# BRIDGE DECK CONDITION SURVEY

## PART 1 - OUTLINE OF THE PROJECT AND FINDINGS FROM THE SURVEY

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Research Report 106-1F
Part 1

Study 2-18 106
Statistical Evaluati f Bridge Deck
Condition Survey Data

Sponsored by

The Texas Highway Department
in cooperation with the
Department of Transportation, Federal Highway Administration

May 1970

TEXAS TRANSPORTATION INSTITUTE
Texas A&M University
College Station, Texas

# ACKNOWLEDGEMENT

Many individuals contributed to the collection and evaluation of the information used in this report. These contributions are gratefully acknowledged. Special acknowledgement is made to Mr. Dale Shafer, Texas Transportation Institute, and to Mr. Charles Shupp, Automation Division, Texas Highway Department, for their contribution in computer programming and processing.

# PREFACE

This report consists of three parts.

Part 1 - A summary report giving survey methodology, description of data, principal findings, conclusions and recommendations. Apart from some graphical summaries no supporting data are given in this part.

Part 2 - Relative frequency tables displaying associations between structural characters and deck conditions. This contains the supporting data in the form of tables for all structural character/deck condition combinations that the authors judged to be of significance - see Part 1, Table 3 for a graphic summary of these combinations.

Part 3 - Computer tabulations. A limited edition of four complete sets of the computer tabulations are ilable for examination - see Part 2 for their locations. Each se nsists of three volumes. Volume 1 contains the 585 pairs of tables resulti from cross-tabulating the 45 structural characters against each of t 13 deck conditions. Each pair of tables consists of a pour frequency table and a relative frequency table, where the relative frequencies are computed on a row basis; i.e., the distribution of pour conditions within a given structural category. Volume 2 contains 809 of the possible 990 cross-tabulation combinations of the 45 structural characters. Volume 3 contains the 78 cross-tabulation combinations of the 13 deck condition characters.

# ABSTRACT

The bridge deck survey herein reported was based on a stratified random sample of bridges. The primary strata were in 25 Texas Highway Department districts; while, within each district, stratification was based on age and/or type of structure. Bridges within the secondary strata were randomly selected at a rate of 20 percent. This ensured an adequate representation of all types of bridges currently in use on highways throughout Texas.

Structure evaluations were made in each THD district by a team from that district. Training and monitoring for consistency were handled by THD D-18 personnel.

The documentation on each bridge included type of construction, age, traffic, location, and other structure-related information. The on-site examination of the bridge deck was done on the b of individual concrete pours. These were scored with respect to scaling, elamination, cracking, and general deck condition. The results of examining 5,300 bridges, whose decks were made up of about 36,000 pours, were t available for summarization.

A complete tabulation of the 45 structural characters versus the 13 deck condition items was made. These association tables were examined and the subset of some 300+, judged by the authors to be of significance, are presented in the form of relative frequency tables. Cross tabulations among structural characters and among condition characters were also made and, while not reported directly, were considered in some of the written

discussion. The computer tabulations can be made available for further study.

This study represents a joint effort by THD and Texas Transportation Institute personnel. THD personnel conducted the time-consuming field survey, and the transfer of data from survey sheets via cards to magnetic tape. TTI personnel assisted in selecting the sample and supervised the data summarization, evaluated the results, and prepared the final report.

* * * *

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the Federal Highway Administration.

# SUMMARY

This report summarizes the findings of a statewide survey of highway bridge decks in Texas. Each structure selected in the stratified random sample was scored by a survey team. This team was comprised of district personnel selected to provide representation from the various technologies involved. Each team was responsible only for surveying those structures falling within its home district. The teams were trained, and their reports monitored for consistency, by THD D-18 personnel. Altogether in the state these teams examined and recorded information on approximately 36,000 deck pours on some 5,300 bridges.

The information was classified as to structural variables and condition variables. There were forty-five structural characteristics, such as bridge type, age, design specification, traffic density, etc., and 13 deck condition variables, such as degre[illegible]d extent of scaling, cracking, delamination, and general deck condi[illegible]. The structural characteristics were paired with condition variables [illegible] tables showing both frequency of pours and percentage of pours unde[illegible]ach condition. All tables were appraised as to whether or not there were evidences of statistical association between the structural characteristics and the condition variables. A relative frequency table was then prepared for each combination which gave evidence of real association.

The study has been able to point to only general trends displayed in the data. It revealed that there are interrelationships between

many of the structural characters and the various measures of deck condition. Certainly no one structural character can be singled out as being the prime suspect causing deterioration.

The study revealed that scaling is enhanced by the use of deicing salt and is markedly reduced in air-entrained concrete. There is considerable longitudinal cracking in pan formed bridges, but it is predominately transverse in other types. Decks supported on steel beams are more severely deteriorated than are those supported by concrete beams. There is only a slight advantage shown for central mixed concrete over transit mixed concrete. The decks with the normal type crown show considerably less deterioration than those with a crown of constant slope. Bridges with higher traffic density show a somewhat lower percentage of severe deterioration than those with low traffic density; but higher traffic density is associated with the newer bridges which were built under more recently established design specifications. Bridges carrying greater wheel loads, too, appear to be in better condition overall than those with lighter loads, but here again, age is a significant factor.

There appears to be a little less cracking and scaling of decks in those bridges in which retarding and water reducing admixtures were included in the concrete mix.

Recommendations made on the basis of the study include:

1. Use only air-entrained concrete for decks on bridges built in areas subject to icing condition, i.e., where salt is likely to be used as a deicing agent.

2. A controlled study should be made to determine if retarders and water reducing admixtures provide better concrete for bridge decks.

3. Determine why slabs supported on steel beams have not been as durable as those supported on concrete beams.

4. There is some indication that slabs using Type III cement are more durable than those using Type I cement. Other variables, primarily age, doubtless play a part, but it should be determined if there is a difference in deck performance due to type of cement.

5. Develop and maintain a formal program of inspection and record keeping on every structure; this would lead to a better understanding of the deterioration process. This would also be of considerable value in establishing the cost of service of a structure and would also serve as a basis for the modification of design, construction, and maintenance criteria.

## IMPLEMENTATION

The interrelation of events of nature, design details, construction practices, service conditions, and maintenance practices on the performance of bridge decks can be seen in the data in Parts 2 and 3 of this report.

It is impossible to single out any one factor as the prime cause of a particular deterioration condition. Nevertheless, it is possible to make certain recommendations which should lead to improved performance.

The recommendations made here are based on information gathered in the survey, common knowledge of the technology necessary to produce high quality durable concrete, and judgment as to the long range value of condition surveys such as was made in collecting the data treated in this report.

It is recommended that the following steps be taken to strengthen current practices for producing high performance bridge decks, to add to knowledge desirable for improvement of practices, and to provide a base from which service costs and service life of structures might be firmly established.

1. Use only air-entrained concrete for decks on bridges built in areas subject to icing conditions, i.e., where chlorides are likely to be used for deicing.

2. The data indicate that crack spacing is reduced and scaling is less severe in concrete in which retarders and water reducers have been incorporated. Field observations should be made to determine the extent

of benefits resulting from the use of these agents.

3. Determine why slabs supported on steel beams have not been as durable as those supported on concrete beams.

4. There is some indication that slabs using Type III cement are more durable than those using Type I cement. Other variables, primarily age, doubtless play a part, but it should be determined if there is a difference in deck performance due to type of cement.

5. Develop and maintain a formal program of inspection and record keeping on every structure which would lead to a better understanding of the deterioration process. Such a program would also be of considerable value in establishing the cost of service of a structure, and could serve as a basis for the modification of design, construction, and maintenance criteria.

6. The data analyses carried out to date, and herein reported, have not fully probed the possibilities inheren the large mass of data collected. Further examination of the data would seem to be warranted, since only individual structural characters ive been examined in detail against the condition variables. Cross-classifications among two or more structural characters, as these affect the condition response variables, could shed light on such aspects as the influence of age of structure upon other structural characters and their resultant performance. Age of structure is one such character but there are several others which may merit similar examination.

# PART 1 - OUTLINE OF THE PROJECT AND FINDINGS FROM THE SURVEY

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## BRIDGE DECK CONDITION SURVEY - PART 1

## I. INTRODUCTION

### A. General Information

The interpretation of data collected by the Texas Highway Department (THD) in a statewide physical survey of highway bridges is the primary purpose of this report. It is hoped that it will be useful to the THD as an aid in determining the overall condition of highway bridges in the state, the planning of maintenance operation, and as a guide in future bridge engineering.

The survey covered essentially all bridges controlled at the state level. It was limited to matters pertaining to concrete bridge decks, but includes substructure conditions as supporting data.

The conditions of the deck were c ved on the basis of individual concrete pours, in terms of cracking, ing, delamination, and general deck condition. Each of these condition ite were scaled by a number code denoting the degree of severity to help fine the main problem of deterioration.

Information relating to the geographical location of the bridge, structural data, construction materials and practices, weather, and maintenance was recorded to assist in the interpretation.

The sections that follow give the conclusions reached from a study of the data; descriptions of the data that were collected; and the basis of evaluation, organization, and interpretation of the data.

## B. The Design of the Sample

The chief consideration in selecting any sample is that it be representative of the population from which it is drawn. The sampling plan selected and used in this survey is commonly known as a stratified random sample. By stratifying and drawing random samples from within the strata it is possible to insure a closer approach to a representative sample than could be obtained by simply selecting a random sample from the designated population.

The basis of stratification recognized the possible influence of geographical location, age of bridge, and general type of structure. The primary strata were the 25 THD Districts, thus blanketing all of the geographical variation in the state. Eight substrata were defined within a district as follows:

1. Structures completed before 1946 - Type I.
2. Structures completed before 1946 - Type
3. Structures completed 1946 - 1955 - Type I.
4. Structures completed 1946 - 1955 - Type II.
5. Structures completed after 1955 - Type I.
6. Structures completed after 1955 - Type II.
7. All ages - Type III and IV.
8. Timber structures.

The age component was partitioned somewhat arbitrarily but with the following general considerations in mind:

Before 1946 - included all structures of pre World War II construction still being used in the highway system;

1946-1955 - during this period the use of continuous steel construction increased rapidly;

After 1955 - the increased construction activity due to adoption of the Interstate Highway Program and the bulk of all prestressed concrete construction occurred during this period.

The structure types group the structures as follows:

Type I - Concrete deck supported by steel stringers
Type II - Concrete bridges and certain timber structures
Type III - Truss bridges
Type IV - Miscellaneous bridge types
Type V - Culverts and other types.

All of the eight substrata listed above were sampled, but number 8 - Timber Structures, was not included in the survey summaries. Since the primary target of the survey was bridge condition, the structures grouped under Type V were not included in the [illegible]le. For the purposes of this survey, any structure with a span twenty or more feet long was classed as a bridge.

The actual selection of the sample of structures to be examined was carried out in the following manner. From structure information already on magnetic tape within THD a new tape was prepared which listed the structures by districts and by substrata within districts. Sample structures were selected within each substratum utilizing a psuedo random number generator. Initially a ten percent sampling rate was used, but this was later increased to twenty percent. As the individual structures were selected from the substrata within a district, locational and other pertinent information was recovered from the master tape and a printed listing prepared for transmission to the individual districts, thus giving them a prepared listing of structures to be evaluated.

The Districts also evaluated and submitted completed data forms for additional structures which were considered to be in a deteriorated condition. This evaluation was to be processed separately from the ten percent random sample to support deterioration findings or to determine actual deterioration quantities.

The total number of bridges in the defined population was 12,160. All types of culverts, as well as bridges not having concrete decks, were excluded from the study. A ten percent sample consisted of 1,218 bridges and ultimately a twenty percent sample (2,436 bridges) was drawn. Eventually, the twenty percent sample was augmented by many other bridges which individual Districts reported. For example, one of the Districts had evaluated seventy percent of the structures under control. Thus, the report is based on an evaluation of 5,282 bridges, more than forty percent of the total in the state.

### C. Collection, Editing, and Tape Preparation of Field Data

The major responsibility for the activities of collection and editing of the field data rested with the THD Maintenance Division (D-18). Their staff, together with personnel from the Bridge Division, participated in the training sessions with the individual District teams. A manual (1)

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[1] Procedure for Interpreting General Deck Condition in Recording Data on Bridge Deck Survey Form No. 1102, Texas Highway Department, Maintenance Operations Division, Austin, Texas. August 1965.

on procedure for determining deck condition was used by each field survey team to achieve optimum uniformity in interpreting bridge conditions. The completed survey records were sent to D-18 where they were carefully scrutinized for consistency of the evaluations, completeness, etc. If there were questions or obvious errors, missing information, etc., the forms were returned to the District for clarification and, if necessary, re-evaluation of the structure(s) in question. This was a massive editing job which had to be worked in along with the regular work load.

Once the survey forms were accepted as satisfactory they were passed along to the Division of Automation. There the data were punched on cards, verified and then placed on magnetic tape for further processing.

The survey form appears in the appendix.

## D. Data Analysis

This project was set up to take the survey data tapes as the starting point and, from this mass of information, extract such meaningful information as might exist.

The basic analysis was one of preparing and interpreting tabulations involving the 45 structure associated variables and the 13 deck condition variables, see Table 1. Additional studies had been proposed in the project outline as approved, but were not accomplished because of time limitations.

Rather than looking only at a subset of data tables believed to be of importance, it was decided to prepare all possible summary tables and then report on those showing meaningful associations. Table 2 shows all of the possible 13 x 45 = 585 tables that were constructed by cross-tabulating

TABLE 1

## BRIDGE DECK CLASSIFICATION CODES

### FACTORS ASSOCIATED WITH THE STRUCTURE

| NUMBER | NAME |
|---|---|
| 1 | District number (of the THD) |
| 2 | Design specification (by year only) |
| 3 | Design loading (by AASHO loading) |
| 4 | Span type |
| 5 | Structure type |
| 6 | Main member type |
| 7 | Stringer spacing |
| 8 | Skew (degrees) |
| 9 | Crown type |
| 10 | Type of deck (kind of concrete) |
| 11 | Simple or continuous structure |
| 12 | Span length of simple span |
| 13 | Span length of beginning span of a continuous unit |
| 14 | Span length of second span of a continuous unit |
| 15 | Total length of continuous un |
| 16 | Number of spans in continuous unit |
| 17 | Unsymmetrical unit (yes or no) |
| 18 | Substructure type |
| 19 | Slab thickness |
| 20 | Traffic volume (vehicles per day) |
| 21 | Structure classification |
| 22 | Heaviest wheel load (kips) |
| 23 | Transit mix (yes or no) |
| 24 | Percentage of entrained air |
| 25 | Type admix |
| 26 | Type cement |
| 27 | Source of cement |
| 28 | Cement, sacks per cubic yard of concrete |
| 29 | Type of aggregate |
| 30 | Type of finish |

## Table 1 (Cont'd)

| | |
|---|---|
| 31 | Month slab placed |
| 32 | Year slab placed |
| 33 | Month bridge opened to traffic |
| 34 | Year bridge opened to traffic |
| 35 | Type of overlay |
| 36 | Month overlay applied |
| 37 | Year overlay applied |
| 38 | Condition of overlay |
| 39 | First year salt applied |
| 40 | Salt applications per year (number) |
| 41 | Sulfate stream (yes or no - does bridge cross sulfate stream?) |
| 42 | Condition of substructure |
| 43 | Slab drainage (good, fair, poor) |
| 44 | Weather at pouring |
| 45 | Moment Condition |

### CONDITIONS ASSOCIATED WIT )IVIDUAL POURS

| NUMBER | NAME |
|---|---|
| 50 | Cracking, degree |
| 51 | Cracking, type |
| 52 | Cracking, average spacing |
| 53 | Cracking, location (on the deck) |
| 54 | Scaling, degree |
| 55 | Scaling, depth |
| 56 | Scaling, percent area |
| 57 | Scaling, location (on the deck) |
| 58 | Delamination, degree |
| 59 | Delamination, visual cracking (yes or no) |
| 60 | Delamination, percent area |
| 61 | Delamination, location (on the deck) |
| 62 | General Deck Condition |

each one of the 45 structural items against each of the 13 condition items.

A rather general table-producing computer program was prepared and the following sets of tables produced, using the edited data tapes:

1. Structure (45) by condition (13) - 585 tables;
2. All possible different combinations among the 13 conditions - 78 tables;
3. Almost all possible different combinations among the 45 structure associated characters - 809 out of a possible 990 tables;
4. Structures (45) by joint condition (4) - 180 tables.

Thus, 1,652 pairs of tables were produced.

The pair of tables consisted of a frequency table, either on the basis of concrete pours (36,058) or of structures (5,282), depending upon the table group; and of a relative frequency table using row totals as the basis. These latter tables were especially useful in assessing the information compiled for structures versus conditions, in which the rows were the categories within a structural character.

The distribution of frequencies in the cells of these tables was such that the use of the chi-square test for independence was not sensitive to changes because there were too many cells with either very low or zero frequencies. For this reason, when it came to screening the tables for evidences of association between variables, a visual assessment was resorted to. Each author screened the table set independently then, for those tables where the decision was not unanimous, they reviewed the particular tables in conference and rendered a decision.

TABLE 2. A LISTING OF DESIGN AND CONDITION PARAMETERS

INDICATING THEIR ASSOCIATIONS

Note: X indicates that the association between the parameters is significant.

| | 50 Cracking Degree | 51 Cracking Type | 52 Cracking Spacing | 53 Cracking Location | 54 Scaling Degree | 55 Scaling Depth | 56 Scaling Pctg Area | 57 Scaling Location | 58 Delamination Degree | 59 Delam. Visual Cracks | 60 Delam. Pctg Area | 61 Delam. Location | 62 General Deck Cond. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. THD District | X | | X | | X | X | X | X | X | | | | X |
| 2. Design Specification | X | X | X | | X | X | X | X | X | | X | | |
| 3. Design Loading | X | | | X | X | X | X | | X | X | X | X | X |
| 4. Span Type | X | X | X | X | X | X | X | | X | | X | | X |
| 5. Structure Type | X | | X | | | | X | X | | | | | |
| 6. Main Member Type | X | X | X | | X | X | X | | X | X | X | X | X |
| 7. Stringer Spacing | X | | X | X | X | X | X | | | | | | X |
| 8. Skew Degrees | X | | | | | | | | | | | | |
| 9. Type of Crown | X | | X | | X | X | X | X | X | X | X | | X |
| 10. Type of Deck | X | X | X | | X | | | | X | | | X | X |
| 11. Continuous or Simple | X | X | | X | X | X | X | | X | X | X | | X |
| 12. Simple Span Length | | X | | | | | | | | | | X | X |
| 13. Cont. Unit 1st Span Lgth. | | | X | | | X | | X | | | | | |
| 14. Cont. Unit 2nd Span Lgth. | X | X | X | | | | X | | | | | | |
| 15. Cont. Unit Total Lgth. | | | | | | | | | | | | | |
| 16. Cont. Unit Nmbr of Spans | X | X | X | X | X | X | | X | | | | X | X |
| 17. Cont. Unsymm. Unit | | | | | | | | | | | | | |
| 18. Structure Type | X | X | | X | X | X | X | | | | | | X |
| 19. Slab Thickness | | | | X | X | X | X | | X | X | X | X | X |
| 20. Traffic Volume/Day | | | | | X | X | | X | X | | X | | X |
| 21. Structure Classification | | | | X | X | X | X | | | | X | | X |
| 22. Heaviest Wheel Load | X | X | | | X | X | X | | X | X | X | | X |
| 23. Transit Mix | | | | | | | | | | | | | X |
| 24. Pctg. of Air Entrained | X | | X | | | | X | X | | | X | | X |
| 25. Type of Admix | X | | X | | | | X | X | X | X | X | | X |
| 26. Type of Cement | X | X | X | X | | | X | X | X | X | X | X | X |
| 27. Source of Cement | X | X | X | X | X | X | X | X | | X | X | X | X |
| 28. Sacks of Cement/C.Y. | X | | X | X | X | X | X | | | X | | X | X |
| 29. Type of Aggregate | | | | | X | X | X | | | | | X | X |
| 30. Type of Finish | X | | X | X | X | | | X | | | X | X | X |
| 31. Month Slab Placed | | | | | X | X | | | | | | | |
| 32. Year Slab Placed | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 33. Month Bridge Opened | | | | | | | | | | | | | |
| 34. Year Bridge Opened | X | | | | X | X | X | | X | X | X | | X |
| 35. Type of Overlay | X | X | X | | X | X | X | X | X | X | X | | X |
| 36. Month Overlay Applied | X | X | | | X | X | | | X | X | X | | |
| 37. Year Overlay Applied | X | | X | | X | X | X | | | | X | | X |
| 38. Condition of Overlay | X | X | X | | X | X | X | X | | X | X | | X |
| 39. First Year Salt Applied | X | | X | | X | X | X | | X | X | X | | X |
| 40. Salt Applications/Year | X | | X | | X | X | X | X | X | X | X | | X |
| 41. Sulfate Stream | X | | X | X | X | X | X | X | | X | | X | X |
| 42. Condition of Substructure | X | | | | X | X | X | | X | X | X | | X |
| 43. Slab Drainage | X | X | X | X | X | X | X | X | X | X | X | X | X |
| 44. Weather at Pouring | X | X | X | X | X | | | | | | | | |
| 45. Moment Condition | X | | X | | X | | | | | X | | | X |

This summary report (Part 1) covers only Item 1 in the listing of table groups presented earlier in this section. The subsets of these tables, evaluated by the authors as showing meaningful associations, are reported individually in Part 2. Part 3 (three volumes of computer output) contains all of the 1652 sets of tables which were prepared but no further summary reports are planned for issue under this project.

All tables included in this report are based on use of all of the available data. This course of action was decided upon after preparing the various sets of tables using only the bridges selected in the original ten percent sample, and comparing these against the comparable tables compiled from the data for all structures observed. The agreement between the two sets of tables was sufficiently striking to justify utilizing all available data.

Table 3 summarizes the information presented in Table 2. The 13 condition variables are ranked in decreasing order of the frequency of significant associations. This serves to point out the relative sensitivity of the various condition variables - ranging from degree of cracking, degree of scaling, and general deck condition being most sensitive, to scaling, cracking and delamination location being least sensitive.

There are a number of degrees of intensity of each condition item and there are very few cases where significant association is so clear that no question can arise in its interpretation. It is for that reason that the interpretations given in this report are judgement oriented, at least to some degree.

TABLE 3

Condition variables ranked with respect to decreasing frequency of significant associations with the 45 structural characters.

| RANK | CONDITION VARIABLE | DESCRIPTION | PROPORTION SIGNIFICANT* |
|---|---|---|---|
| 1 | 50 | Cracking, degree | 37/45 |
| 1 | 54 | Scaling, degree | 37/45 |
| 2 | 62 | General deck condition | 34/45 |
| 3 | 55 | Scaling, depth | 33/45 |
| 4 | 56 | Scaling, percent area | 30/45 |
| 5 | 52 | Cracking, average spacing | 28/45 |
| 6 | 60 | Delamination, percent area | 25/45 |
| 7 | 58 | Delamina[illegible], degree | 21/45 |
| 8 | 51 | Cracking [illegible]e | 20/45 |
| 9 | 59 | Delamination v[illegible]ble cracking | 20/45 |
| 10 | 57 | Scaling locati[illegible] | 18/45 |
| 11 | 53 | Cracking location | 17/45 |
| 12 | 61 | Delamination location | 14/45 |

*(Number of significant tables)/(Total number of structural characters)

## II. CONCLUSIONS:

The conclusions presented here are based on data collected from approximately 36,000 concrete pours in some 5,300 bridges. The data appear in Part 2, and the method of treating it is explained in later sections. The general conditions of the deck reported on the field survey forms by THD as General Deck Condition (GDC) are used here as the basis of most of the conclusions. That data form is filed in the Appendix of this report. General Deck Condition class 30 designates beginning deterioration; class 40, extensive deterioration; and class 50, serious condition. Table 4 gives tabulated percentages of pours in support of the conclusions given here.

1. Sixty-one percent of all pours display some deterioration, GDC 30 and higher; fifteen percent are in serious condition, GDC 50 and higher.
2. Decks made of nontransit mix concrete are in a little better condition than decks of transit mix material.
3. Decks on concrete beams show less deterioration than those supported by steel beams.
4. Decks supported by prestressed beams display the lowest deterioration followed closely in order by slab span decks. Decks on continuous steel girders show the highest percentage of deterioration.
5. The normal crown deck shows much less deterioration than the constant slope crown deck.

## TABLE 4

## PERCENTAGE OF CONCRETE POURS OF THE VARIOUS CLASSIFICATIONS OF GENERAL DECK CONDITION

| Structural Character | General Deck Condition (62) | | | | | | | | | GDC Class 30 & Higher | GDC Class 50 & Higher | Percentage of Total Pours |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 31 | 32 | 33 | 40 | 44 | 50 | | | |
| Total Percentage of All Pours | 12 | 27 | 15 | 2 | 9 | 13 | 3 | 4 | 11 | 61 | 15 | 100 |
| Transit Mix (23) Yes | 12 | 26 | 14 | 2 | 11 | 15 | 3 | 4 | 8 | 62 | 15 | 61 |
| No | 13 | 30 | 18 | 3 | 8 | 13 | 3 | 5 | 5 | 57 | 7 | 39 |
| Beam Type: (06) | | | | | | | | | | | | |
| Steel I-Beam | 6 | 20 | 16 | 3 | 9 | 14 | 3 | 6 | 15 | 74 | 23 | 37 |
| Plate Girder | 4 | 20 | 13 | 1 | 11 | 21 | 4 | 12 | 6 | 76 | 14 | 4 |
| Reinforced Concrete | 14 | 32 | 15 | 2 | 9 | 12 | 2 | 2 | 11 | 54 | 12 | 47 |
| Prestressed Concrete | 33 | 29 | 12 | 3 | 9 | 7 | 4 | 2 | 1 | 38 | 1 | 9 |
| Span Type: (04) | | | | | | | | | | | | |
| Continuous Steel | 6 | 19 | 14 | 3 | 9 | 17 | 4 | 7 | 13 | 75 | 21 | 29 |
| Simple Steel | 6 | 24 | 21 | 2 | 7 | 10 | 4 | 6 | 14 | 70 | 20 | 14 |
| Pan-formed Reinf. Conc. | 10 | 28 | 11 | 1 | 4 | 17 | 1 | 3 | 14 | 62 | 15 | 19 |
| Reinf. Conc. Beam & Slab | 16 | 32 | 15 | 2 | 7 | 11 | 2 | 2 | 11 | 52 | 13 | 10 |
| Reinf. Conc. Slab | 18 | 37 | 18 | 3 | 5 | 8 | 2 | 1 | 6 | 45 | 8 | 16 |
| Prestressed Beam | 29 | 30 | 13 | 3 | 9 | 7 | 4 | 2 | 2 | 41 | 3 | 9 |
| Crown Type (09) | | | | | | | | | | | | |
| Normal | 13 | 30 | 16 | 2 | 7 | 10 | 2 | 3 | 13 | 57 | 17 | 71 |
| Constant Slope | 6 | 19 | 4 | 2 | 12 | 21 | 4 | 6 | 7 | 75 | 26 | 25 |
| Traffic: (20) | | | | | | | | | | | | |
| 0 to 2k/day | 15 | 32 | 15 | 2 | 6 | 8 | 2 | 2 | 18 | 53 | 18 | 43 |
| 2k to 5k | 10 | 30 | 16 | 3 | 8 | 13 | 4 | 4 | 9 | 60 | 12 | 19 |
| 5k to 15k | 11 | 21 | 15 | 2 | 10 | 20 | 2 | 4 | 8 | 68 | 15 | 22 |
| 15k to 30k | 8 | 19 | 15 | 2 | 11 | 19 | 3 | 14 | 3 | 73 | 9 | 9 |
| Heaviest Wheel Load (22) | | | | | | | | | | | | |
| 5 kips to 6 kips | 14 | 32 | 7 | 8 | 8 | 6 | 1 | 0 | 23 | 54 | 24 | 3 |
| 7 kips to 8 kips | 15 | 30 | 14 | 1 | 6 | 8 | 2 | 2 | 20 | 55 | 22 | 16 |
| 9 kips to 10 kips | 14 | 31 | 16 | 3 | 7 | 9 | 2 | 2 | 11 | 56 | 16 | 39 |
| 11 kips to 12 kips | 9 | 22 | 15 | 2 | 11 | 18 | 4 | 7 | 6 | 69 | 12 | 40 |

6. Bridges with lower traffic density (vehicles per day) display the same GDC 30 deterioration as those with high density traffic. GDC 50 deterioration is greatest with low traffic density, and low traffic density is associated with older bridges.

## III. RESULTS OF THE STUDY

### A. Basis of the Evaluation

Detailed data collected in the survey are contained in Part 3 of this report, and those data are organized into tables in Part 2. The results given in this section were drawn entirely from the data contained in Parts 2 and 3. Only that portion of the data related to deterioration is shown here.

Over 5,000 bridges consisting of more than 35,000 concrete pours were studied. The decks were examined for cracking, scaling, delamination, and general condition. Each of these categories was broken down into sub-sets in the effort to identify the causes and extent of the deterioration that was found in the survey. The data were collected by a field crew in each district of THD and they were recorded on the form shown in the Appendix.

Analyses of the data show only general trends in causes of deterioration. It has not isolated any one specific construction or maintenance, or design detail which is the sole cause of deterioration. The results are discussed in the text that follows.

### B. General Deck Condition

This general condition is classified on the survey form as follows: GENERAL DECK CONDITION, (GDC). See Figure 1 and the THD Survey Form in the Appendix.

Deterioration begins with GDC 30. GDC 40 represents extensive deterioration and a GDC 50 deck is in a serious state of deterioration. Evaluations, then, of the condition of bridges in the state are here

| GDC NUMBER | DESCRIPTION |
|---|---|
| 10. | GOOD: NO CRACKING, SPALLING, SCALING, DELAMINATION OR ROUGHNESS. |
| 20. | MINOR FINE CRACKING, SLIGHT ROUGHNESS OR VERY SLIGHT, SHALLOW AND INFREQUENT SPALLING OR SCALING, OR COMBINATION THEREOF. NO DELAMINATION. |
| 30. | MODERATE CRACKING, SPALLING OR SCALING. MINOR AND INFREQUENT DELAMINATION. MINOR SURFACE LOSS. OR COMBINATION THEREOF. |
| 31. | TRANSVERSE CRACKS ON BOTTOM OF DECK SHOWING LEAKAGE. |
| 32. | LEAKING TRANSVERSE CRACKS COMBINED WITH 20. |
| 33. | LEAKING TRANSVERSE CRACKS COMBINED WITH 30. |
| 40. | EXTENSIVE CRACKING, SPALLING OR SCALING. MODERATE DELAMINATION AND SURFACE LOSS WITH OCCASIONAL POPOUTS OR POT HOLES. LOOSE OR ROTTEN CONCRETE. OR COMBINATION THEREOF. |
| 44. | LEAKING CRACKS ON BOTTOM OF DECK COMBINED WITH 40. |
| 50. | SEVERE CRACKING, SPALLING OR SCA[illegible] EXTENSIVE DELAMINATION. EXTENSIVE SURFACE [illegible] WITH RUSTY STEEL SHOWING. EXTENSIVE LOOSE [illegible]TTEN CONCRETE. EARLY OR BEGINNING TENSION CRACKS ON BOTTOM OF DECK. OR COMBINATION THEREOF. |
| 51. | LEAKING CRACKS ON BOTTOM OF DECK COMBI[illegible] WITH 50. |
| 52. | EXTENSIVE OR SEVERE TENSION CRACKING ON BOTTOM OF DECK COMBINED WITH ANY OF THE ABOVE. (REPLACE LAST DIGIT, 2, TO DENOTE COMBINATION. i.e., 54 INDICATES 52 COMBINED WITH 40. |
| 60. | DECK FAILURE: CRACKING THROUGH DECK WITH LOSS OF INTEGRITY BETWEEN CONCRETE AND STEEL OR HOLES COMPLETELY THROUGH DECK. |

Figure 1. General Deck Condition Classification.

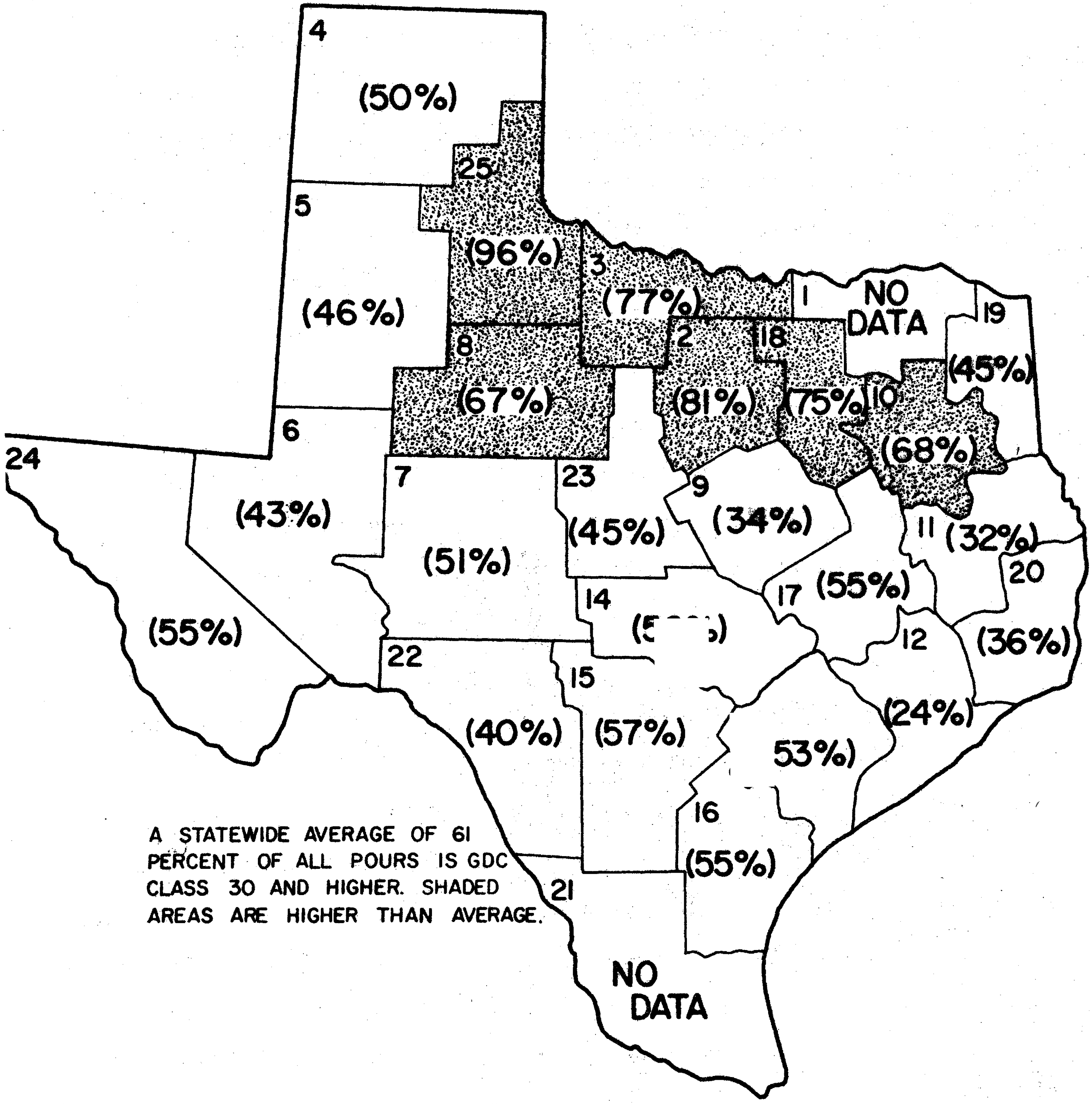
based on conditions ranging from GDC 30 through GDC 50. GDC's 31, 32, 33 and 44 indicate that the deck is cracked completely through. It would be expected that steel in decks with those classifications is open to chemical attack, and that the decks are in the process of rapid deterioration or conditioned for it.

The statewide distribution of GDC 30 and higher is shown in Figure 2. Throughout the state 61 percent of the pours are classed 30 and higher, and 15 percent are classed 50 and higher. Districts with the highest percentage of serious deterioration are spread along an east-west band in the northern portion of the state.

Figure 3 shows the relationship between a few selected design parameters and general deck condition. In that figure it is seen that the percentage of GDC 30 pours increases with decreasing specification year; i.e., the older the bridge the higher the percentage of pours beginning to deteriorate. The [illegible] trend may be seen in Part 2 of this report in the table of general condition of the deck vs. year the slab was placed. No such trend is seen [illegible] GDC 50.

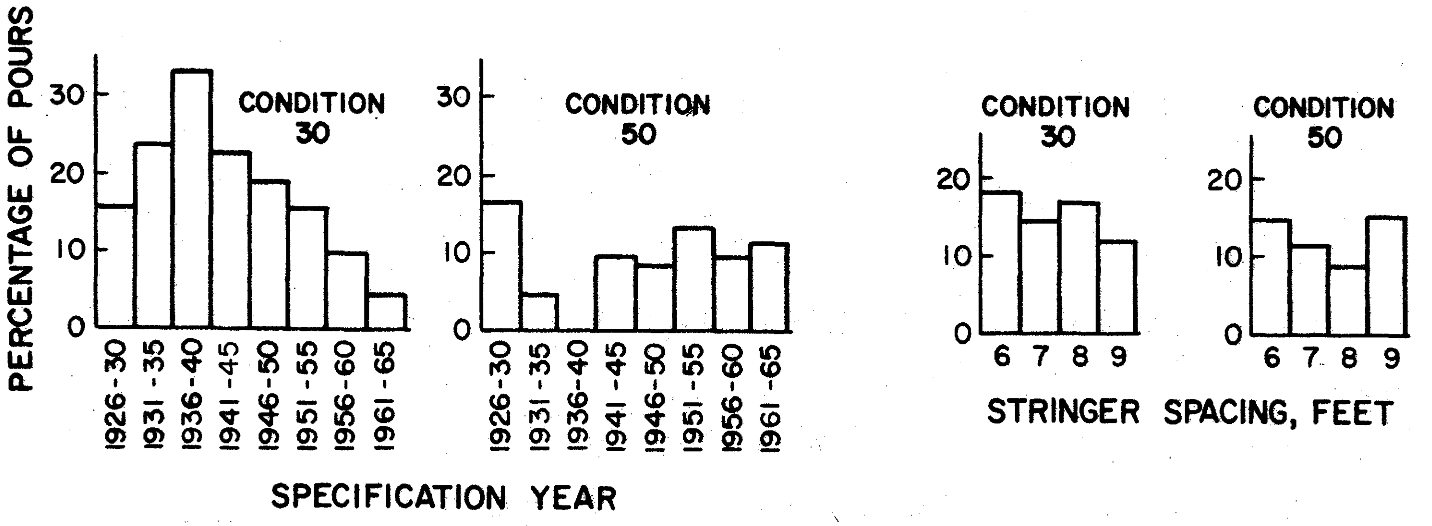
Figure 3 shows a slight advantage in favor of concrete main members as compared with steel I-beams. However, from Table 3 it may be seen that the condition is influenced by a number of other factors as well.

Evaluation of the data has shown that there is an association between a number of design and service factors and the condition of the bridge decks. The newer bridges have greater stringer spacing, Figure 4, and the source of materials is highly related to geographical location as is the use of salt on bridges, Figure 5. These are but a few of the



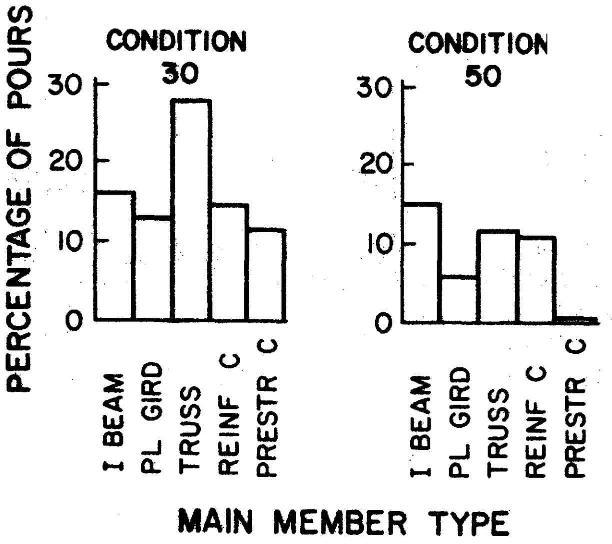
A STATEWIDE AVERAGE OF 61 PERCENT OF ALL POURS IS GDC CLASS 30 AND HIGHER. SHADED AREAS ARE HIGHER THAN AVERAGE.

Figure 2. Distribution of General Deck Condition 30 and higher. The percentage of pours is shown in brackets for each numbered THD district. The districts with higher than average percentages are shaded.



**(a) PERCENTAGE OF POURS vs. SPECIFICATION OF YEARS.**

**(b) STRINGER SPACING vs. PERCENTAGE OF POURS**



**(c) PERCENTAGE OF POURS vs. MAIN MEMBER TYPE**

Figure 3. Selected design parameters vs. percentage of pours for GDC 30 (moderate condition) and GDC 50 (severe condition).

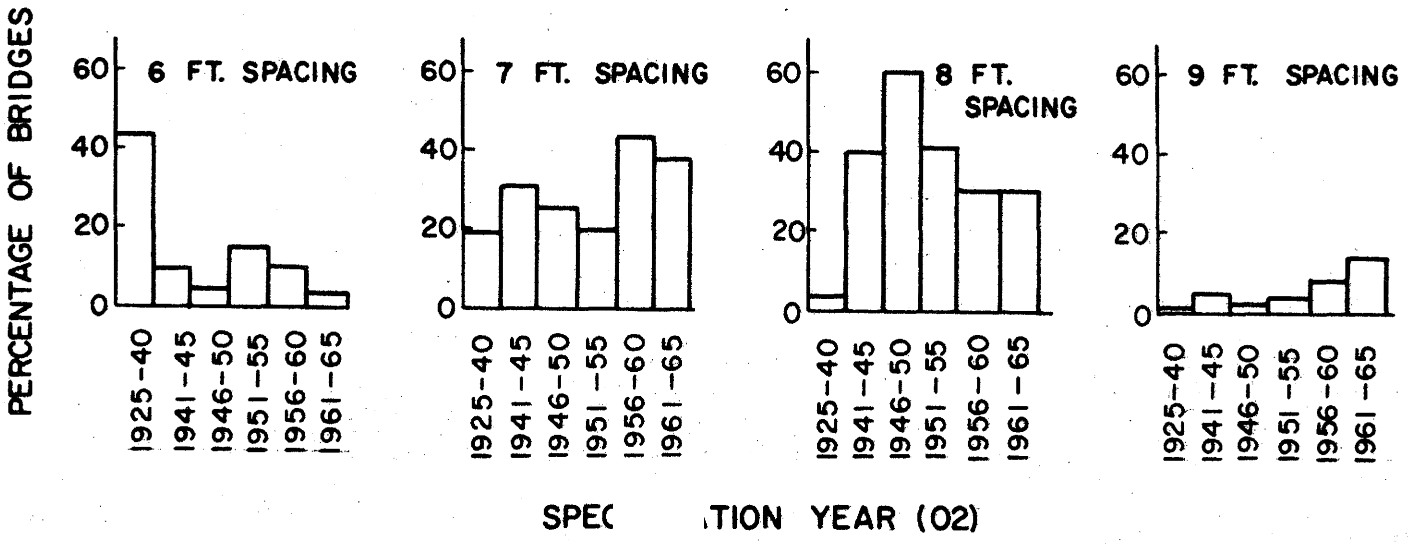


Figure 4. Percentage ( lges vs. specification year (02) for each of four stringer spacings (07).

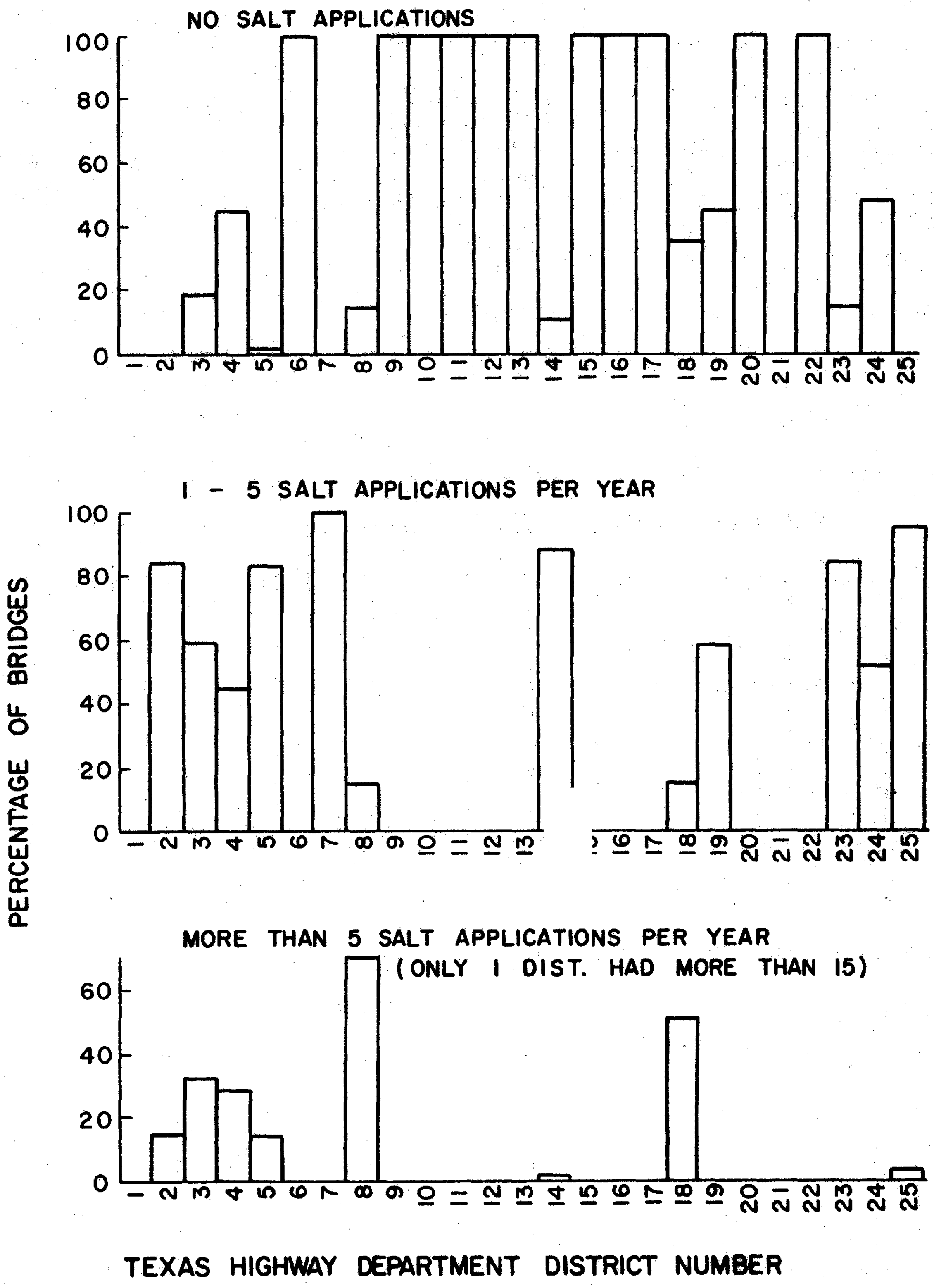


Figure 5. Percentage of bridges vs. THD districts (01) for each of three salt application groupings (40).

interrelationships that bear on the complex deterioration problem.

## C. Cracking

The survey collected data on cracking in respect to degree, type, spacing, and location on the deck.

Sixty-seven percent of all pours have zero to minor cracking, and 27 percent have moderate cracking, Figure 6. Districts 2, 3, 8, 15, and 17 show the highest percentages of extensive cracking. Districts 2, 3, and 8 are in the same region of the state, but other districts in that region have much less extensive cracking. The spacing of cracks decreases as the age of the structure increases.

Cracking type is predominantly transverse with no geographical pattern of type or spacing. The longitudinal cracking percentage is low, but what there is of it occurs primarily between beams in very thin slabs such as are constructed with pan forms. There is more cracking in wheel paths than in any other specific location, although it is more generally scattered over the deck area.

The small percentage of extensive cracking, 5 percent of all pours, is scattered over the decks. This is as one might expect because it has progressed through minor and major stages, spreading as it progressed.

Figure 7 shows that the degree of cracking increases with the type of supporting beam in the following order: prestressed concrete, reinforced concrete, steel I-beam, and steel plate girder. Generally, too, continuous spans have more cracks than simple spans. Traffic volume and transit mix are not factors in degree of cracking, but

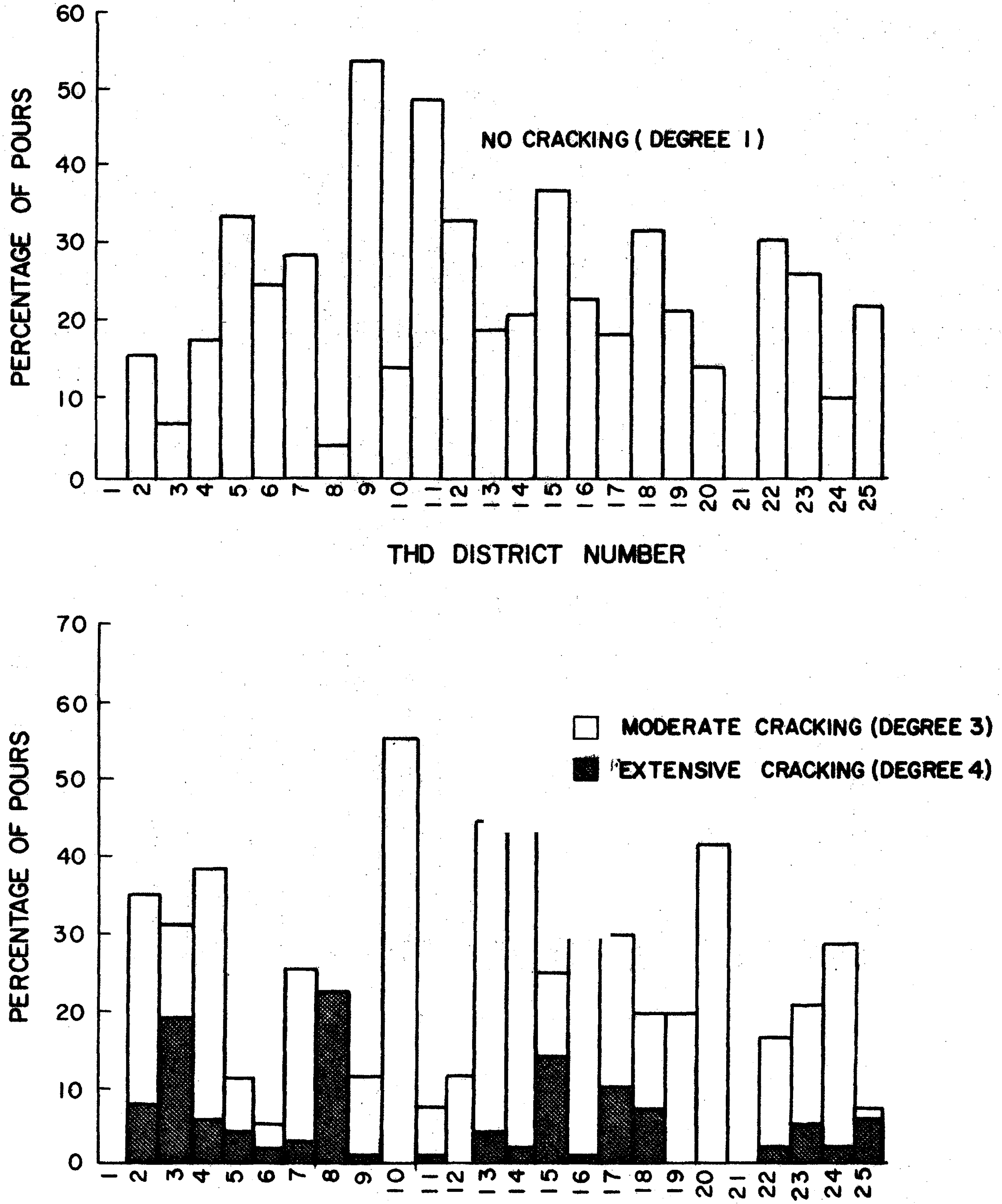


Figure 6. Percentage of pours vs. THD districts (01) for each of three degrees of cracking (50).

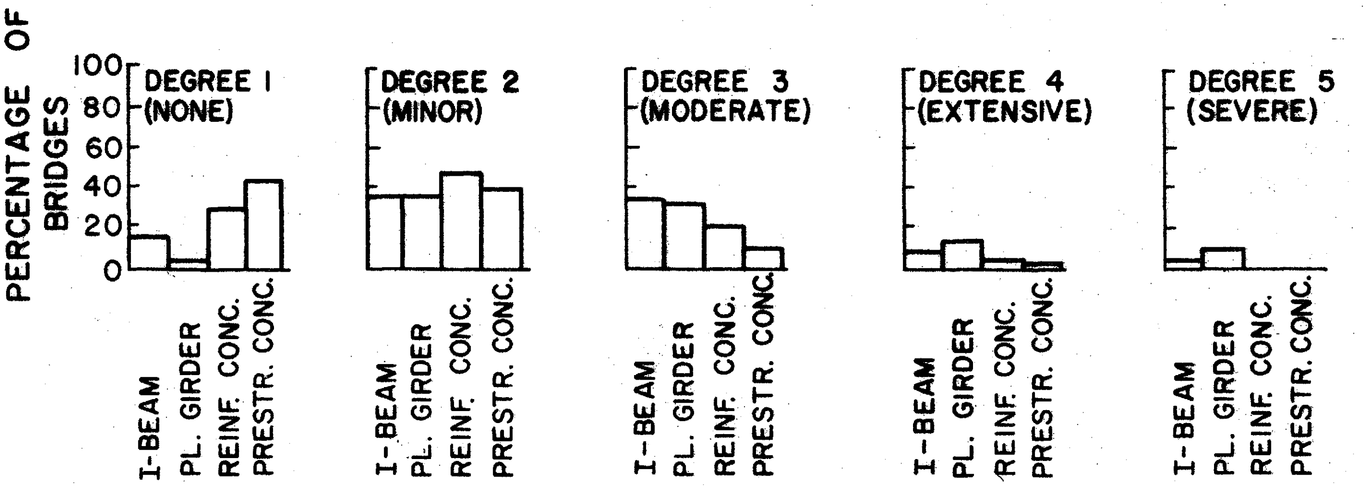


Figure 7. Percenta[illegible] bridges vs. main member type (06) for each of five deg[illegible] cracking (50).

cracking is reduced when water reducing admixtures are used. Entrained air and set retarders are associated with greater spacing between cracks, but the main factor in that association could possibly be age of slab rather than admix. The degree of cracking is higher the earlier the year of the first salt application. But, here again, age of structure must be taken into account.

D. Scaling

The survey data rate scaling by degree, depth, and percentage of area of deck scaled, as well as location on the deck. No distinction was made on the survey forms between scaling and spalling. Some of the deeper scaling, 3/4 inch or more, possibly should be classified as spalling, although no such classification is made here.

Scaling does not appear to be a serious problem on bridge decks in Texas. Figure 8 shows the degree of scaling for the various highway districts. Those districts with the most severe cases of scaling are located generally in the north and west parts of the state. Those with the higher percentages of pours with moderate and higher ratings are ger ly in the urban areas shaded in Figure 9.

Of all bridges surveyed, 40 percent of t pours had no scaling, 41 percent had minor scaling, 14 percent had moderate scaling, and 5 percent were scaled more seriously. Forty percent of the pour area had no scaling and 62 percent of the area had 5 percent or less scaled surface area. Twenty-nine percent of all pours was scaled 0.20 inches or less in depth. Four percent was scaled deeper than 3/4 inch. About 25 percent of the pours was scaled in wheel paths, 11 percent in gutters, and 52 percent of the scaling was scattered over the slab.

There is some indication that post World War II bridges are somewhat more seriously scaled than those constructed prior to that period.

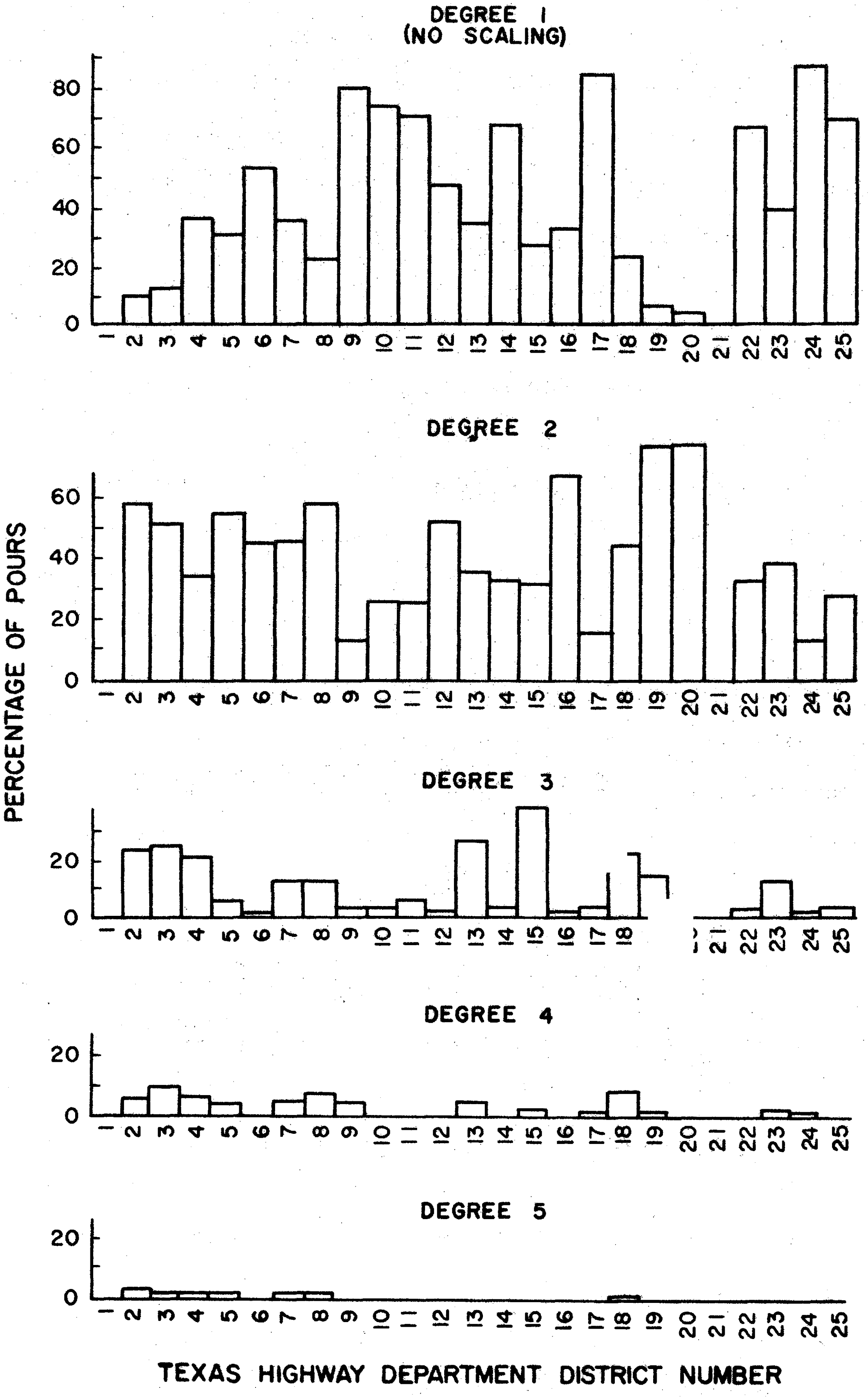
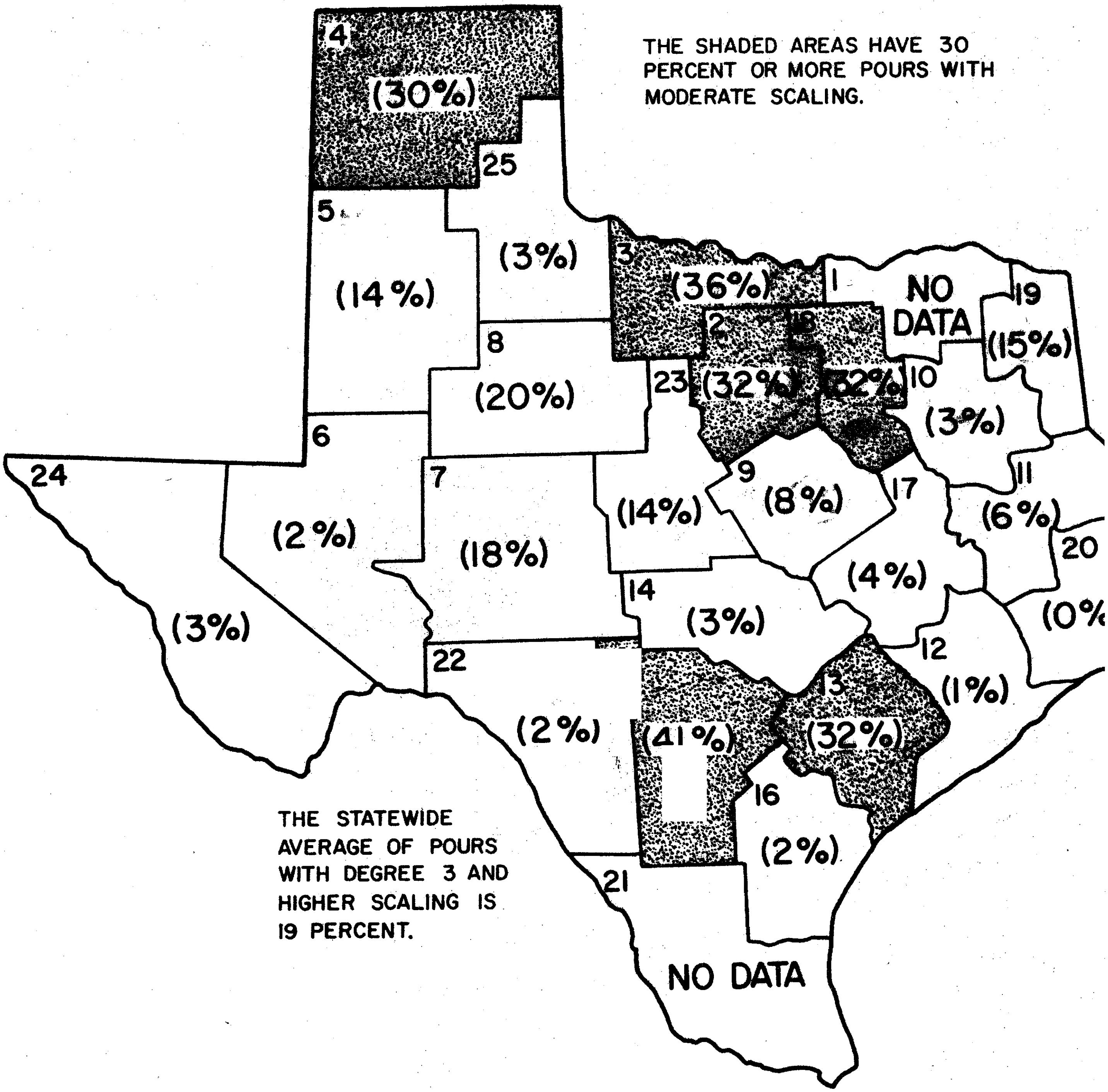


Figure 8. Percentage of pours vs. THD districts (01) for each of five degrees of scaling (54).



THE SHADED AREAS HAVE 30 PERCENT OR MORE POURS WITH MODERATE SCALING.

THE STATEWIDE AVERAGE OF POURS WITH DEGREE 3 AND HIGHER SCALING IS 19 PERCENT.

Figure 9. The percentage of pours with moderate (3) and higher degrees of scaling are shown in parentheses within the districts.

Among the bridges constructed after World War II, scaling is a little more advanced in the older ones. Salt application was light prior to about 1950 (reference Part III, Table 34/39) and traffic volume began to increase rapidly about that year (reference Part III, Table 20/34). Scaling increases with both of those factors.

Scaling is a little less serious in degree and extent of area in slabs supported by concrete beams although the difference is not great. See Figures 10 and 11. Thicker slabs, too, show less tendency to scale than thinner ones, and scaling is reduced with more closely spaced beams.

The crown of constant slope, crown type 2 in the survey, shows a trend toward increased scaling when compared with the normal type crown. The same trend is shown for continuous spans compared with simple spans.

All of the admixes (water reducers, retarders, and air-entraining agents) are associated with reduced scaling. The findings are not definitive enough to indicate possible design levels for air entrainment as an aid in reducing scaling.

Low cement factor is closely associated with scaling, as might be expected. The higher cement factors produce more resistant concrete. Scaling grows more serious with the number of years of salt application and the number of applications per year.

E. <u>Delamination</u>

Delamination data collected in the field show degree, location on the deck, and extent of delaminated area.

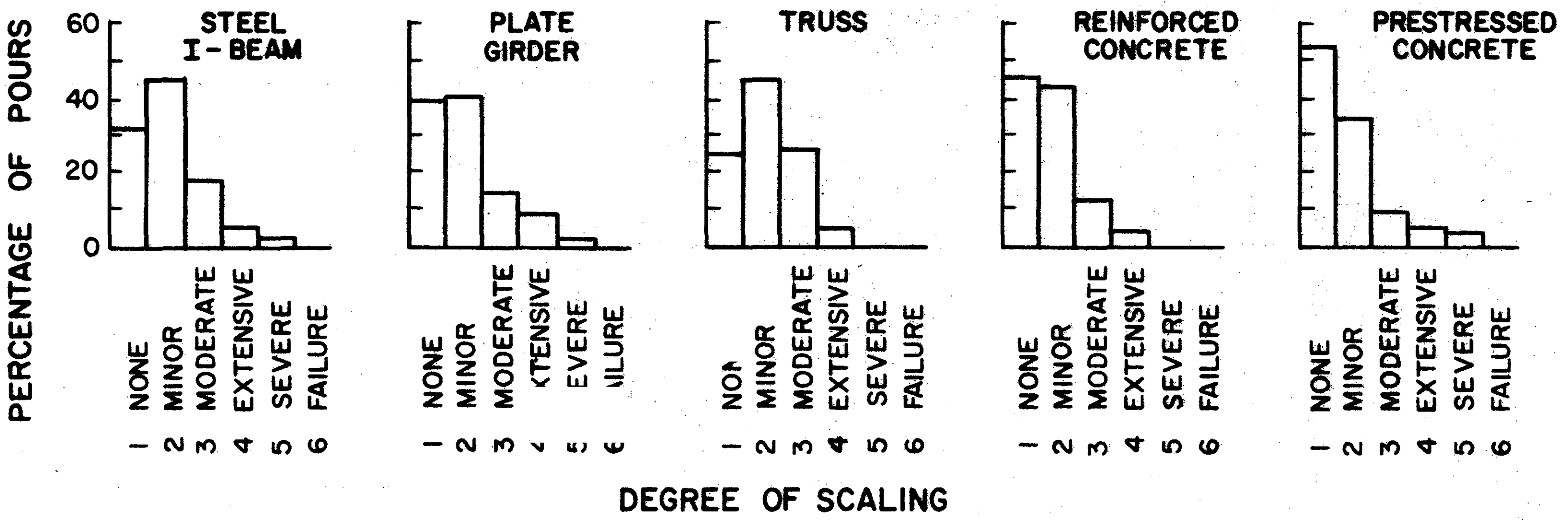


Figure 10. Percentage of pours vs. degree of scaling (54) for each of five main member types (06).

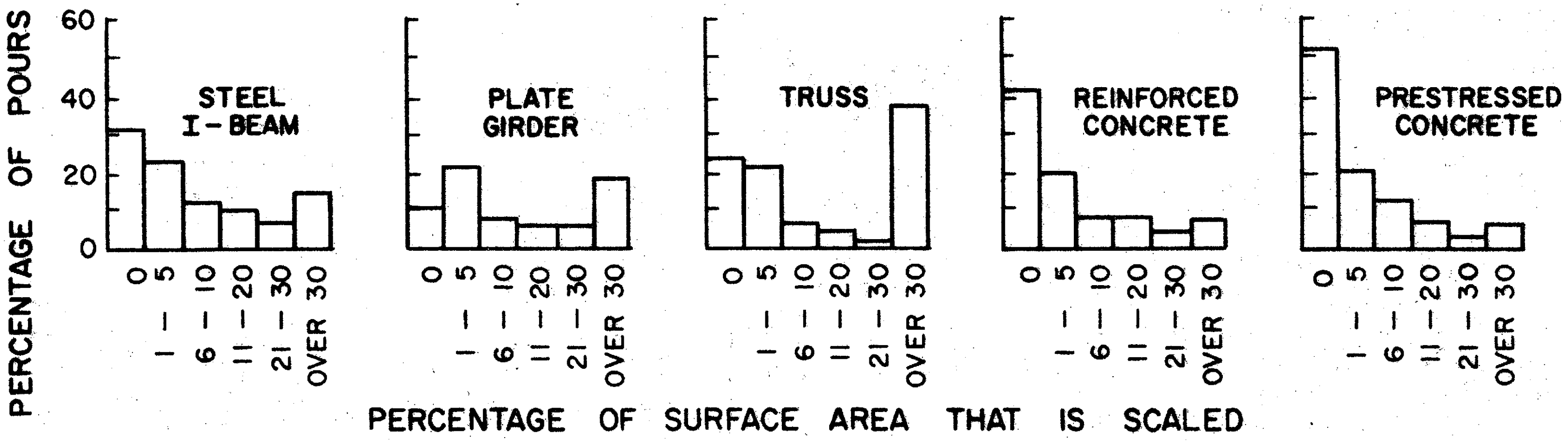


Figure 11. Percentage o s vs. percentage of surface area scaled (56) for each of five main r types (06).

Among the 35,658 pours studied, 81 percent revealed no delamination. Roughly, this is the equivalent of one bridge in a hundred being completely delaminated. Only small, isolated areas were found in 13 percent of the pours, and 6 percent were delaminated more extensively. Figure 12 shows that the northwest half of the state is the area more extensively affected by delamination and Figure 13 shows the distribution of delamination by districts throughout the state.

Visible cracking over the delamination was found in 90 percent of the pours observed to be delaminated. Most of the delamination was found to be either generally scattered over the deck, or in wheel paths. No clear pattern was established.

Delamination is more prevalent in heavily traveled bridges and those designed for heavier loads. It appears to be more of a problem in slabs from 5-1/2 to 6-1/2 inches thick than in thinner or thicker ones, see Figure 14, and grows more serious as the number of salt applications per year increases.

The age of a bridge plays a definite role in delamination. Those constructed in the 1960's show considerably less deterioration than the older ones, and age is probably a major factor in some of the associations mentioned later.

Plate girder structures display more delamination than other types, followed in order by steel I-beam, prestressed concrete, and reinforced concrete. Figures 15 and 16 show, however, that differences are not great. Age possibly is a contributing factor. The steel beam bridges are, in general, older than the prestressed beam bridges, but not

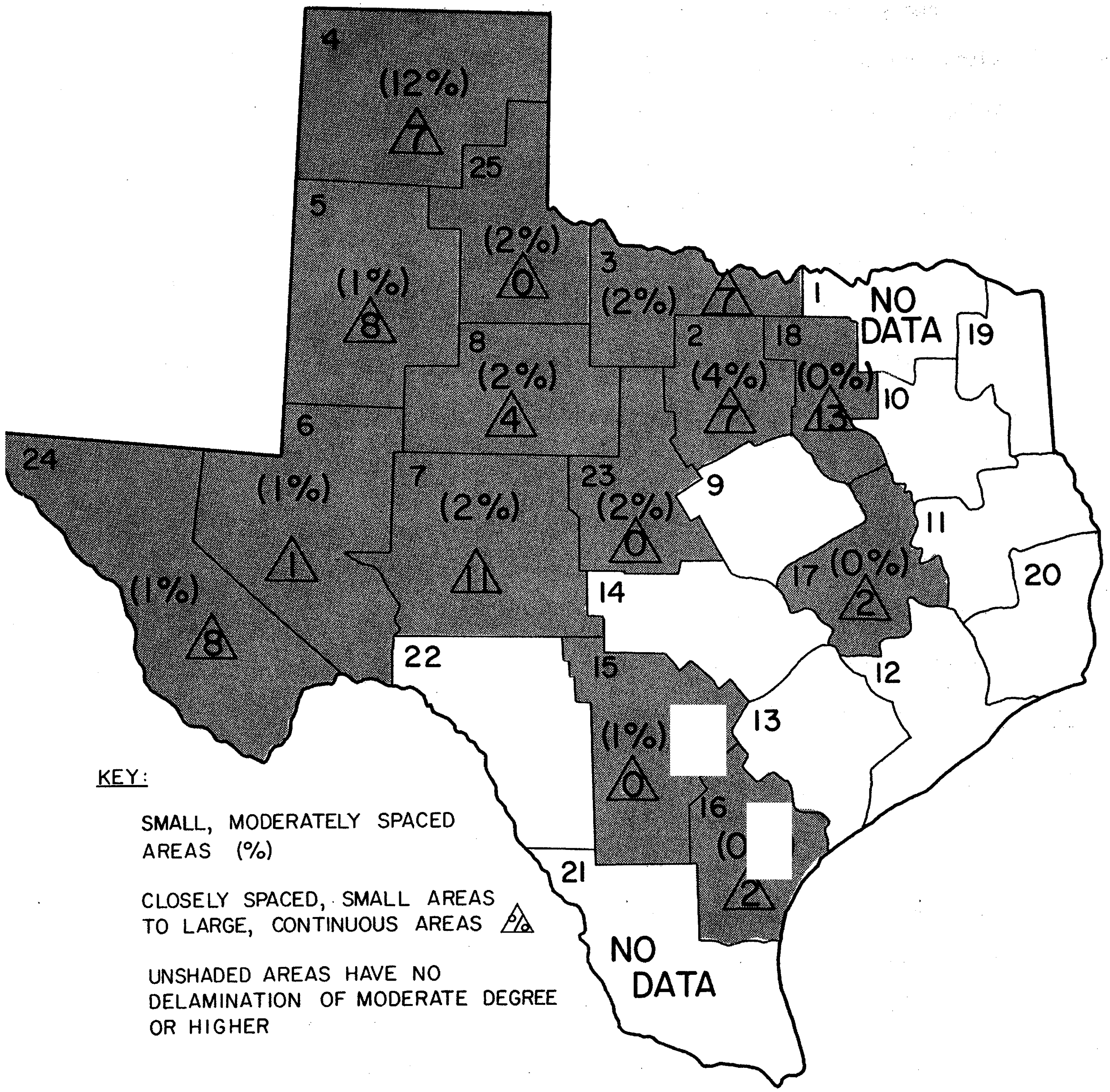


Figure 12. Delamination of moderate degree and higher; percentage of pours by districts.

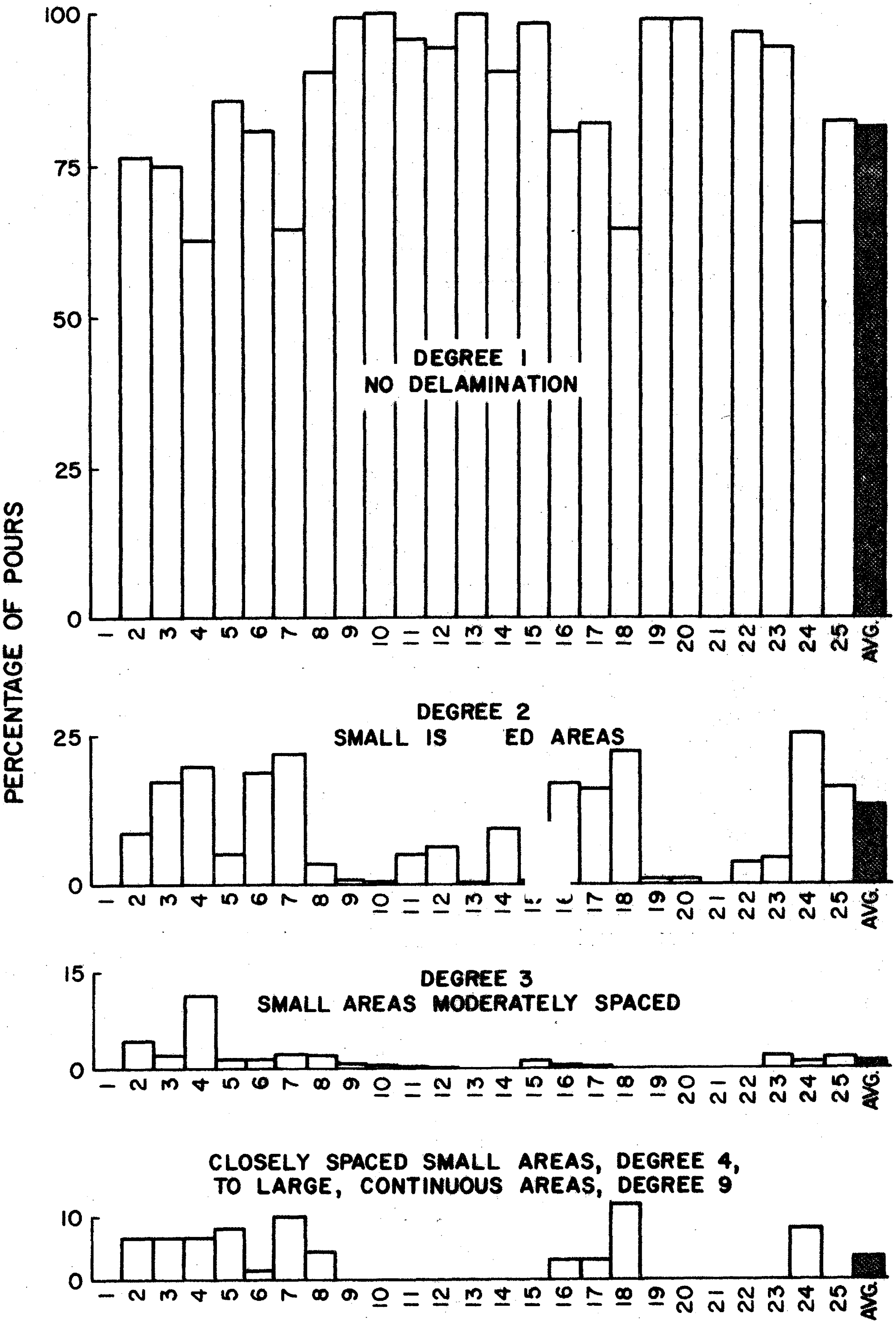


Figure 13. Percentage of pours vs. THD districts (01) for each of four levels of delamination (58).

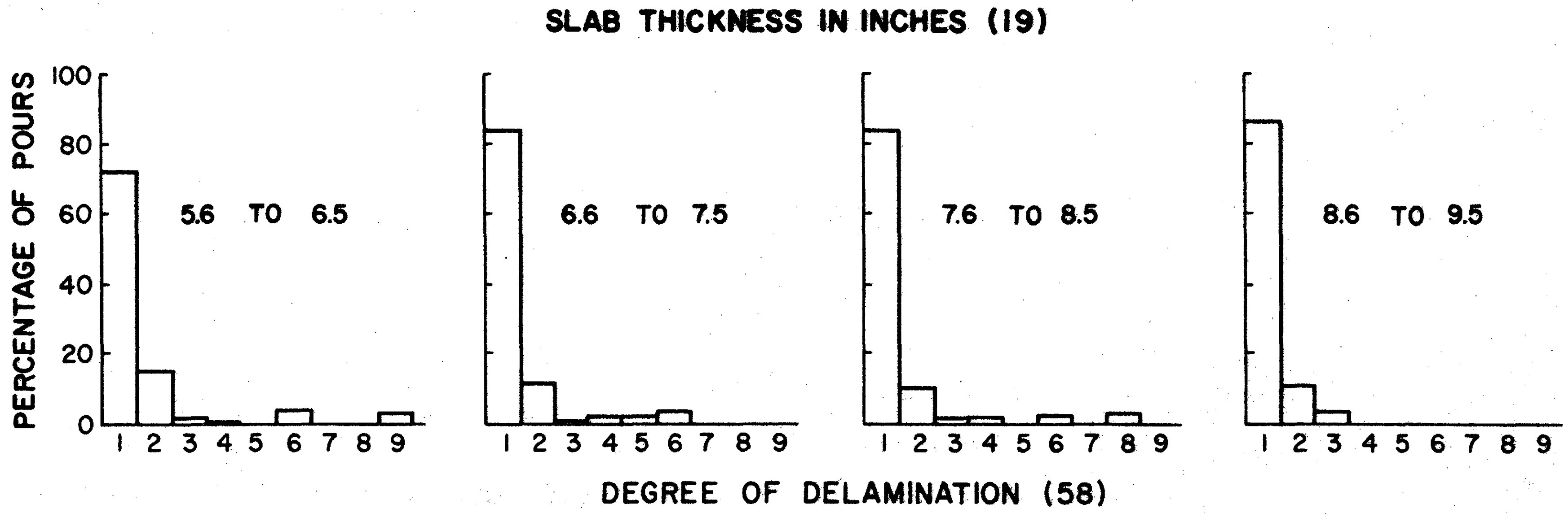


Figure 14. Percentage of pou degree of delamination (58) for four slab thicknesses (19).

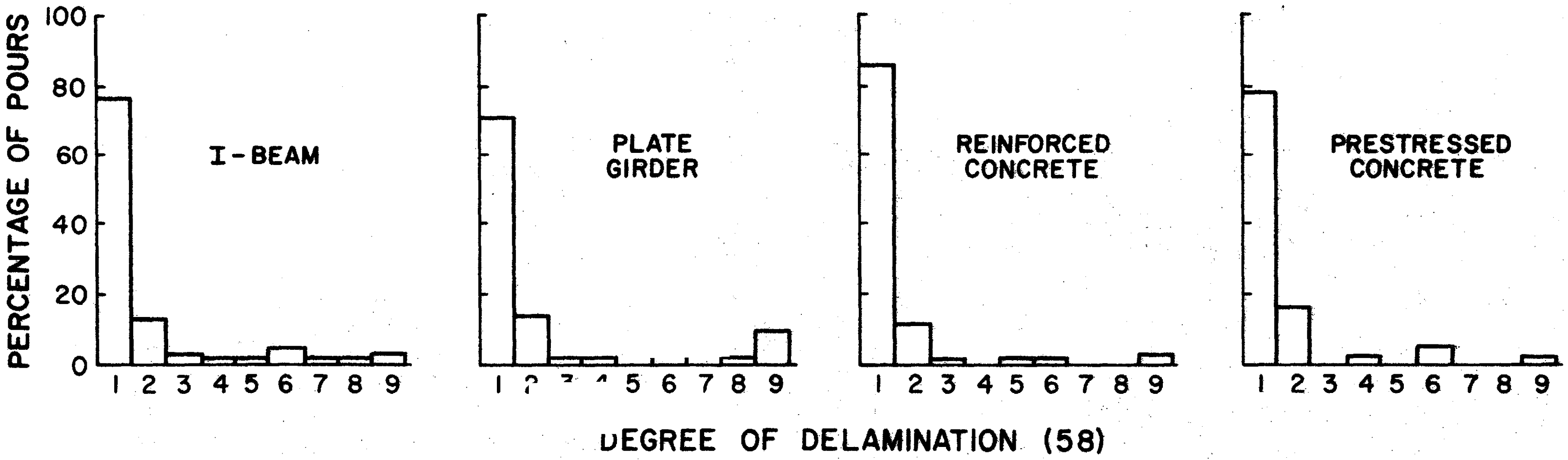


Figure 15. Percentage of pours versus degree of delamination (58) for each of four main member types (06).

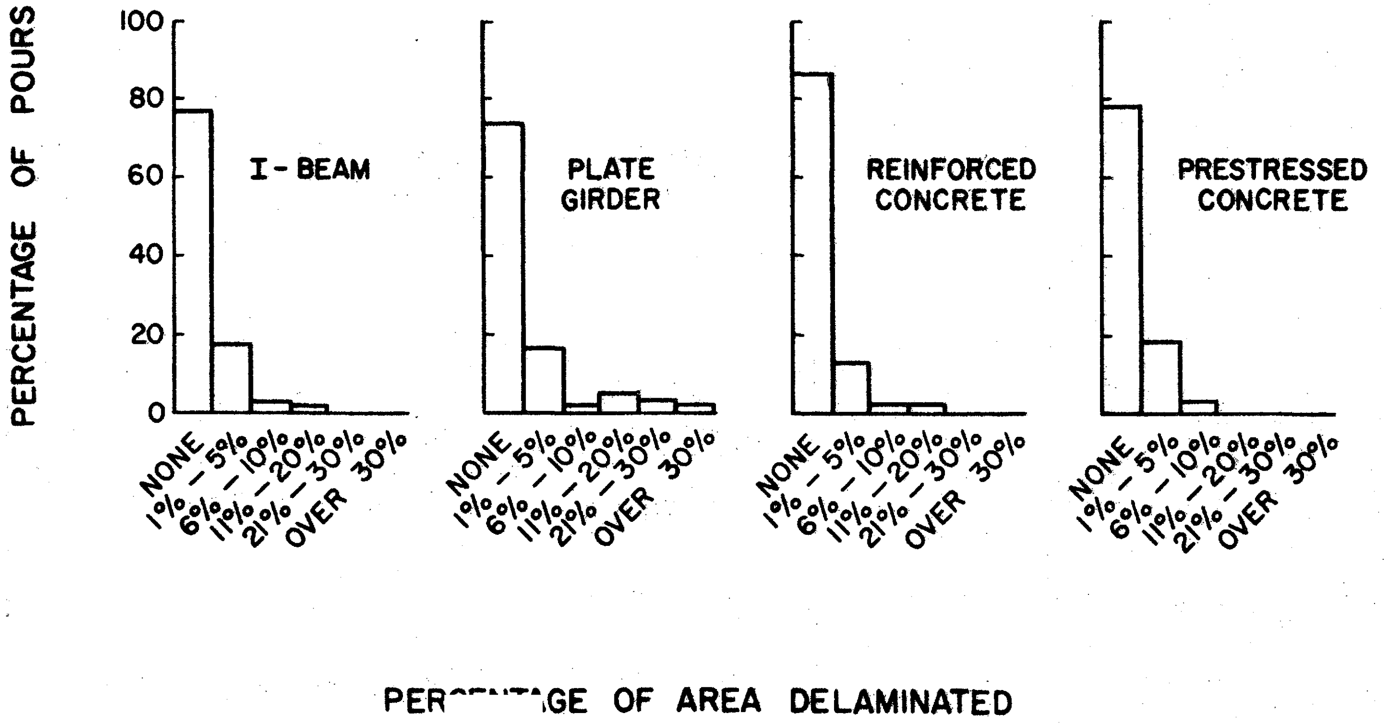


Figure 16. Percentage of pours versus percentage of area delaminated (60) for each of four main member types (06).

necessarily older than those of reinforced concrete. The crown of constant slope appears to contribute to delamination problems. There is less trouble seen in the data in decks with the normal crown.

Almost all of the concrete used in decks is made of Type I cement, but the 2 percent that is made of Type III cement shows less delamination. It should be noted, however, that the latter type was used very little prior to the 1960's. Lightweight concrete, accounting for 3 percent of the pours studied, has less deterioration than the more widely used normal weight material. Here, again, age could be a strong factor because of the rather recent introduction of lightweight concrete for use in bridge decks.

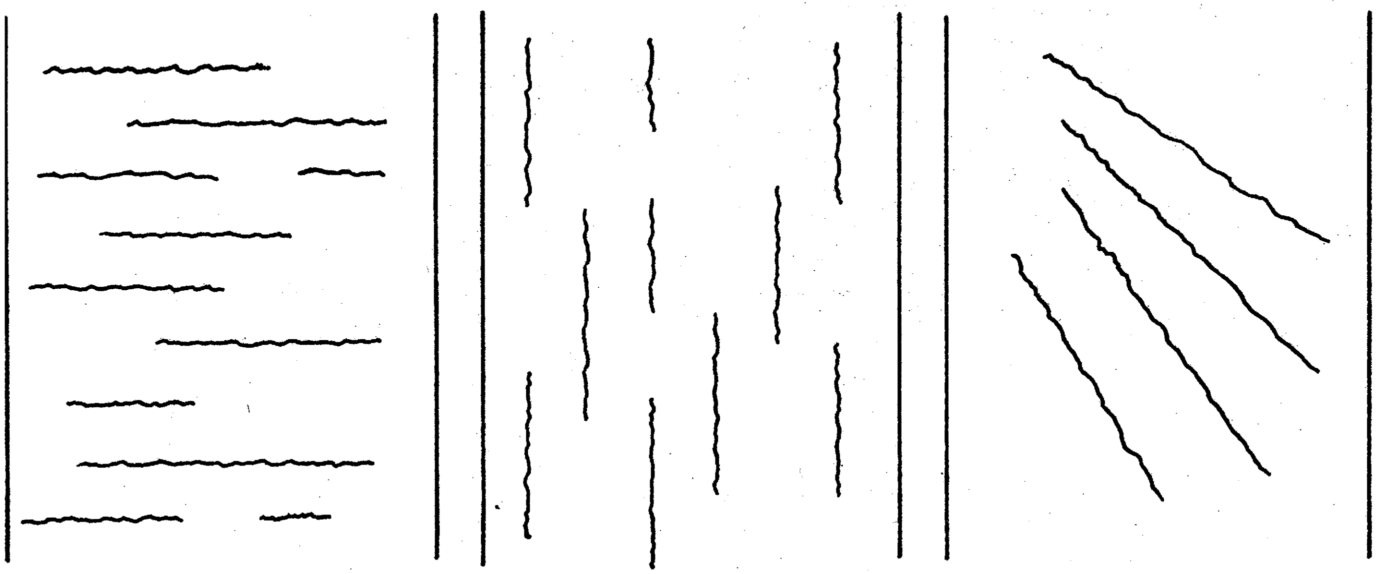
Retarders and water reducers are associated with less delamination.

The belt finished concrete is somewhat more highly delaminated than is the float finished material.

There is a marked decrease in del    ation in pours placed between the years 1959 to 1960. The data indicate that significant air entrainment was begun in 1960. This fact may be re    ed to the apparent decrease in delamination.

# IV. APPENDIX

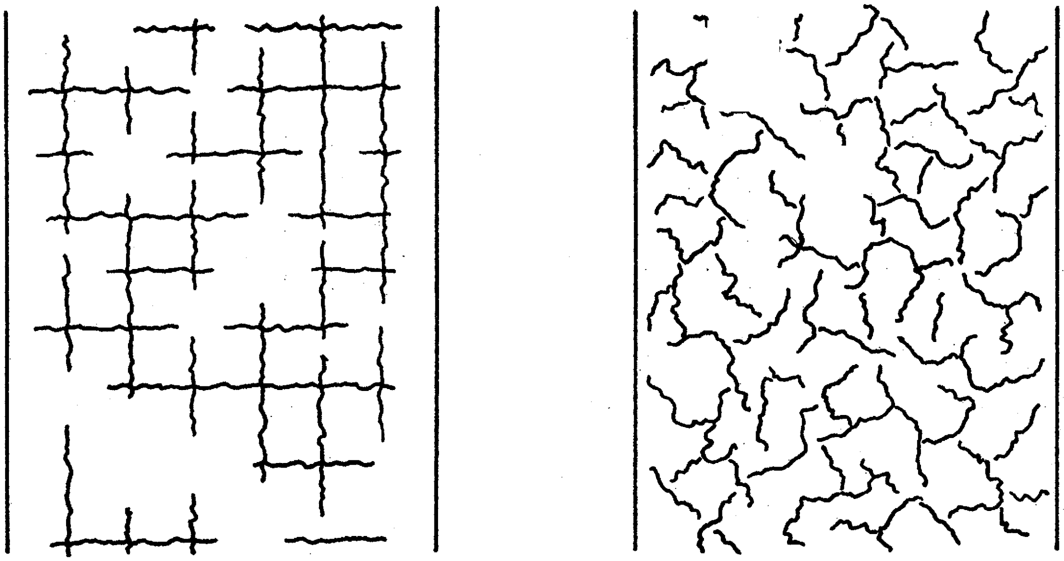
## THD BRIDGE DECK SURVEY FORM



Transverse

Longitudinal

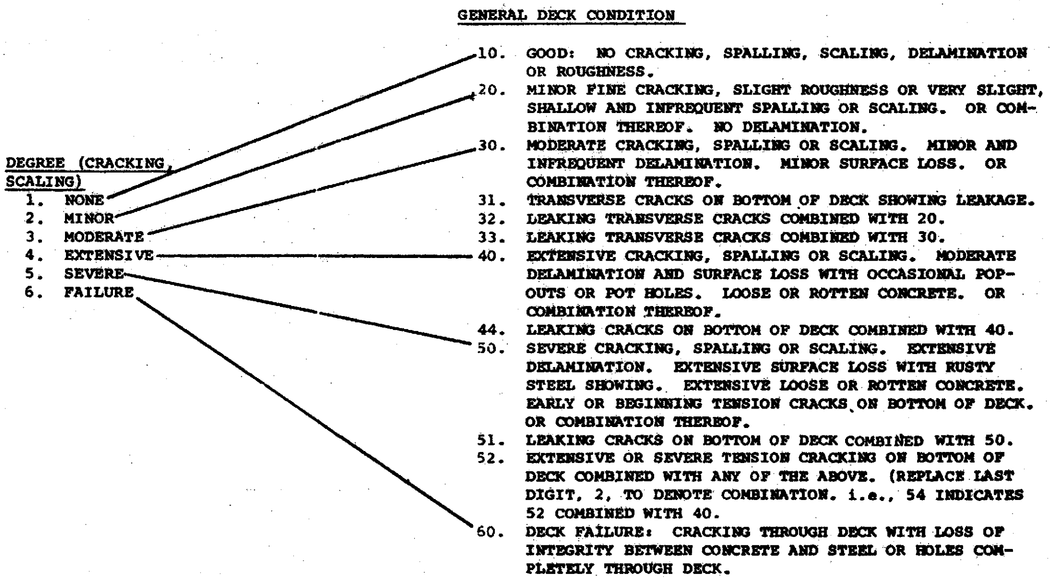
Diagonal



Checkerboard

Map, Alligator
or Random

Types of Cracking



DEGREE (CRACKING, SCALING)

1. NONE
2. MINOR
3. MODERATE
4. EXTENSIVE
5. SEVERE
6. FAILURE

GENERAL DECK CONDITION

10\. GOOD: NO CRACKING, SPALLING, SCALING, DELAMINATION OR ROUGHNESS.

20\. MINOR FINE CRACKING, SLIGHT ROUGHNESS OR VERY SLIGHT, SHALLOW AND INFREQUENT SPALLING OR SCALING. OR COMBINATION THEREOF. NO DELAMINATION.

30\. MODERATE CRACKING, SPALLING OR SCALING. MINOR AND INFREQUENT DELAMINATION. MINOR SURFACE LOSS. OR COMBINATION THEREOF.

31\. TRANSVERSE CRACKS ON BOTTOM OF DECK SHOWING LEAKAGE.

32\. LEAKING TRANSVERSE CRACKS COMBINED WITH 20.

33\. LEAKING TRANSVERSE CRACKS COMBINED WITH 30.

40\. EXTENSIVE CRACKING, SPALLING OR SCALING. MODERATE DELAMINATION AND SURFACE LOSS WITH OCCASIONAL POP-OUTS OR POT HOLES. LOOSE OR ROTTEN CONCRETE. OR COMBINATION THEREOF.

44\. LEAKING CRACKS ON BOTTOM OF DECK COMBINED WITH 40.

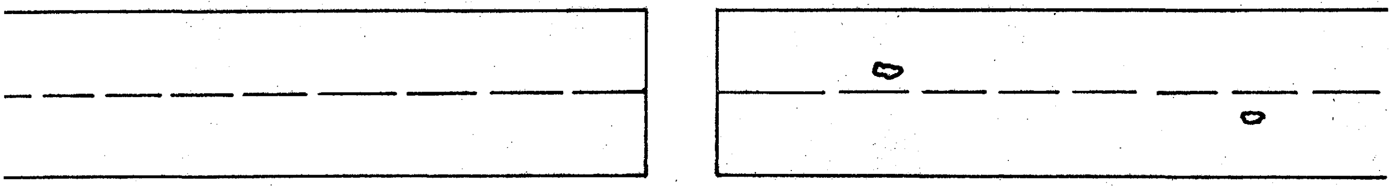
50\. SEVERE CRACKING, SPALLING OR SCALING. EXTENSIVE DELAMINATION. EXTENSIVE SURFACE LOSS WITH RUSTY STEEL SHOWING. EXTENSIVE LOOSE OR ROTTEN CONCRETE. EARLY OR BEGINNING TENSION CRACKS ON BOTTOM OF DECK. OR COMBINATION THEREOF.

51\. LEAKING CRACKS ON BOTTOM OF DECK COMBINED WITH 50.

52\. EXTENSIVE OR SEVERE TENSION CRACKING ON BOTTOM OF DECK COMBINED WITH ANY OF THE ABOVE. (REPLACE LAST DIGIT, 2, TO DENOTE COMBINATION. i.e., 54 INDICATES 52 COMBINED WITH 40.

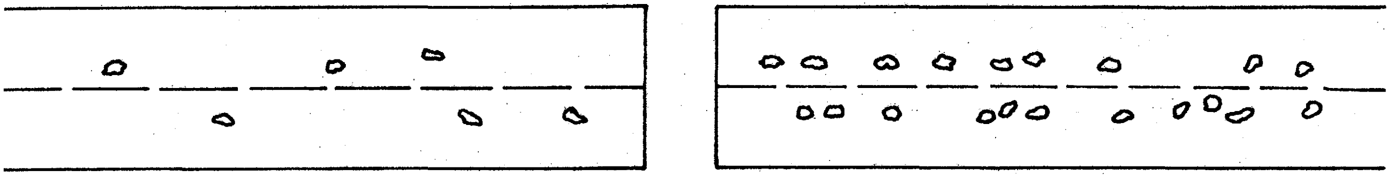
60\. DECK FAILURE: CRACKING THROUGH DECK WITH LOSS OF INTEGRITY BETWEEN CONCRETE AND STEEL OR HOLES COMPLETELY THROUGH DECK.

Relationship Beween Classifications



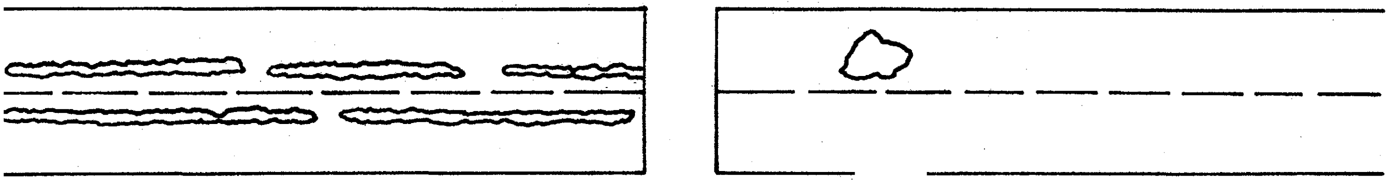
1. NO DELAMINATION

2. SMALL, ISOLATED AREA OR AREAS



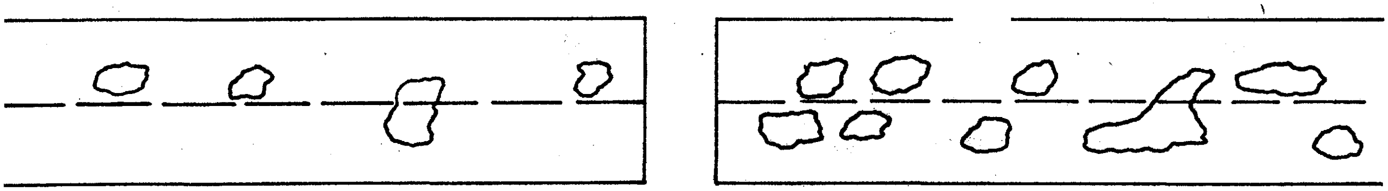
3. SMALL AREAS MODERATELY SPACED

4. SMALL AREAS CLOSELY SPACED



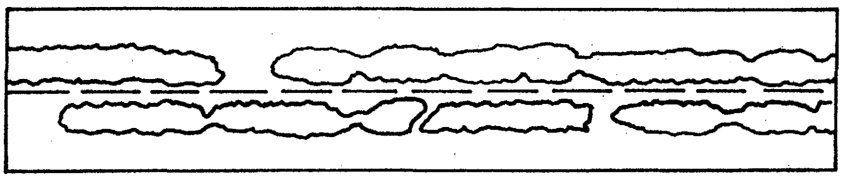
5. SMALL AREA CONTINUOUS

6. LARGE, ISOLATED AREA OR AREAS



7. LARGE AREAS MODERATELY SPACED

8. LARGE AREAS CLOSELY SPACED



9. LARGE AREA CONTINUOUS

Degree of Delamination