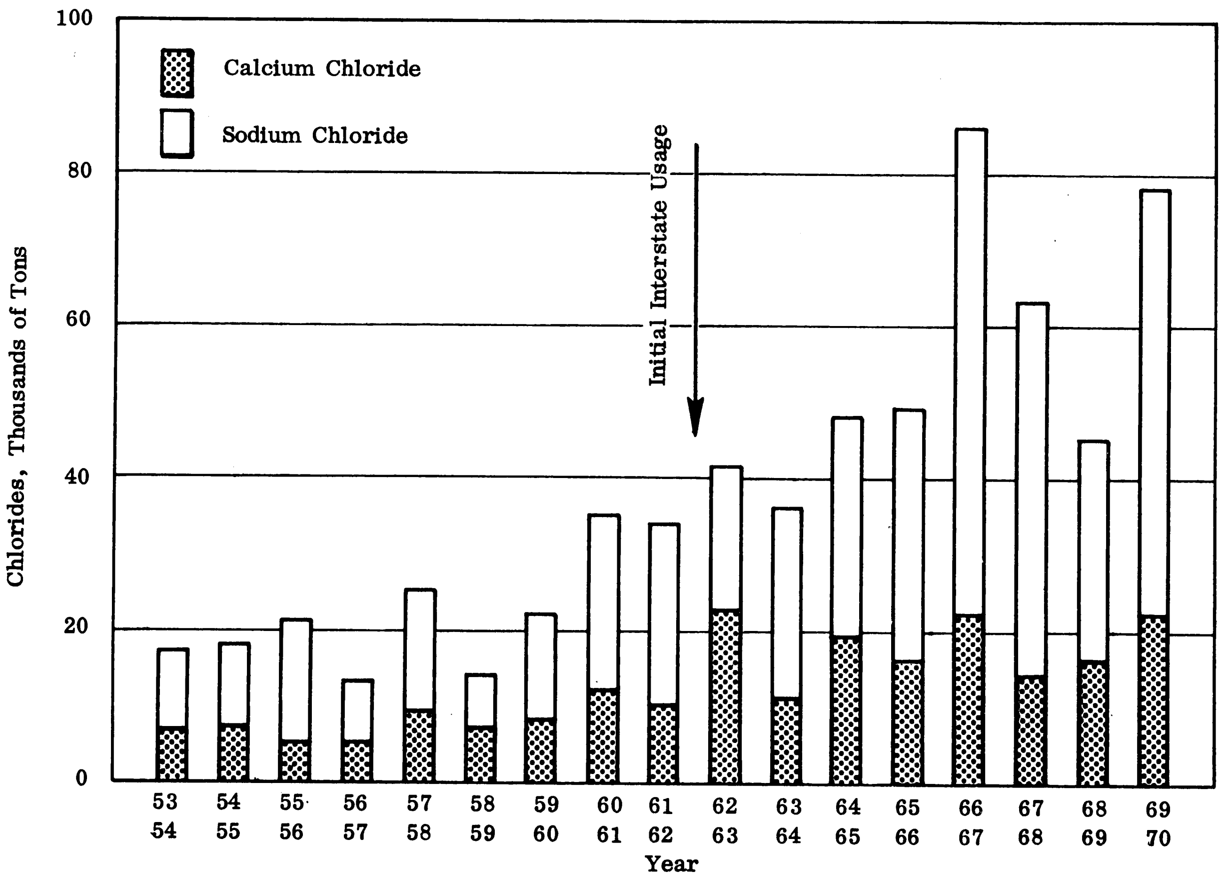


Figure 15. Use of chlorides for deicing all systems, (interstate, primary, and secondary).

Environmental

It is well recognized that the environment to which concrete is exposed greatly influences its performance. It is apparent that this performance is affected by temperature variations, particularly in the vicinity of the freezing point and simultaneously with the presence of moisture. The combination and quantification of these two characteristics into a meaningful measure applicable for concrete is complex and numerous techniques have been used. There is still much to be done as reflected by the fact that the area of assessing and quantifying the environmental characteristics to which concrete is exposed in practice was given highest priority in a recent summary of research needs (NCHRP 1970 b).

In Virginia temperature variations due to latitude are not great. A horizontal cross section of the state, however, carries one from ocean influences to mountain extremes and shows much sharper contrast. Freezing weather has been experienced in July in some sections of southwestern Virginia. Precipitation is primarily dependent upon proximity to the ocean, although the greatest eight-hour rainfall (Virginia Minerals 1969) recorded in the United States occurred in the Piedmont in 1968 during Hurricane Camille.

The Commonwealth of Virginia embraces parts of six physiographic provinces from east to west as follows: Coastal Plain, Piedmont and Triassic Lowlands, Blue Ridge, Ridge and Valley, and a very small portion of the Applachian Plateau. The boundaries of these provinces along with those of the Department of Highways' eight construction districts, which follow political boundaries, are shown in Figure 16. The characteristics of the provinces influence not only the available materials but also the climatological factors as well. In the Coastal Plains, aggregates are overwhelmingly natural silicious gravels and sands with a few crushed stone sources. The Coastal Plain contains the only substantial sources of suitable natural concrete sand and this sand is shipped to the other provinces. The climatography of the province is semimarine and the wide expanse of water tempers both summer heat and the winter cold, especially the latter, while comparatively high humidity is mitigated by land and sea breezes. Relatively heavy precipitation occurs (Hibbard 1941).

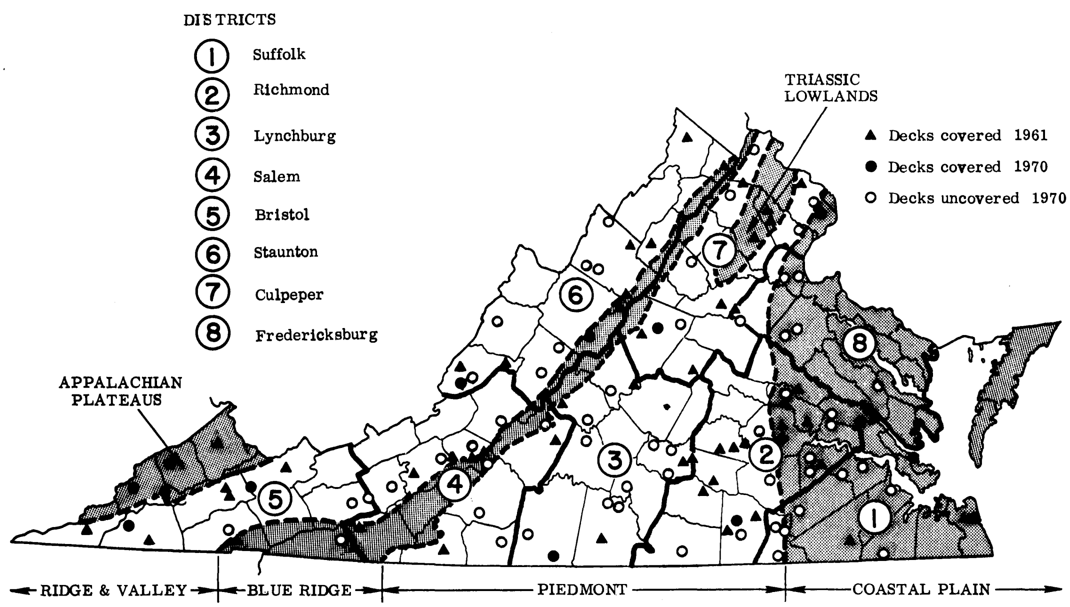


Figure 16. Boundaries of physiographic provinces, construction districts, and location of decks surveyed.

In the Piedmont and Triassic Lowlands aggregates are igneous and metamorphic (crushed stone) and the climate is primarily controlled by latitude. Fairly warm summers and mild winters characterize this section, and the temperature varies primarily from north to south. Precipitation is plentiful (Rice 1944).

The predominant aggregates in the other three provinces are carbonates, with some sandstones and shales. Elevation is the primary climatic factor. Temperatures are lower, with wide variations in short distances. Snow is plentiful.

With such variations in climate, it would be of value to have some index which accounts for freezing and the presence of moisture. Most published materials are oriented toward climatological characteristics important for agriculture, which are generally opposite to those important in the weathering of concrete. One exception is the "weathering index" developed by ASTM Committee C-15 (1956) and utilized as an exposure guide in the ASTM Specifications for Clay Building Brick, C 62. The "weathering index" is defined as

> the product of the average annual number of freezing cycle days and the average annual winter rainfall in inches, defined as follows:
>
> A Freezing Cycle Day is any day during which the air temperature passes either above or below 32 F. The average number of freezing cycle days in a year may be taken to equal the difference between the mean number of days during which the minimum temperature was 32 F or below and the mean number of days which the maximum temperature was 32 F or below.
>
> Winter Rainfall is the sum, in inches, of the mean monthly corrected precipitation (rainfall) occurring during the period between and including the normal date of the first killing frost in the fall and the normal date of the last killing frost in the spring. The winter rainfall for any period is equal to the total precipitation less one tenth of the total fall of snow, sleet, and hail. Rainfall for a portion of a month is prorated.

The generalized map for the United States is shown in Figure 17. It will be seen that Virginia lies in the area of "severe weathering" with the exception of a small area in the extreme southeast. The weathering index has been considered within ASTM Committee C-9 as a potential indicator for use with modular specifications for concrete aggregates. Larson and Malloy (1966) calculated the weathering index for Pennsylvania with the hope of relating it to performance. They indicated that their sample was not yet large enough to permit sound evaluation. They did indicate, however, that a macroscopic approach to exposure had not proven successful and that a more microscopic approach should be pursued.

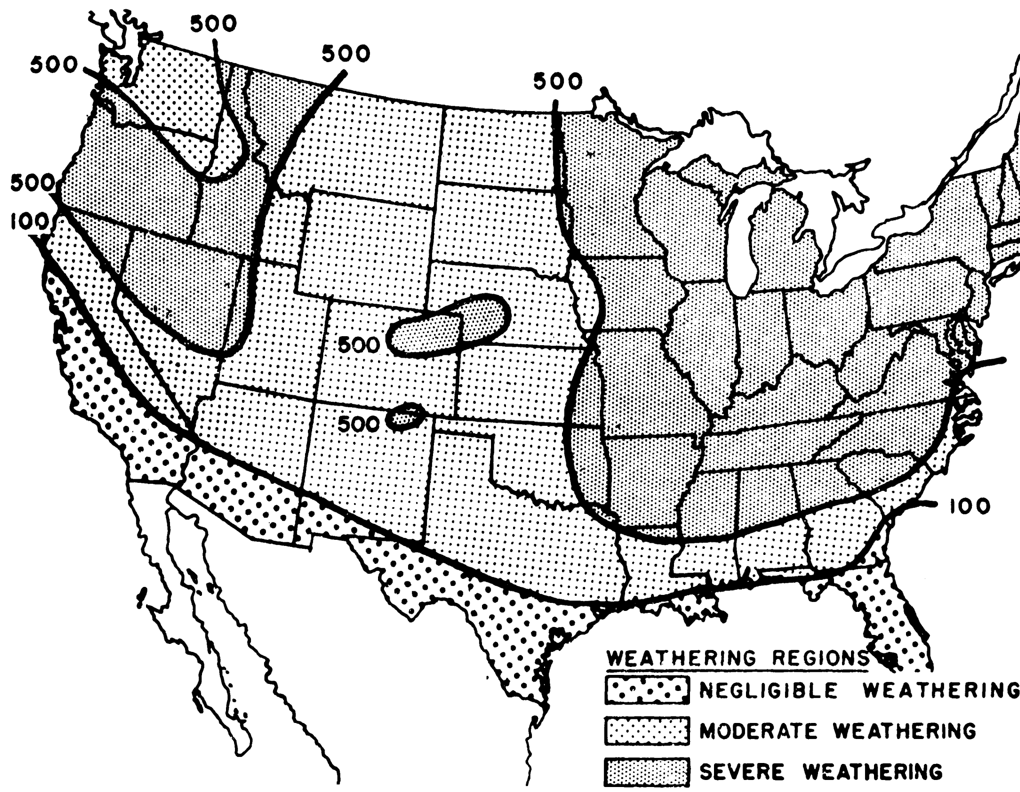


Figure 17. Area in which weathering index of brick is less than 100.

Preparation of a map showing the weathering index for Virginia was conceived as a part of this project. Tapes which purported to contain the data from stations in Virginia for the period 1900 - 1955 were obtained for computer processing from the State Office of the U. S. Weather Bureau. Extensive work with these tapes disclosed that either the data were not sufficiently complete or the tapes were not of sufficient quality for the job. The scope of the project did not warrant preparation of the map from original source data but a recommendation pertaining to such a preparation is made later in this report.

At least a measure of the exposure conditions can be gained from the limited published maps, even those with agricultural orientations.

Figure 18 is a map published by Russell (1943) showing the distribution of "effective" freezing and thawing alterations per year for the eighteen-year period, 1914-1931 inclusive. His concern was with the alterations within the soil as determinable from the air temperatures.

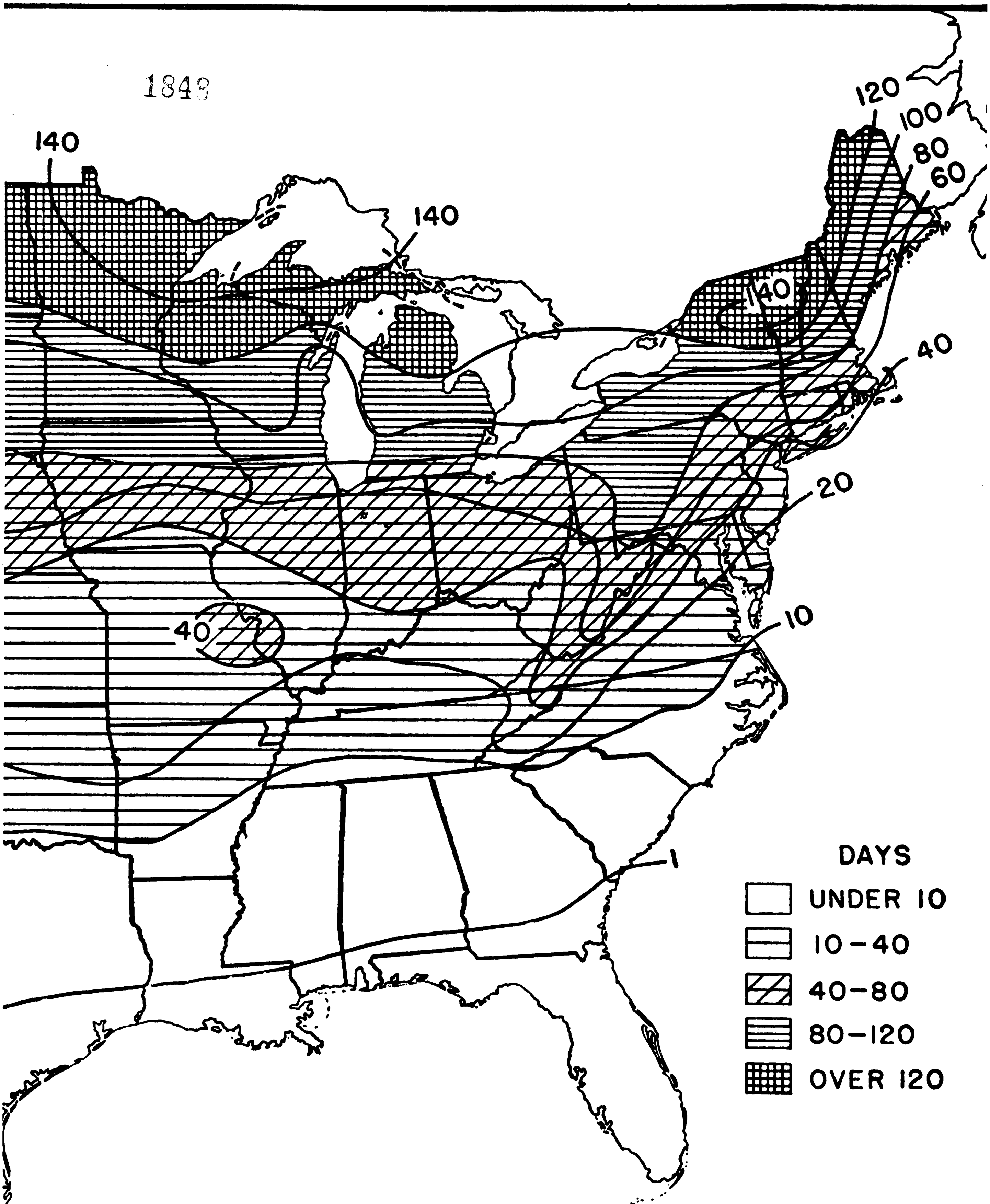


Figure 18. Map showing "effective freezing and thawing cycles for eastern United States." (After Russell.)

While it is an easy matter to determine temperatures of the air and those at a slight depth within the soil, it is extremely difficulty to measure the temperature of the soil-surface itself. The surface temperature is subject to much more rapid and to wider variations than is that either above or below, where determinations are ordinarily made. The only data available in sufficient numbers for distributional studies are those taken in standard instrument shelters at a height of five feet above the surface. Temperatures thus determined fail, often by rather notable amounts, to exhibit the extreme variations experienced at the earth's surface.

For the ground to freeze something more is required than a short drop in temperature to below 32°F. There is a duration factor as well. From many standpoints the effect of lingering temperature barely below freezing is the same as a much more pronounced drop of short duration. The observations made by cooperative observers ordinarily involve a single reading of maximum and minimum thermometers each 24 hours. From these it is often impossible to know much about the duration of any particular low temperature, or the exact number of times the temperature has actually fluctuated past any particular point that might be regarded as critical. Such limitations render it impossible to determine precisely the entire number of times that temperatures fluctuate above or below freezing during the year. The number of alternations between freeze and thaw at the ground surface is even less determinate.

The standard air temperature of 32°F is not a good criterion of effective freeze in terms of such a process as rock weathering. Air reaching the bulb of a thermometer in an instrument-shelter is ordinarily warmer than that immediately in contact with the ground and it may be either notably warmer or colder than that a short distance within the soil. When 32°F is reported as a minimum temperature for a particular day the chances are strong that it represents a freeze of only short duration, one not likely to form ice on pools or interstitially below the surface. From the biological viewpoint the concept 'killing frost' is similar in many respects to that of 'effective freeze' at the surface. It is somewhat easier to observe, however, as the effects on vegetation are evident enough. Under ordinary conditions a short drop in temperature to 28°F constitutes a killing frost, but several hours in the range of 28 - 32°F may be equally effective. The former condition is ascertained readily from records of cooperative observers; the latter is not. With such considerations in mind it was decided that for the purposes of the present study each drop in temperature to 28°F, or lower, be considered as evidence of an effective freeze at the surface. It appears reasonable to believe that the number of cases in which temperatures that low fail to be effective in freezing the surface, for the reason of insufficient duration, will be offset by about a similar number of cases in which prolonged temperatures between 32°F and 28°F are thus effective.

> For an effective thaw the temperature must rise at least to 32°F and remain above freezing long enough to melt surface ice. To effect complete melting the duration may vary on up to days or even months. Melting does not occur simultaneously in all parts of a frozen layer. It occurs first around the margins of surface pools and at interstitial contact surfaces. Once it has progressed to the point where a subsequent freeze will permit new expansive growth of ice, the thaw is effective as far as such processes as rock weathering are concerned and this condition follows soon after surface temperatures rise above freezing. Standard air temperatures may lag behind surface temperatures. When, during rising temperatures, 32°F is reached five feet above the ground the surface itself may be considerably warmer. Under such conditions an effective thaw has been experienced. With such considerations in mind it was decided that for purposes of the present study each rise in temperature to 32°F, or above, be regarded as an effective thaw at the surface.
>
> In making the frequency counts indicated on the accompanying map ... the daily temperature records of a station were followed through the period under consideration and each rise to 32°F following a drop to 28°F, or less, was counted as a single alternation between effective freeze and thaw. If experience should require modification of these critical values there would follow some change in the actual number of alternations per year. It is improbable, however, that the trends of isarythms would show appreciable change. Areas of highest and lowest frequencies would occupy the same positions, and gradients between them would be similar to those shown ....

Although Russell's application was to soils, the reasoning he used has been applied by others to concrete. Larson and Malloy (1966) considered a F-T cycle as a change of air temperature from above 34°F to below 26°F. In evaluating the performance of specimens exposed in a marine environment, Kennedy and Mather (1953) used an air temperature of 28°F as an indication of freezing salt water in the pores of concrete. Decks with residual deicers might approximate this condition. From Figure 18, it is apparent that there is a wide variation of "effective" cycles across Virginia; from as few as 23 in the southeast to as many as 91 in the northeast. With respect to cycles of freezing and thawing, 68 is typical in the western area of the state. These frequencies represent as high as are found in the United States with the exception of the Rocky Mountain areas.

The data from Russell are supported by data published in connection with agricultural studies. Important characteristics are shown in Figures 19-22. In the absence of a single parameter, the severity of climate will be rated semi-quantitatively by ranking the eight construction districts on the basis of the information in Figures 19-22. From least to most severe these would appear to be Suffolk, Richmond, Fredericksburg, Lynchburg, Culpeper, Salem, Bristol, and Staunton.

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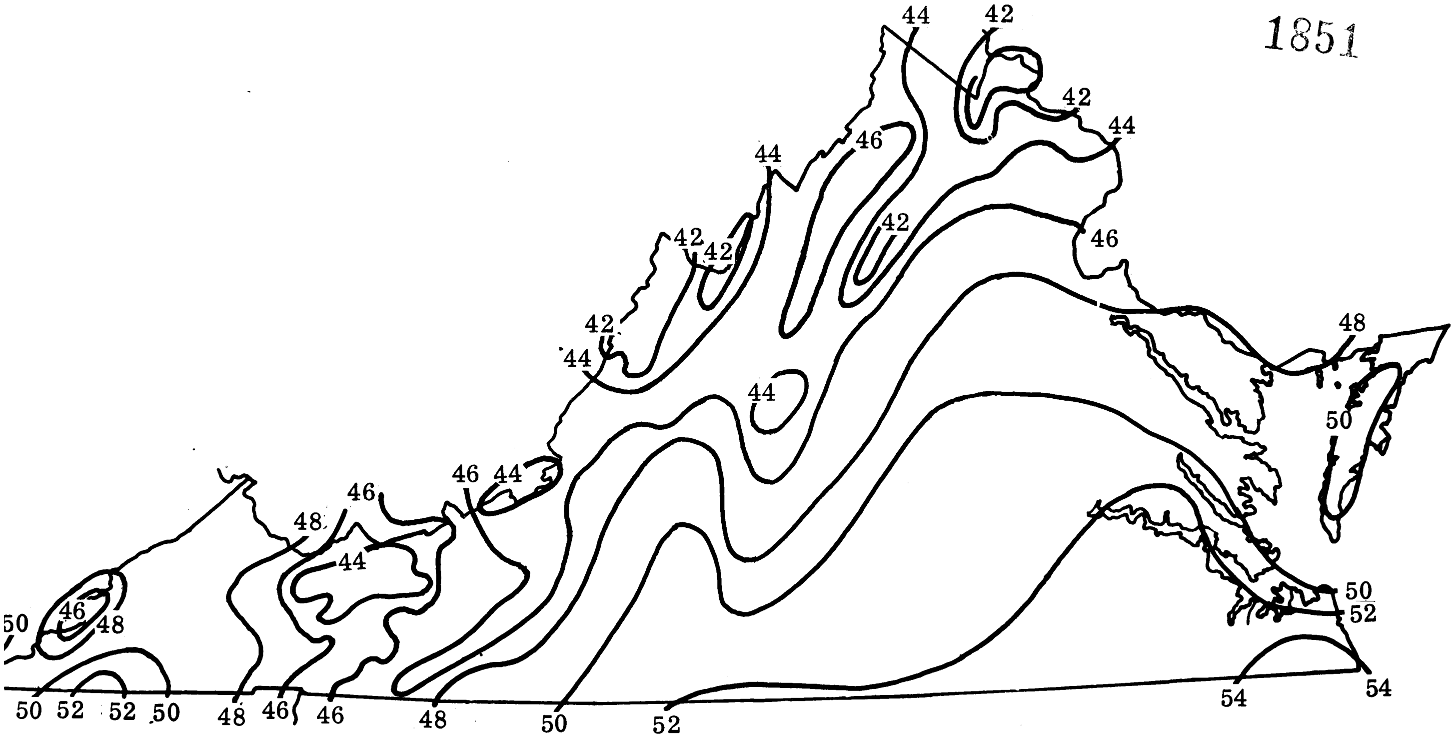

Figure 19a. Mean maximum temperature in degrees F, January, based on period 1931-52.

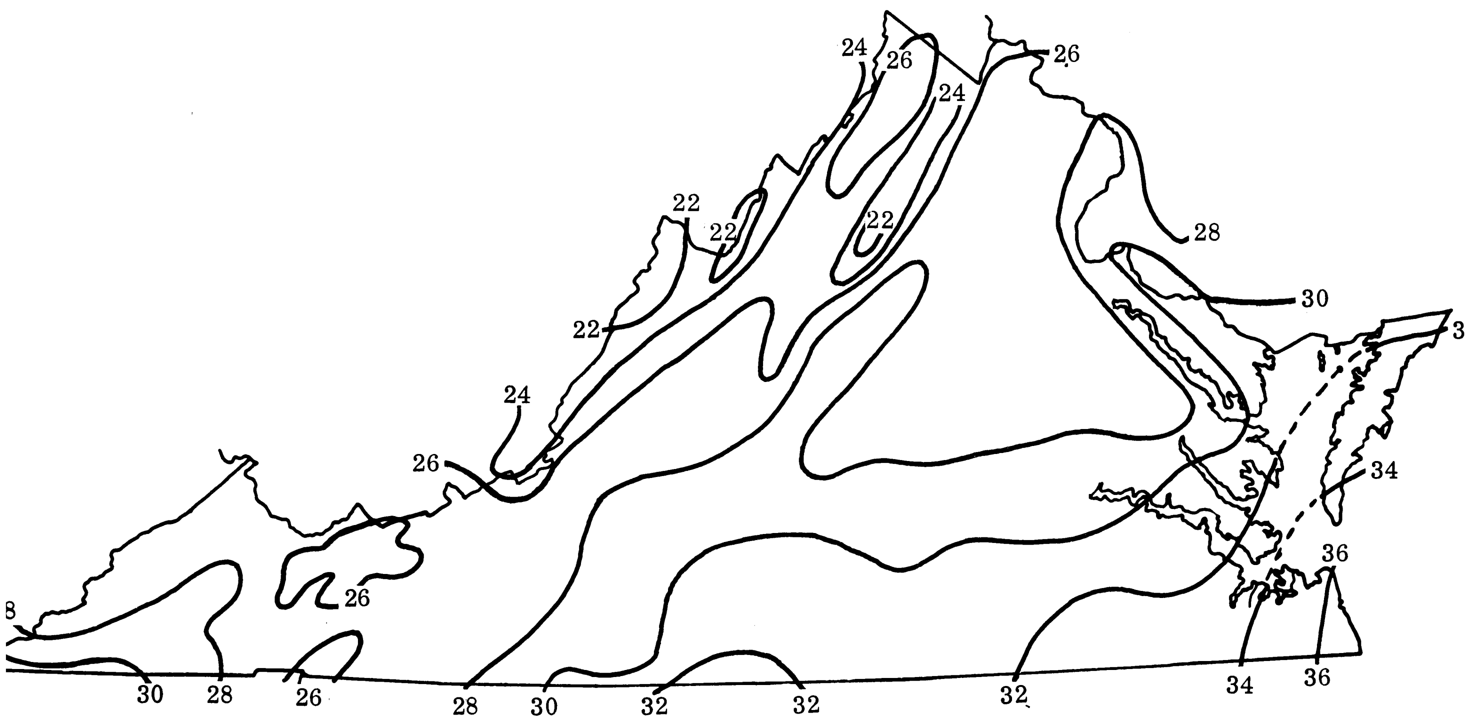

Figure 19b. Mean minimum temperature in degrees F, January, based on period 1931-52.

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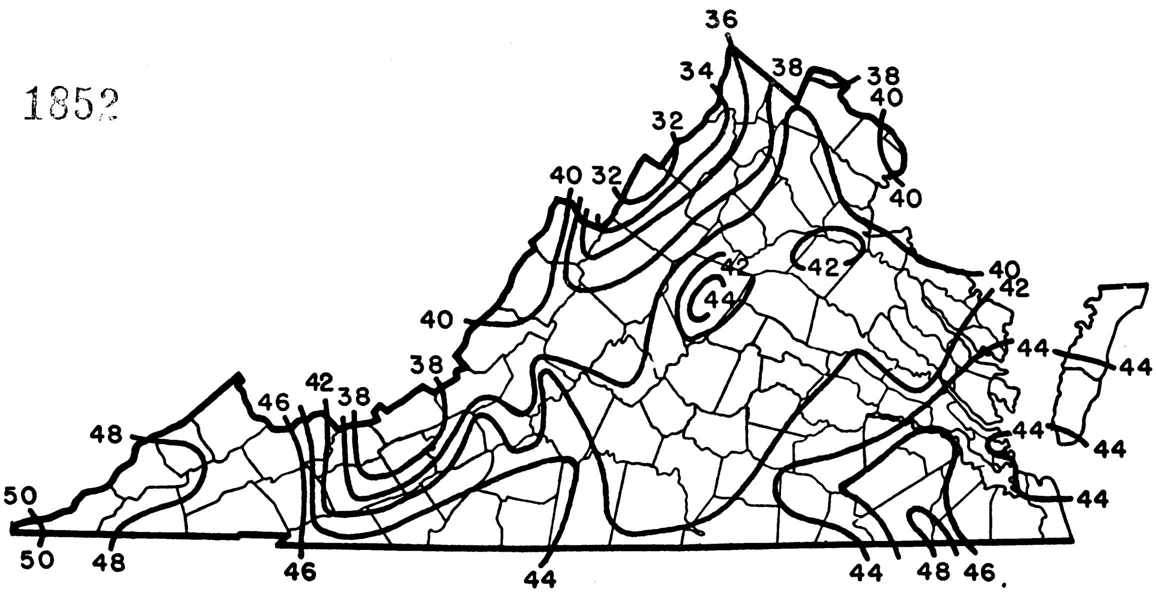

Figure 20. Average annual precipitation, inches. (After Hibbard.)

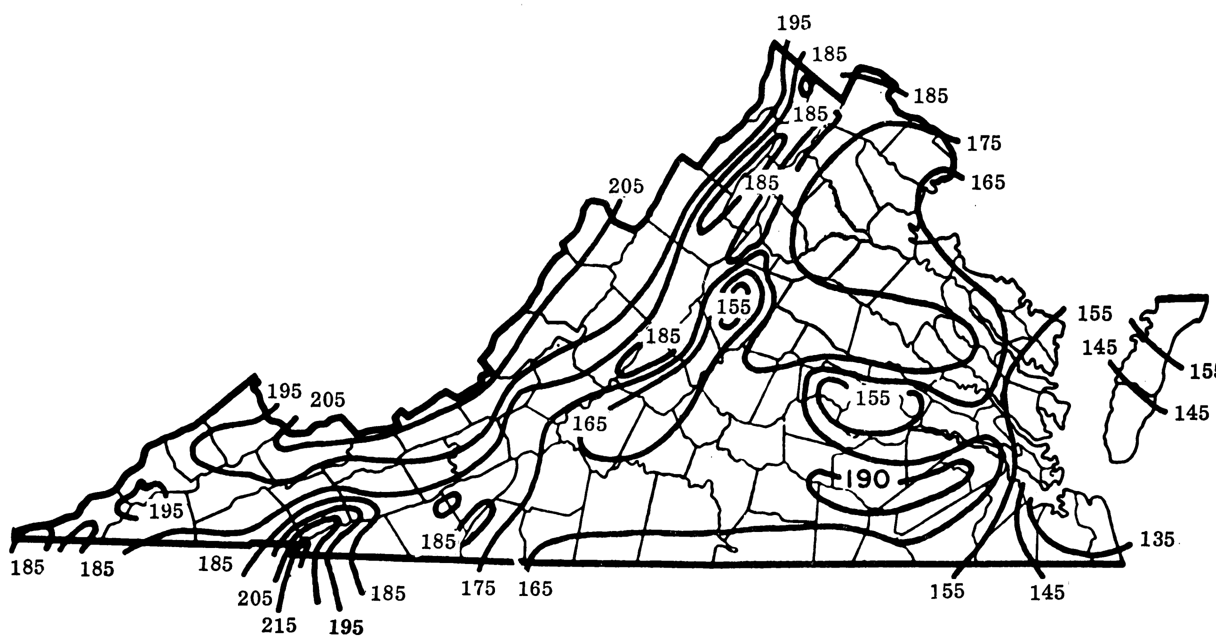

Figure 21. Average number of days during which killing frosts occur.

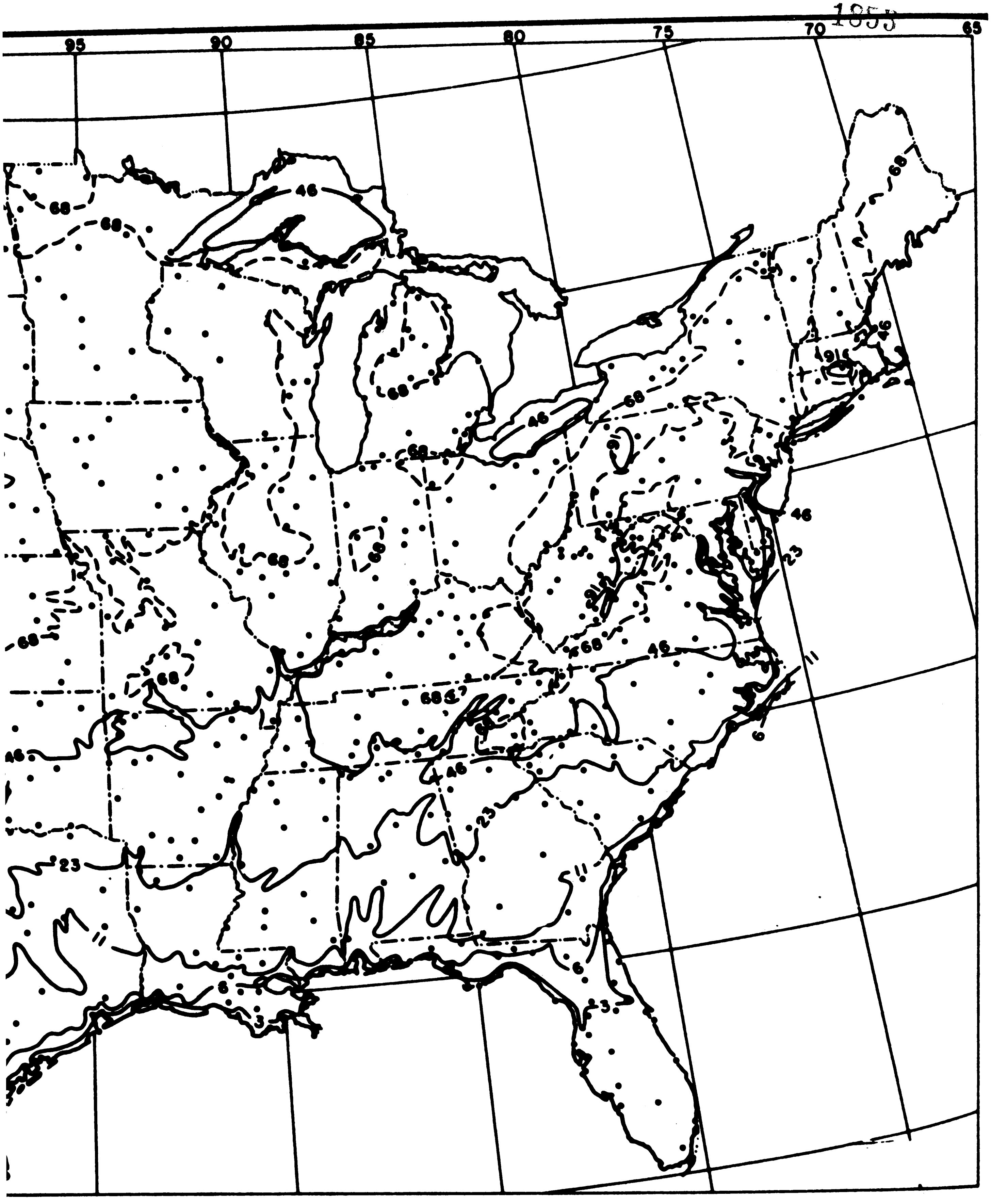

Figure 22. Isolines showing days with snow cover greater than 1". (After Hibbard.)

Investigation of relationships between climatic factors and all of the defects shown in Table III is not fruitful for many reasons. The mechanisms of formation for many of the defects are not directly related to the climate or are only secondarily so. In the case of scaling, which is, such a small portion of the spans were free from scaling that there is nothing against which to compare them. In the case of spalling, which may be indirectly influenced by the weather in that the potential for corrosion from applications of chlorides increases with severity of climate, the opposite is the case; nearly all are free from spalling.

Only one comparison was attempted. The distribution of the bridges showing scaling in the three most severe classifications (Table IV) was obtained. The results are shown in Table VIII.

TABLE VIII

OCCURRENCE OF MODERATE TO SEVERE SCALING BY DISTRICTS (1961-1970)

District (In order of Decreasing Exposure Severity)	Number of Spans Inspected	Spans Affected with Scaling as a Percentage of those Inspected
Staunton	37	38
Bristol	36	3 (18 of 36 spans resurfaced)
Salem	32	25
Culpeper	29	35
Lynchburg	56	12
Fredericksburg	17	70
Richmond	30	26
Suffolk	31	13

The results are not particularly definitive except that the two least affected districts are in the lower half of the listing (reflecting less severe exposure). The high result in the Fredericksburg District may be related to the small sample. If this is excluded there are more severely affected districts in the upper half of the listing than in the lower half, thus reflecting the general relationship between exposure and performance. As noted earlier Larson and Malloy (1966) found only a limited correlation between macroclimate and performance.

RELIABILITY AND REPRODUCIBILITY OF THE SURVEYS

The many factors affecting deck performance and the variability, even within a given span, raise questions as to the reliability and reproducibility of these and similar surveys. Although no direct proofs are possible several indications from the experiences in Virginia lend support to the reliability.

It should be borne in mind that the random survey (BPR — PCA 1969) did not include the same number of bridges from each district. Although it is not mentioned in the report, the breakdown by district was as follows:

Bristol	20
Salem	21
Staunton	15
Culpeper	25
Fredericksburg	5
Suffolk	11
Richmond	24
Lynchburg	19
Total	140

This turns out to be a relatively good distribution although there were relatively few in the Suffolk and Fredericksburg Districts, which have comparatively mild exposures. The same is true, however, for the Staunton District, which is a severe exposure. Thus the sample to some extent represents the median exposure.

The concept upon which the PCA — BPR random survey was based was that the condition of the bridges within a given state would be estimated from surveys of a randomly selected source and that randomly drawn samples from the eight participating states would reflect the condition of bridges over the nation. The sample size was determined using statistical concepts with the intent that the limit of error would be ± 8 percent, with a probability of not exceeding this limit fixed at two standard deviations; that is, 95 percent of the results would fall within the ± 8 percent limit.

At approximately the same time that the random survey was conducted in Virginia, the Council was conducting a less detailed survey of all of the decks in the four western districts. This survey made in 1964 was a part of the study of Potentially Reactive Carbonate Aggregates (Sherwood and Newlon 1964). The results have not been completely analyzed. Some preliminary results from a single district are, however, of interest and are shown in Table IX.

The general agreement between surveys of two different groups of bridges shown earlier in Table VI and the concurrence reflected in the reasonable progression of defects recorded from two separate surveys of the same group suggest that the observational techniques and method of selecting the sample size used in the PCA — BPR Survey do result in essential agreement and are reliable and reproducible.

1856

TABLE IX

RESULTS FROM RANDOM AND COUNCIL SURVEYS ON COMPARABLE SPANS

Defect	Random Survey (1961)	Council's Survey of One District (1964)
Deck Resurfaced	40	38
Moderate or Worse Scaling	18	22
Cracking	33	40
Spalling	0	0

DISCUSSION OF VIRGINIA'S DECK PERFORMANCE

When compared with the performance of decks in the other states included in the random survey and with published reports from other areas, the performance of the decks included in the Virginia sample is comparatively good. It is true that 51 percent of the spans have been resurfaced within twenty years of their original construction, but there are indications that many of these resurfacings had been placed more as a matter of convenience than for correction of subpar performance. Others were placed with the hope of delaying potential problems. The rate of resurfacing has been decreasing in recent years.

While the state is located in a temperate climate the weathering conditions are in some respects severe, particularly with respect to cycles of freezing and thawing. The late adoption of air entrainment is reflected in the high incidence of scaling. For those bridges constructed with concrete containing entrained air, the concrete did not contain amounts consistent with the amounts subsequently shown to be required for durability of structural concrete.

The absence of widespread spalling and serious cracking is fortunate, and while reasons cannot be definitely stated, the use of 1-11/16" clear cover and a high proportion of simply supported spans are likely major contributors. Seventy-five percent of the uncovered spans in the original sample were simply supported.

As previously shown in Table VII, the specification requirements for deck concrete have been progressively upgraded since about 1965. This upgrading has been concomitant with upgrading of construction techniques including the requirement of machine screeding and a general emphasis upon the demands for diligence in inspection and controls. Intensive training and certification programs for producer and Department personnel involved in concrete construction have also provided benefits. Although no quantitative data are available for assessing the improvement in deck performance, it is generally conceded that despite the increased demands being placed upon concrete in decks, and the increasing use of deicing chemicals,the performance has improved since the survey was made. The initial PCA — BPR survey and this updating provide a basis, along with the Council's finishing study,from which to assess quantitatively from future surveys the benefits of improvements in materials and construction procedures and increased attention to the details of good practices.

CONCLUSIONS

Based upon the observations and data developed, the conclusions below appear warranted. It should be emphasized that the behavior reflected by the results is that obtained under specifications and techniques used during the period of construction (1940-1961) rather than those currently in use.

(1) Listed in order of decreasing frequency, the defects observed during the 1970 resurvey were scaling, cracking, popouts, spalling, and rusting. This is the same order as was reported for the initial survey in 1961.

(2) The percentage of spans affected by each of the defects increased between surveys. Considering all defects except those in the lowest severity category of each classification, scaling increased from 13 to 31 percent, cracking from 3 to 13 percent, and spalling from 0 to 6 percent. Changes in the other defects were insignificant. These changes are believed to be reasonable in view of the environmental factors and the specification requirement, subsequently upgraded, which existed at the time of construction.

(3) The types of cracking observed in 1970 in decreasing order of frequency, were transverse, random, pattern, longitudinal, and diagonal. No "D" cracking has been found in either of the Virginia surveys, or nationwide.

(4) The order of frequency of defects from the sample in the random survey as well as from the smaller sample included in the Council's study of finishing methods on bridges exposed for about the same period as those in the random survey was approximately the same and the percentages of spans affected by each type of defect agreed closely. The percentages of spans showing the various types of cracking also agreed closely.

(5) Because the details concerning the construction of the decks included in the random survey are not available, correlations of the materials and construction characteristics with performance is not possible. The close agreement between the performance of the decks in the random survey and those in the Council's finishing study, for which detailed observations were made during construction, indicates that causative relations developed from that study can be extrapolated to the performance of the larger sample.

(6) Analyses of weather data developed in connection with this survey indicate the wide variety of environments to which Virginia's bridge decks are subjected concomitant with the variation in locally available materials, and emphasize the difficulties of meeting these variable conditions with a single specification applied statewide.

1858

(7) The agreement among the results from surveys conducted at different times and on different samples validates the survey methodology and sampling plan developed for the original survey.

(8) Action taken in 1966 to upgrade specifications for bridge deck concrete (see Table VII) included upgraded requirements for entrained air content, and water-cement ratio, both of which should greatly reduce the incidence of the most prevalent defect observed in the survey, namely scaling.

(9) Although not documentable, the comparatively low frequency of surface spalling when compared with performance in the other states included in the survey is probably related to the provision of 1-11/16" clear cover reinforcement. Adequate cover, per se, is not a complete solution to the problem of surface spalling since the quality of concrete is also important, but there is no evidence to support the belief that the concrete quality was significantly better in Virginia than in other states.

RECOMMENDATIONS

(1) In view of the changes in specification requirements and construction techniques initiated in 1965, it would be of value to assess the performance of decks constructed under the new requirements. The concurring results from the random study and finishing study suggest that the approach used in either study would be valid.

(2) The variety of physical and climatological characteristics confronting the state suggest that efforts be made toward a modular and regional specification, not only for bridge decks but for other applications as well. One phase of this would be to refine the characterization of the environments to which concrete is exposed under field conditions.

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APPENDIX

DEFINITIONS AND FORM USED IN BRIDGE SURVEY

The following criteria were used in the surveys and are taken from PCA — BPR Report No. 5 (1969).

The observations were reported on a standard data sheet as shown in Figure A-1. One or more sheets were required for each bridge. Data describing each bridge included: state; county; highway number; survey bridge number; state bridge number; year built; type of deck covering, if any; type of deck repairs, if any; traffic volume (ADTC); use of air-entrained concrete; availability of construction records; span lengths; and span types.

A dual bridge was considered as two individual bridges. A widened bridge was either dropped from the survey or inspected only for information on the old portion.

Any observed defects were reported for each individual span.

On the data sheets, scaling was reported as an estimated percentage of the affected span's deck area for the average severity condition — in box 1 for light scale; box 2, medium scale; box 3, heavy scale; and box 4, severe scale. An X was also placed in the box that designated the most severe scaling condition observed in the span. For example, in Figure A-1, 70 percent of the area of span 4, had an average scaling condition classified as medium scale, and heavy scale was encountered in portions of the scaled areas.

The six classifications of cracking — box 1 for transverse; box 2, longitudinal; box 3, diagonal; box 4, pattern or map; box 5, "D"; and box 6, random — were reported as being light, medium, or heavy (L, M, or H). Light cracking meant widely spaced, fine cracks or only a few cracks in the span. Heavy cracking meant closely spaced, wide (prominent) cracks, or many cracks in a span. For example, in Figure A-1, medium transverse cracking (box 1) was observed in span 1 of the bridge, heavy in span 3, and light in span 4. Random cracking (box 6) of the same severity was found on the same spans. There was no visible longitudinal (box 2), diagonal (box 3), pattern (box 4), or "D" (box 5) cracking in any spans.

The presence of any rust stains on the deck surface was reported by an R in the box for the particular span.

Surface spalls were reported as small (box 1) or large (box 2). The number of spalls in each affected span were reported.

Joint spalls were reported by the estimated linear footage spalled along the joint. The spalls were classified according to the type of joint on which they occurred: along a metal expansion device (box 1); along a joint filled with sealing material (box 2); or along a construction joint or open joint (box 3).

Popouts were reported as being few (F) or many (M) in the judgment of the inspector.

1862

R-300 (6/70)

DATA SHEET FOR RANDOM BRIDGE SURVEY INSPECTION REPORT

HAYS CREEK AT BROWNSBURG

State VA. County ROCKBRIDGE Highway Nos. 252 Bridge No. CXL1-1

Year Built 1958 Deck: Uncovered ✓ Covered ____ Type of Cover NONE

Is detailed construction data available? ____

What type of deck repair or reconstruction has been done? NONE

Span No. 1 has been selected as the N (S) E W end of bridge. (Circle One)

****

AE

Classification of Deck Deterioration

Span No.		1	2	3	4	5	6	Remarks
Length-ft.		57	57	57	57			
Girder Type		SS-IB-SC						
Scaling	1	75%	90%	60%				1968 ADTC 315
	2	X	X	X	70%			
	3				X			
	4							
Cracking	1	M		H	L			
	2							
	3							
	4							
	5							
	6	M		H	L			
Rusting	1							
Surface Spall	1							
	2							
Joint Spall	1							
	2							
	3							
Pop-Out	1			FEW				

Comments: 2 LANES 4-57' S.B. SPANS (MSC -24-55⅓)
3rd SPAN - MIDDLE SECTION HAS HEAVY CRACKING TRANSVERSELY
4th SPAN - 20% HEAVY SCALING

Date of Inspection 6-17-70 Inspector NORTH - DAVIS District Office ____

Figure A-1. Survey Data Sheet.