THE STATE OF TEXAS

A STUDY OF
BRIDGE DECK DETERIORATION

VOLUME 1

MATERIALS AND TESTS DIVISION

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SUPERVISING CONCRETE ENGINEER

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TEXAS HIGHWAY DEPARTMENT

A STUDY OF
BRIDGE DECK DETERIORATION

Volume I

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PREFACE

This report is the result of a directive from Mr. D. C. Greer, State Highway Engineer, to determine the causes of deterioration in Texas structures and to recommend corrective measures. It is prepared in two volumes. This volume is the Discussion and Summation of the report. Volume II contains the description of Field Survey investigations and records.

Field surveys, sample taking, and laboratory investigations required a cooperative liaison between District and Austin Office personnel. Without the excellent cooperation exhibited by all concerned, this project would not have been possible.

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I. SCOPE:

Severe deterioration of structural concrete, primarily in the deck, on bridges on the State's primary and secondary highway systems led to the initiation of this study. The purpose of this study has been to investigate as fully as possible, in the shortest possible time, causes which directly or indirectly create or accelerate distress in the structural concrete.

Selected objectives were as follows:

1. Review of past and current research efforts by:
    - a. Search of background literature.
    - b. Conference with other organizations that either have conducted or are presently conducting similar investigations.
2. Determine the type and scope of concrete deterioration actually occurring in Texas highway bridges by:
    - a. Partial evaluation of Bridge Deck Condition Survey conducted under the direction of the Maintenance Division of the Texas Highway Department.
    - b. In-depth investigation of 100 selected structures representing a cross-section of environmental conditions, materials sources, traffic loadings and structural types and further representing sound and distressed concrete.
3. Evaluation of materials used in the manufacture of concrete by laboratory research.
4. Evaluation of available information and actual design and con-

struction procedures used in the manufacture, placement and curing of concrete.

5. Evaluation of structural design to the extent reflected by types of bridges most adversely affected.
6. Effect of maintenance practices which may affect the hardened concrete; such as, the use of de-icing salts and sealing of the deck surface.
7. Adequacy of existing test procedures to insure uniform batching, mixing and placement of concrete.
8. Recommendations which will tend to eliminate or reduce the deterioration of structural concrete on future structures.

II. SUMMARY OF OBSERVATIONS:

A. Partial analysis of the intensive Bridge Deck Condition Survey conducted under the direction of the Highway Department Maintenance Division on 4094 structural units, representing approximately 25% of total structures on the highway system in Texas, furnished sufficient information to justify the following:

1. Without the introduction of some additional parameter, no consistent correlation was readily apparent between the general condition of the deck and the total length of the span or the thickness of the slab when all types of structures were considered.
2. The thin slab continuous type structures were the most seriously damaged in twenty-three highway Districts and the continuous I-Beam or plate girder type structures suffered greater damage in twenty of those twenty-three Districts.
   Serious cracking occurred in 8 to 34% more thin slab continuous structures than the simple span type, with 61% of all continuous I-Beam structures being moderately to severely cracked.
   In comparison with all other types of structures, the Continuous I-Beam averaged 14 to 40% more in the number having scaling. The Continuous I-Beam and the Continuous Slab and Girder types averaged 14 to 26% more structures showing delamination.
3. Based on the results of the total number of units surveyed state-wide, the types of structures in descending order of severity of damage are as follows:
   a. Continuous I-Beam
   b. Continuous slab and girder, cast-in-place

c. Simple I-Beam

d. Pan form slab and girder, cast-in place

e. Prestressed beam*

f. Continuous slab

g. Slab and girder, cast-in-place

h. Simple slab

*Conceivably, this type of structure could have rated higher in degree of distress had the ages of the majority of surveyed structures been more comparable to those of other types, rather than relatively young.

4. The type and extent of distress could not be attributed to reactive aggregates or cement in that similar damage occurred throughout the State regardless of type or source of materials.
5. The use of de-icing salt accelerated the rate of distress but similar severe damage occurred on a large percentage of non-salted structures, precluding consideration of de-icing salts as a primary cause.
6. Entraining air in the concrete deck decreased the percentage of structures damaged but did not decrease the severity of the deterioration. Sufficient information was obtained during the in-depth portion of this study to cast doubt on reports of structures supposedly using air-entrainment, making the comparison of air versus non-air-entrained bridge decks questionable.
7. The structures constructed after 1950 had a greater percentage damaged than those constructed prior to that date. Structures built after 1960 are deteriorating rapidly and the trend indicates that the results of 1950-1960 construction period will be repeated.

8. Comparison of the Texas Highway Department Standard Specifications for 1938-1950 and 1951-1960 disclosed the following changes capable of abetting forms of deterioration:
    a. Reduced from 10 to 7 the number of days prior to opening to construction or public traffic.
    b. Reduced from 4 to 2 the number of days before using for carting or wheeling batches of concrete to adjacent pours.
    c. Reduced minimum curing time of slab from 8 to 6 days.
    d. Reduced the minimum cement content from 6.0 sacks to 5.0 sacks per cubic yard.
    e. Increased the maximum water cement ratio from 6.25 to 7.0 gallons per sack of cement.
    f. Allowed the use of transit-mix concrete.

B. 100 structures studied in depth, reflecting both good and distressed concrete, plus information from the Bridge Deck Condition Survey on all units, yielded the following significant information:

1. Texas highway structures are susceptible to and are suffering the following types of damage in all degrees of severity:
    a. Shrinkage cracks, primarily transverse and random, formed while concrete was still low in strength and, in some cases, still semi-plastic.
    b. Transverse and longitudinal leaking cracks, generally symetrically located to reflect position of reinforcing steel.
    c. Transverse deflection cracks in the tension portion of the

slab formed both before and after concrete reached full strength.

d. Diagonal cracks at the corners of pan form slabs.

e. Delamination at all levels down to bottom steel.

f. Scaling, or deterioration of surface mortar.

g. Discolored, leaking areas on underside of pan form and thin slab structures.

2. Few complete construction records of actual concreting operations made and practically none have been retained except for average design and strength data. In isolated instances where information was available, below specification flexural beam strengths were found to have occurred for an extended period of time before design corrections were made.

3. Petrographic examinations of core samples revealed low level reactivity of materials in only two structures and these indicated insufficient activity to affect the concrete harmfully.

4. Numerous occasions of reinforcing steel not having sufficient cover, in many cases less than 1 inch and, in some cases, exposed on the top surface of the deck.

5. Evidence in 66 structures of excess mixing water in form of water voids, bleed channels, light, dull colored mortar, and soft paste. Field notes reported as much as 6 inch slump in some cases.

6. Poor gradation or segregation of aggregates with many cases of intermediate sized material lacking or missing altogether.

7. Non-uniform distribution of entrained air, varying between cores

from the same structure as much as 6.0%.

8. Concrete design data reflected the use of entrained air but core samples revealed that none was present.
9. Non-uniform consolidation as evidenced by wide range of absorption and density of core samples taken from the same structure.
10. Compressive strengths of core samples varied up to 1500 psi. within a single structure. Samples from 11 structures had strengths less than 3000 psi.
11. Concrete had been placed and cured under extreme temperature conditions. Summer operations included temperatures up to 109^o on and following pouring date, and winter operations included temperatures down to -4^o on and following date of pouring operations.
12. Concrete had been placed and finished under adverse weather conditions, e.g., sandstorms, 60 mph. winds and rain.
13. Materials, designs and batches were misused in correcting for abnormal weather conditions occurring during pouring operations.
14. Similar patterns of distress were found in structures which had or had not been treated with de-icing salts.
15. Only minor scaling and infrequent delamination were found where adequate air and proper amounts of mixing water were used.
16. Several structures contained low areas or pockets of poor drainage which hold water on the deck.

17. Some areas of the State utilize aggregates which contain porous, soft particles and freeze-thaw susceptible aggregates as concrete materials.

18. Follow-up inspections of structures in four highway Districts approximately 6 months after initial investigation show a rapid rate of regression.

C. Laboratory study of the effect of varying cement content on the physical properties of concrete resulted in the following:

1. Increasing the cement content from 5.0 to 6.0 sacks per cubic yard resulted in:
    - a. Equal or increased density of 1 to 4 lbs. per cu. ft. in hardened concrete.
    - b. Reduced linear shrinkage at 7 and 28 days up to 80%.
    - c. Increased compressive strengths at age of 28 and 90 days up to 20%.
    - d. Reduced per cent absorption in hardened concrete by 0.5 to 1.25% for all combinations of air-entraining and set-retarding admixtures. No change or slight increase in per cent absorption for reference, air-entrained, and Retarder A concrete.
    - e. Increased the durability factor of plain concrete by approximately 100%, from 11.0 to 21.5, when tested in tap water.
2. Use of air-entraining and set-retarding, water-reducing admixtures resulted in the following:
    - a. NVR (Neutralized Vinsol Resin) in the 5.0 sack design yielded the lowest concrete density, highest shrinkage at 7 days, the lowest compressive strength at 28 days and only a slight

reduction in per cent absorption. Changing to the 6.0 sack design increased the hardened density by 4.0 lbs. per cu. ft., decreased the 7 day shrinkage by 60%, increased the 28 day compressive strengths by 11% and had no effect on the per cent absorption compared to values obtained with the 5-sack mix.

b. Lignosulfonate (Retarder A) and Hydroxylated Carboxylic (Retarder B) set-retarders increased the compressive strengths and slightly reduced the shrinkage of 5.0 and 6.0 sack designs. Retarder B increased the hardened concrete density compared to the reference concrete while Retarder A had little effect.

c. Retarder A **or** Retarder B, plus NVR "D" resulted in lower compressive strength, density, absorption, and shrinkage with both 5.0 and 6.0 sack design when added in accordance with the manufacturer's recommendation.

d. Retarder A when combined with NVR "D" prior to addition to the concrete mix increased concrete density by 5.0 lbs. per cu. ft., increased compressive strength by 1600 lbs. per sq. in., and reduced absorption by 1% for the 5.0 sack mix and, for the 6.0 sack mix, increased density by 5.5 lbs. per cu. ft., compressive strength by 2450 lbs. per sq. in., and reduced absorption 0.5%, as compared to values obtained by adding the admixtures to the concrete separately.

Retarder B when compared in a similar manner, 5-sack vs. 6-sack mix, yielded a lower density, lower compressive strength and increased shrinkage.

   e. Retarder A or Retarder B, when combined with double dosage of NVR "D" without compensation for additional air and workability, resulted in lower densities and absorption, and maintained high durability factors through 240 cycles, at which point the durability factors for 5.0 sack mixtures dropped slightly lower than those obtained with 6.0 sacks, but were still well above minimum at 300 cycles.

3. Durability tests performed by cycles of freeze and thaw, with companion samples thawing in plain water or brine solution, resulted in:
   a. Reference or plain specimens for 5.0 sack mix failed after 78 cycles in brine solution and 55 cycles in tap water. Durability factors of 15.5 and 11.0, respectively.
   b. Reference or plain specimens for 6.0 sack mix failed after 94 cycles in brine solution and 103 cycles in tap water. Durability factors of 19.0 and 20.5, respectively.
   c. Retarder B specimens for 5.0 sack mix failed after 141 cycles in brine solution and 160 cycles in tap water. Durability factors of 28.2 and 31.9, respectively.
   d. Retarder B specimens for 6.0 sack mix failed after 122 cycles in brine solution and 155 cycles in tap water. Durability factors of 24.2 and 20.9, respectively.
   e. With a 5.0 sack mix, Retarder A or Retarder B, plus double NVR "D", had a durability factor of 80 at 300 cycles.
   f. All mix conditions containing Retarder A or NVR "D", and combinations of Retarder A with NVR "D", with the exception

noted in (e), gave little evidence of weight loss or deterioration through the specified test life of 300 cycles.

D. Laboratory study of the effect of cement composition on the physical properties of mortars containing various admixtures yielded the following:

1. The set-retarding properties of the admixtures tested varied between cements as much as 3:15 hours for Retarder A and 4:10 hours for Retarder B.
2. Entrained air varied up to 3.4% between cements for NVR concretes and up to 4.6% for Retarder A plus NVR.
3. Water-reduction capabilities of water-reducing admixtures varied between cements from 6 to 15% for Retarder A and from 0 to 2% for Retarder B.
4. Water-reduction capabilities of air-entraining admixtures with various cements were from 3 to 12% for NVR "S" and 2 to 9% for NVR "D".
5. Water-reduction capabilities at each test condition were approximately the same with all cements with two exceptions. Cement A yielded 3% to 6% less water reduction for all conditions except with Retarder B, which gave no more than 2% reduction with all cements.
6. Cements A and T were the two cements high in C_3A, 13.16 and 13.4%, respectively, yet Cement T consistently yielded the least retarding of initial set while Cement A yielded the most retardation in six of the eight test conditions.
7. All admixtures and their combinations yielded 28 day compressive

and tensile strengths lower than control specimens on all cements except with Retarder B which increased or closely maintained strengths.

8. 7-day tensile strengths for different cements varied by approximately 30% for Retarder "B", NVR "D", and Retarder B plus NVR "S". This variation reduced to approximately 15% at 28 days.
9. 7-day and 28-day tensile strengths varied between cements by approximately 10 - 15% for all mixtures containing Retarder A, NVR "S", and Retarder B plus NVR "D".
10. Test conditions yielded a wide range in compressive strengths with variations of approximately 43% between cements.

III. SUMMATION OF INVESTIGATION:

Certainly no single item is responsible for the patterns of distress and deterioration of concrete in Texas structures. The body of this report has attempted to lay out the major factors affecting the serviceability and life of concrete structures and the general patterns of deterioration associated with these major causes as found in Texas. Much of this investigation has been based on core samples taken from both sound and deteriorated structures and while it is readily recognized that a core sample is like any test sample, in that it is not necessarily representative of the concrete as a whole, it does represent conditions *at* that location. If the sample indicates good sound concrete, the whole deck is not necessarily good throughout but, if the sample discloses any item of questionable quality of materials, construction or design, then it is known that the concrete is distressed in at least that portion. This condition was found to exist in a large number of the bridge decks.

Most of the causative elements generally considered detrimental to concrete and structural performance have been found associated with deteriorated structures in this State. It is possible that the occurrence of only one of these elements in low intensity should not have had the damaging effect currently existing and anticipated to continue, but the combination of several has served to assume catastrophic proportions.

If it were necessary to summarize the results of this report into one statement, it would be: Susceptibility to all forms of deterioration found in Texas structures existed at the completion of construction.

The tendency for cracking to occur in one form or another was created with 1) the selection of structural types that allow sufficient deflection at the time of construction and afterwards under traffic loading for tension or deflection cracks to form, 2) the improper use of mixing water and admixtures promoting the formation of plastic and dry shrinkage cracking, and 3) the premature hardening of the upper portion of the concrete prior to the completion of normal bleeding action in the lower regions of the concrete causing a subsidence about the upper reinforcing steel and creating a weakened plane in that area. This subsidence was found in only a small percentage of the 100 structures closely studied and was similar to that described by Kansas in their report (1). The proximity of the reinforcing steel to the surface of the deck apparently establishes a vertical plane of weakness which encourages the formation of cracks when one or more causative elements are present.

Mr. Bailey Tremper quoted the results of several investigations revealing the need for a minimum cover of 2 - 2½-inches for unprestressed concrete over reinforcing steel in his Discussion "Corrosion on Reinforcing Steel" (14). This recommendation was supported by Mr. Orrin Riley, Project Engineer for Howard, Needles, Tammen and Bergendoff, in his report "Bridge Deck Repair Techniques on the New Jersey Turnpike". (9) Mr. Riley also makes the statement that "all decks may crack, most of them do, and some of them must." (10) The findings of this investigation are in agreement that "some of them must".

When the deck has suffered cracking of any form and from any cause, then there will be saturation by rain and de-icing solutions which are able to penetrate into the concrete inner surfaces. There, crystallization, subsequent freezing, or drying action can begin to cause different forms of deterioration. If the cracks extend to the reinforcing steel following construction, or progress to that level under traffic loadings, the solutions are able to attack and corrode the steel until sufficient pressure is built up by crystallization or corrosion products to create horizontal planes of fracture. In the thin slab continuous type structures particularly, these weakened planes are finally broken free under the impact of traffic loadings and the flexure of the structure, becoming areas of incipient spalls which, experience has shown, generally continue to enlarge. Table 1, Appendix A, shows the relation of deterioration by scaling and delamination to that of cracking in the continuous thin-slab structures. The close association of many of the delaminated areas with the reinforcing steel similarly indicates an association between the cracking and the steel location in these structures and the pan form structures.

On the basis of observation and investigation, cracking due originally to plastic or dry shrinkage or deflection is believed to propagate along the pattern of the weakened vertical plane created adjacent to the reinforcing steel under traffic impact, structural deflection, and the attack of the deteriorating effects of wet-dry cycles, freeze-thaw cycles and de-icing solutions. As the structural integrity of the concrete is weakened by the extending cracks, it is probable that additional cracking begins to form at right angles to the original crack, still following the pattern of the reinforcing steel mat, until an area in the deck has been completely outlined by vertical cracks through the deck in a checker-board pattern. Traffic impact and other deteriorating elements then can begin to destroy the bond with the steel of the isolated section of the deck and enlarge the cracks until friction will no longer hold that portion in place.

A similar type of bridge failure was reported by Mr. Orrin Riley (9). His description of the deterioration and the manner of its progression is very similar to that found on Texas structures and described here.

A plausible explanation of the rapid progression of the damage to the point of failure is described by Linger and Gillespie (7) in their investigation of failure by fatigue in concrete. It was their findings that a rapid reduction in elastic modulus takes place during the first 15 per cent of the total cycles to failure. This is followed by a leveling off of the rate of reduction up to 85 per cent of the total cycles. The remaining 15 per cent result in a rapid reduction in the modulus ending in failure. This would tend to explain why rapid deterioration resulting in severe damage or failure seemed to begin suddenly in many of the structures observed.

Concrete bridge decks which were found to have entrained air properly dispersed and in adequate amounts by current design standards and which did not have evidence of excessive mixing water had only minor scaling. Table 7, Appendix A, lists the core samples and the corresponding percentage of air voids found along with a brief description of the surface of the deck at that point.

The value of air-entraining admixtures in improving scale resistant qualities of concrete has been demonstrated in numerous investigations conducted by most authorities in concrete technology. However, there is a tendency to accept the beneficial qualities at face value without understanding the proper usage. The necessity for designing, mixing, and placing air-entrained concrete properly is reflected by the reduced scaling on the structures in which sufficient air was properly entrained and dispersed. The results of the laboratory investigations reported in Appendices B and C on the effect of admixtures and the properties of mortar and concrete indicate the wide variety of reactions which can result when an admixture or cement is changed. The results were further supported by other investigations such as are reported in the Journal of the American Concrete Institute for November 1963. The findings for both air-entraining and set-retarding admixtures were:

1) The specific effects of some admixtures vary with the type, quantity, and properties of cement used.

2) Some specific effects of an admixture usually cannot be predicted accurately prior to testing.

3) Tests should be made with job materials under the anticipated ambient conditions and construction procedures.

4) Entrained air should always be required under conditions of severe natural weathering and where de-icing salts are used to remove ice.

ASTM publication STP 169A, Concrete and Concrete-Mixing Materials, and STP 266, a symposium on Effect of Water-Reducing and Set-Retarding Admixtures on Properties of Concrete, reported similar results.

The large percentage of core samples from concrete reportedly air-entrained, which revealed non-uniform, inadequate, or zero air content actually present is an example of the need for better design and control techniques. A better understanding of the capabilities and the limitations of air-entraining admixtures, as well as all other types of admixtures, is necessary before acceptable results can be expected and obtained. This can only be accomplished by proving a design with pilot batches through use of the batching and mixing equipment and all materials proposed for use in the project at conditions as close as possible to those anticipated. The presence of an admixture on an approved list cannot guarantee its acceptable performance with all job materials, equipment and conditions.

Countless tests, numbering literally in the thousands, performed over extended periods of time, have proven that the water-cement ratio is the most important single factor influencing the strength of concrete. The degree of drying shrinkage of concrete is also controlled primarily by the water content. Slight changes in the water-cement ratio within the ranges normally used directly affect the durability of concrete to a great degree. Therefore, the use of excess water in the mixing and placing of concrete, as has been found in many core samples, has a direct detrimental effect on the satisfactory service life of a structure and its inherent ability to withstand deteriorating forces. Placing concrete when expected temperatures may be critical to the finishing and curing operations should be avoided unless special hot weather techniques are employed and satisfactory curing procedures such as fogging are employed.

The non-uniformity in concrete evidenced in samples taken from bridge decks is generally directly associated with the mixing operation. Excess vibration during placement may affect a wet, or higher slump, concrete but usually not to the extent noted in this investigation. Transit-mix concrete, with proper equipment in good operating condition and adequate supervision at the batching site as well as at the point of discharge, is considered capable of performing satisfactorily. With the current shortage of personnel trained in all phases of concrete operations, it is doubtful that transit-mix concrete is being controlled to the extent of insuring the delivery of a uniform product consistent with that designed. Certainly greater care should be used and more tests made prior to acceptance of the material. The accepted procedure on many projects observed in the past has been to perform air and slump tests and mold beams for strength tests on the third or fourth load of concrete delivered, then to clean up the equipment until "x" number of cubic yards have been delivered before repeating the process. Every load of concrete should be tested at least once for air content where air-entrained, and twice for slump. The aversion to rejecting loads of concrete which has increased over a period of years is quite often the result of inexperienced inspectors and every effort should be made to overcome both the aversion and the inexperience.

The change from 6.0 to 5.0 sacks of cement with reduced curing times apparently is proving to be false economy. The change to

6.0 sacks of Type II cement in areas using de-icing salts, while in itself certainly not detrimental to a structure, is not apt to prove much of a benefit unless additional curing time is allowed for the slower strength gaining cement. In light of the current level of deteriorated structures in this State, the old concept of "an extra sack of cement and a few days extra curing for cheap insurance" is worth considering. The results of increasing the cement to 6.0 sacks per cubic yard in the Laboratory Investigation, outlined in Appendix B, support an increased cement content.

The use of hot mix asphalt concrete (HMAC) and asphalt seal coats on bridge decks as riding surfaces, protective coatings, and maintenance rehabilitation has been common and widespread. In many observations concrete "sealed" by these methods has been found to be more extensively damaged where de-icing salts are used than supposedly unprotected concrete. HMAC contains sufficient voids to allow the passage of de-icing salt solutions and normal solutions of rain water bearing compounds into the interface with the concrete. Here the solutions are trapped and penetrate localized areas of the concrete in concentrated amounts. Similar actions occur at a reduced rate with asphalt seal coats. As the asphalt in the seal coat tends to become more brittle with age, the tendency to crack under cold weather conditions becomes more pronounced until eventually passages are opened to the concrete surface.

The use of de-icing salt on bridge decks has become a common policy with many State Highway Departments to maintain traffic movement during periods of adverse weather conditions. In NCHRP

Report 19 (16) by Boies and Bortz, the use of various de-icing agents was investigated and there appeared to be two forms of deterioration found in connection with chloride solutions. The first was the cement mortar deterioration reported by most investigators with low concentrations of de-icing salt solution. The second was a general softening and deep cracking with high concentrations, reflecting possible chemical attack. This appears to be the pattern of deterioration described in this report as porous, discolored areas on the underside of the structure. If this type of damage is occurring where the bridge deck is becoming saturated with these salts, then the proper use of entrained air, good drainage, flushing the deck regularly, and the development of a good deck seal becomes doubly important.

Advantage should be taken of the progress of modern concrete technology in many areas. One of the most important of these is an improved method of selecting proportions for concrete. The most widely accepted method has been presented by A.C.I. Committee 613 (15) of which several variations have been developed by using organizations. In this design method, proportions are based more on the characteristics of the materials, type of construction, and environment of structure. The amount of cement is based upon required performance rather than a set specification value.

Much has been said and published about methods for increasing concrete and structural performance and much is still to be explained; but at the present level of knowledge, concrete difficulties should be the exception rather than the rule.

IV. RECOMMENDATIONS:

The following recommendations are based on the observations made in this investigation and the experience of other State Highway Departments in similar studies:

A. Quality Design and Control of Concrete:

1. Upgrade the experience level of personnel engaged in the design and control of concrete operations through specialized training schools.
2. Adopt a modern method of designing concrete based on the properties of component materials and design function, e.g., "Recommended Practice for Selecting Proportions for Concrete" by ACI Committee 613.
3. Prove selected design and proposed batching equipment by producing test batches with all selected materials, including admixtures, with project equipment, at ambient temperatures expected to prevail during the project.
4. Require a minimum of two slump tests per load of concrete, the first to be taken as the load is about to be discharged.
5. Require a minimum of one test for entrained air per load of concrete where applicable.
6. Require uniform production from concrete batching and mixing equipment prior to the placement of any material. "Level off" batches when plant first commences production on a project should not be placed unless all requirements are met.
7. Reject immediately any concrete which has too high a slump,

requires additional water above that designed prior to discharge, is non-uniformly mixed, or for any other reason that concrete fails to measure up to acceptance requirements.

8. Require verification of proper location of reinforcing steel prior to and after placement of concrete.
9. Restrict the placing of concrete to times when the surrounding air temperature is 85^{o} or less, unless proper methods for hot weather concreting, including use of a set-retarding admixture, are followed. This should include the use of fogging during the initial curing operation.
10. Avoid pouring days when extreme temperature ranges can be anticipated unless, as in the case of cold weather concreting, the freshly poured concrete can be protected by maintaining the temperature of the air surrounding it at a safe level.
11. Obtain maximum density by proper consolidation.
12. Require wet curing through the total number of days set forth in the specifications. Fogging should be used during hot weather operations.
13. Require the keeping of a complete log of mix proportions, control tests, mixing time, slump, air, wet unit weight, etc. for each pour.
14. Ensure proper surface drainage by control of finished grade and surface finishing operations.
15. Do not allow the use of transit-mix operations where sufficient trained personnel are not available to control all phases.

B. Specifications

1. Increase the minimum cement content from 5.0 to 6.0 sacks per cubic yard.
2. Decrease the maximum water-cement ratio from 7.0 to 6.5 gallons per sack of cement.
3. Increase the required wet curing time from 6 to 8 days.
4. Increase the period required for keeping all loads off of pour from 2 to 4 days.
5. Adjust curing times to provide for slower strength gain when Type II cement is used.
6. Require the use of properly air-entrained concrete in areas where de-icing salt is used and regular freeze-thaw and wetting-drying cycles are expected.
7. Change existing specification establishing entrained air limits from 4.0 to 8.0% to 6.0 ± 2% entrained air.
8. Require the use of an air-entraining admixture when a hydroxylated carboxylic type set-retarding admixture is used.

C. Structural Design

1. Review design standards for modification to eliminate or reduce cracking due to excessive flexibility or vibration stresses during and following construction.
2. Increase minimum cover over reinforcing steel to 2 inches.

D. Maintenance Practices

1. Seal all new deck surfaces with 2 coats of 50% linseed oil anti-spalling compound.
2. Avoid the use of hot-mix asphaltic concrete on all structures

and bituminous seal coat patches and wearing surfaces on all new decks.

3. Flush de-icing salt off of deck after each usage where possible and at least twice per season.

V. FUTURE STUDY:

1. Adoption of any of the recommendations made in this report will require that follow up investigations be made for evaluation of the corrective effort.
2. Investigations should be made with cement contents in excess of 6.0 sacks per cubic yard and should include various aggregate and cement sources. The amount of freeze-thaw action in some sections of Texas is equal to that of States presently requiring 6.0 to 7.0 sacks.
3. Research should continue in seeking an impermeable, resilient coating to be applied to all bridge decks where undesirable solutions are present.
4. Bridge structures should be resurveyed at least annually to determine condition and rate of deterioration. This will enable the use of corrective measures before extensive or severe damage is incurred.
5. Investigate the proper usage of membrane curing compounds as interim curing measures. Due to the time element, this was not included as a part of this study. However, references have been studied in the search of published literature revealing difficulties encountered with this material.
6. Investigate the effect of neoprene bridge pads. Published research in this area has indicated that while the frequency of vibration is decreased when the elastomeric bearings are used, the dynamic and non-dynamic amplitudes and deflections are increased.

VI. DISCUSSION:

History of Investigation in Texas

The problem of concrete bridge deck pavement distress and deterioration has been a plague to Highway Engineers throughout this nation and many foreign countries for more than a quarter of a century. The ever increasing demands placed on highway systems by expanding traffic, population, greater wheel loadings, and the need to keep highways open to movement regardless of adverse winter weather conditions have created a whole new set of problems for the researcher, the designer and the project engineer.

Concrete bridge structures throughout this country are suffering the same general types of distress. The distress varies in form, degree, and location, but is basically similar in all States. This widespread problem has aroused a common interest among highway engineers which has resulted in the initiation of both field and laboratory research directed toward determination of the causes and deriviation of possible solutions.

Texas structures follow the same general pattern as found in other States, e.g., leaking cracks, heavy scaling and deep delamination. Here, as in other States, no panacea has been developed to resolve the difficulty. The extreme range of environmental, material, and traffic conditions is reflected by the occurrence in Texas of practically every type of damage or distress which previously has been reported by other States. These similarities give emphasis to the findings of both broad scale and specific investigations of this problem, conducted by various State and allied research organizations.

General awareness of the severity of the problem of deteriorating concrete in bridge decks over the whole State of Texas began slowly approximately seven years ago when a large number of structures in seven highway Districts located throughout the State required an extensive repair program be established by the Maintenance Division. In 1965, the Maintenance, Bridge, and Automation Divisions, working together established a Bridge Deck Condition survey based on a 10% random survey of the total concrete deck bridge population and reported in a format allowing computer analysis to determine the extent and character of the deterioration on a State-wide basis. Shortly thereafter it was decided to include all structures within the scope of the survey which had suffered at least moderate damage in any form. This survey is still in operation and the evaluation of the data has commenced. A report is expected within the next year.

In August 1964, after working closely with the Maintenance and the Equipment and Procurement Divisions, the Materials and Tests Division Chemical Laboratory prepared a purchasing specification for de-icing salts to be used on Texas structures. Several other State Highway Departments were contacted for information concerning their specifications and testing of this material. Subsequent study resulted in the specification item titled "Salt, Rock, Sodium Chloride (95% Minimum), Road Building (and De-Icing)", which is attached in Appendix G.

As an interim measure until an extensive study could be made, the Bridge Division made certain specification and design changes for new construction which it felt would possibly check the occurrence of distress. These changes included:

1. Increasing the top cover of reinforcing steel by ½-inch in 1961.
2. Deck slabs tied down to steel beams with shear lugs for stiffer construction (1961)
3. Change to Type II cement, sulfate resisting, in areas where de-icing agents are in use.
4. Cement content increased from 5.0 to 6.0 sacks per cubic yard in some areas where de-icing agents are in use.

In May 1966, the Materials and Tests Division was charged with the responsibility of planning and carrying out this study on a top priority basis, and reporting recommendations for the preclusion of deteriorating concrete in bridge structures in the shortest possible time, preferably within six months.

A review of published literature was immediately started on similar, current projects underway in Kansas (1), Michigan (2), Pennsylvania (3), and Missouri (4) & (5), along with a literature search for published reports on specific problem areas. During this time, conferences were held with representatives of interested Divisions and Districts to review past efforts and to partially outline the extent and types of damage found to exist on structures in the State.

After a tentative project outline had been formulated, personal conferences were held with the individuals responsible for the Pennsylvania Report (3), T. D. Larson and J J. Malloy, and the Kansas Report, John McNeal, Carl Crumpton and William Wendling, to review the proposed outline in the hope that by so doing misdirected efforts would be avoided.

Project Outline

Basic Assumptions:

Due to the immediacy of the problem and the abbreviated time available, the project outline adopted was based on certain assumptions. These included:

Distress in structures was caused by deficiencies in either 1) materials, 2) construction, 3) structural design, 4) environment, 5) maintenance practices, or any combinations of the five.

1. Materials:

   The widespread occurrence of deteriorated structures throughout all areas of the State representing concrete made with all types and from most sources of materials led to the decision to eliminate the possibility of unsound or reactive materials from primary consideration in this study. If materials, as such, were indeed a problem, it was believed petrographic analysis of core samples taken from distressed structures would reveal the difficulties and the course of the investigation could be revised.

2. Construction:

   This included such items as control of materials, concrete design, uniform mixing, workability and slump control, proper reinforcing steel placement, uniform placement of concrete, proper use of vibrators, control of entrained air, weather conditions at and following placement, and type and duration of curing. This information could be derived only from project diaries, construction records, weather records, visual examination of the structures and core samples taken from them, and from microscopic examinations on prepared sections of the cores for determination and location of aggregate fractions, amount and dispersement of entrained air, and evidence of excess mixing water.

Equipment and the experience required to perform the microscopic examinations necessary for linear traverse and petrographic studies on core samples were not available in the Department. Purchase of the necessary equipment and training personnel to operate it would have been unrealistic in light of the time element involved, therefore, five private consultants and consulting organizations agreed, when asked, to perform the required studies.

Inadequate knowledge regarding the use and effect of concrete admixtures prompted the inclusion of limited laboratory investigations on 1) effects of varying cement content on the physical characteristics and durability of plain concrete, set-retarded concrete, air-entrained concrete and combinations thereof, and 2) the effect on the properties of concrete mortar of varying types of admixtures and a selected group of commonly used brands of cement.

3. Structural Design or Type:

Reports on investigations conducted by other State Highway Departments (1, 2, 3, 4 and 5) all indicated that some forms of distress, e.g., transverse cracking, were more numerous in continuous type structures, both reinforced concrete and structural steel types. Initial scattered samplings indicated that a similar pattern existed with Texas structures. Therefore, a partial evaluation of the Maintenance Division's Bridge Deck Condition Survey was initiated to establish types of structures most affected by the different forms of deterioration, relation between structures treated with de-icing salt and those not treated, and structures with and without entrained air. Results obtained by this method were verified by the 100 structures studied in depth.

4. Environment:

A record of the type of weather environment in which the structures had existed since construction was necessary for an evaluation of this sort. Copies of weather records, which had been placed on data processing tape by the Texas Water Development Board were obtained and the Automation Division of the Highway Department wrote a program for obtaining weather history for each of the structures selected for in depth study. This information included the daily record of precipitation and temperature extremes for the months of construction. Also obtained was the total number, for each year since construction, of wet-dry cycles, freeze-thaw cycles, freeze-thaw cycles with precipitation, days with 32^{o} or less and precipitation, and inches of precipitation, from the U S. Weather Station nearest each structure.

5. Maintenance Practices:

The basic maintenance practices of primary interest in this study are the effects of 1) maintaining a "bare-deck" policy through the use of de-icing salts, 2) sealing the surface with linseed oil applications, and 3) overlaying the deck with hot-mix bituminous concrete and asphalt seal coats. In an effort to determine the identity and cause of discolored areas of the deck where suspected salt damage had occurred, samples of concrete were chipped from the top and bottom surfaces of the concrete deck and from core samples for analysis by x-ray diffraction by local consultants. Samples of the cores also were tested by the Materials and Tests Chemical Laboratory for determination of ion exchange capacity.

The effect of sealing the deck with either linseed oil or asphalt was to be based on the bridge deck survey and visual comparison of damage.

Results of Investigation

A. Definition of Forms of Deterioration:

The types of distress found in the Texas structures were 1) cracking, 2) scaling and 3) delamination. These three types of deterioration are defined as follows:

1. Cracking:

This type of distress is defined as a cleavage or separation visible on the surface and usually perpendicular to it, varying in depth, width and direction of travel. This type of distress is the most widespread and is present in all critically deteriorated Texas structures.

There has been some difference of opinion as to whether or not cracking should be considered a form of distress or deterioration. The Kansas study (1) reported that "Only a small percentage of the cracks observed was associated with serious forms of deterioration." In contrast, both the Michigan report (2) and the Missouri report (4) support findings that cracking definitely can be related to more serious and progressive forms of deterioration.

Linger and Gillespie (7) in their study of concrete fatigue and fracture pointed out the effect of microcracking on the rapid and drastic loss in modulus of elasticity through repetitive load cycles, and the corresponding effect of fatigue loadings on the expected life of concrete. Concrete in this condition does not need the action of additional factors such as de-icing agents or freeze-thaw cycling to be critically affected and any action which first weakens the structural integrity of the deck logically makes failure by fatigue a strong possibility.

2. Scaling:

   Scaling is the loss of surface mortar, often progressive in action, caused by the breaking down of the paste constituent. This type of deterioration is similar to that identified as "surface mortar deterioration", "progressive scale" or "salt scale" by other researchers.

   Scaling has been found in several investigations to be closely related to any one of several factors, e.g., excessive finishing of surface, excess mixing water, de-icing agents, freeze-thaw cycles, wet-dry cycles and misplacement of reinforcing steel. Highway Research Board Bulletin No. 323 (8) relates the account of several State investigations in summary form, many of which list the above examples as causative factors.

3. Delamination:

   This type of deterioration is the horizontal cracking which occurs at various depths from immediately beneath the surface to several inches deep. Delamination often is found in close proximity to the top steel and occasionally to the bottom steel, and often has been associated with transverse cracking. Delamination is similar in nature to the "fracture plane" described by the Missouri report (4) and the "spalls and hollow areas" described by the Kansas and Michigan reports (1, 2).

B. Partial Analysis of Bridge Deck Condition Survey (BDC).

The BDC Survey had been in operation a sufficient length of time for a large number of the surveys to have been completed. It was logical, therefore, to make these results the basic source of information as to general condition, location and definition of types of distress occurring. For clarity and for later correlation the terms and descriptions used in this study are the same as set forth in the Bridge Deck Condition Survey Manual (6), a part of which is included in this report as Appendix F.

For this particular correlation, the in-depth study of 100 structures was considered too small for any general conclusions to be of merit, so the total BDC survey, consisting of 4094 structural units, representing approximately 2919 structures, was selected for partial evaluation. The BDC survey, when completed by the Maintenance Division, will make possible a much more detailed evaluation, but general, meaningful trends were obtained to complement this investigation.

The BDC survey reports were reviewed for compatibility between the general deck condition ratings and the individual cracking, scaling or delamination ratings. Few ratings were bettered, but a large number were changed to reflect a more severe degree of deterioration, where specific conditions warranted. Many of the structures surveyed previously had experienced failure of a portion of the deck and had been repaired. These apparently were reported to reflect their repaired surface condition.

Following this review, statistical breakdowns were made in order to correlate general deck condition with structure type, de-icing salt versus non-de-icing salt treated structures, air-entrained versus non-air-entrained structures, effect of structure age, and length of span and thickness of slab.

An effort was made to determine whether the span length and slab thickness of the deck could be evaluated separately from the main structural elements. Both span length and thickness, individually and in combination, were compared to the general rated deck condition. No meaningful pattern was developed in this approach.

Table 1, Appendix A, lists, by percentages based on the number of each type of structure surveyed, each major type of structure in descending order of percentage of structural units affected, and a breakdown by types of deterioration. It is readily seen that the continuous, thin slab type structures suffer the most distress of all types and degrees, and that the continuous structural steel beam types are the most affected. The more severe deterioration indicated by the second figure in parenthesis reflects the same pattern.

Table 2, Appendix A, is similar to Table 1 in listing by structure types a resume of the number of air-entrained versus non-air entrained structures reflecting deterioration. Only structures which have been constructed since 1960 were included in this breakdown. Texas Highway Standard Specifications were rewritten in 1960 and provided for the use of entrained air.

The use of de-icing salts and ensuing damage are given in Table 3, Appendix A. The comparisons here were limited to structures from Highway Districts using de-icing salts in normal winter time operations and having, also, structures which have not received exposure to salt.

The effect of the age of the structures on the number distressed is indicated in three age groups in Table 4, Appendix A. The age groups coincide with the dates of major standard specification changes made by the Texas Highway Department in 1951 and 1960. A substantial increase in the percentage of structures affected by all types of deterioration is seen for the period 1951-1960. The continuance of this trend is reflected in the amount of deterioration already present for the four year period from 1961-1964. This indicates that unless some means is found very quickly to protect these structures, a very large bridge deck rehabilitation program will be necessary once again in a few short years.

The increase in the number of deteriorated structures which occurred during the 1951-1960 period over the period prior to 1950, indicated the necessity for reviewing the changes in the Texas State Highway Department Standard Specifications in 1951 (12) and 1961 (13) from the previous Standard Specifications (11).

The following were major changes made in the 1951 specifications which would promote early cracking as well as other forms of deterioration:

1. The period prior to use of the structure by either construction traffic or traveling public was changed from 10 days to 7 days.
2. Period prior to use of slab for carting or wheeling batches of concrete to adjacent pours was changed from 4 days to 2 days.
3. Minimum curing of slab with wet mats was reduced from 8 days to 6 days.
4. Minimum cement content for Class A structural concrete was reduced from 6.0 to 5.0 sacks per cubic yard.
5. Maximum permissible water cement ratio was increased from 6.25 to 7.0 gallons per sack of cement.
6. The use of transit-mix concrete was allowed.

All of these changes are capable of reducing either the rate of strength gain or the ultimate strength of concrete, or both. The difficulties in producing and placing uniform concrete of adequate quality are revealed by the large number of construction problems indicated in the in-depth portion of this study. The specification changes listed above, in effect, increased the probability of the misuse of good concreting procedure resulting in a distressed structure.

All methods of comparison used reflect that more of the continuous, thin slab type structures are adversely affected by deteriorating forces than any others. In the in-depth investigation portion of this study, structures which used the same materials, concrete batch designs, and general construction methods were compared and in those instances of a continuous I-Beam and another structural type, the continuous I-Beam type was found to suffer the most severe damage. These findings agree with those previously referred to in the Michigan and Missouri reports (2, 4).

C. In-Depth Investigation of Texas Structures:

100 structures located in 14 Highway Districts representing all major climatic extremes, materials sources, and maintenance problems were selected for intensive investigation. Figures 2, 3, and 4 show elevation views of six of the eight types of structures investigated. Additional structures with severe deterioration were included in some instances. The selected structures are listed in Table 5, Appendix A, and Figure 1 gives the geographical location.

Each structure upon selection was resurveyed and photographed. In this study, insufficient time was available to divide each deck into small segments for fine measurements of length and width of cracks, exact measurements of depth of scale and soundings for delamination. Many of these data were available in the original BDC survey reports. During inspection of the structures, locations for core sampling were made. Four inch cores subsequently were taken from the deck by Materials and Tests Division personnel working with the individual District personnel.

A total of 484 cores were obtained. These cores were photographed

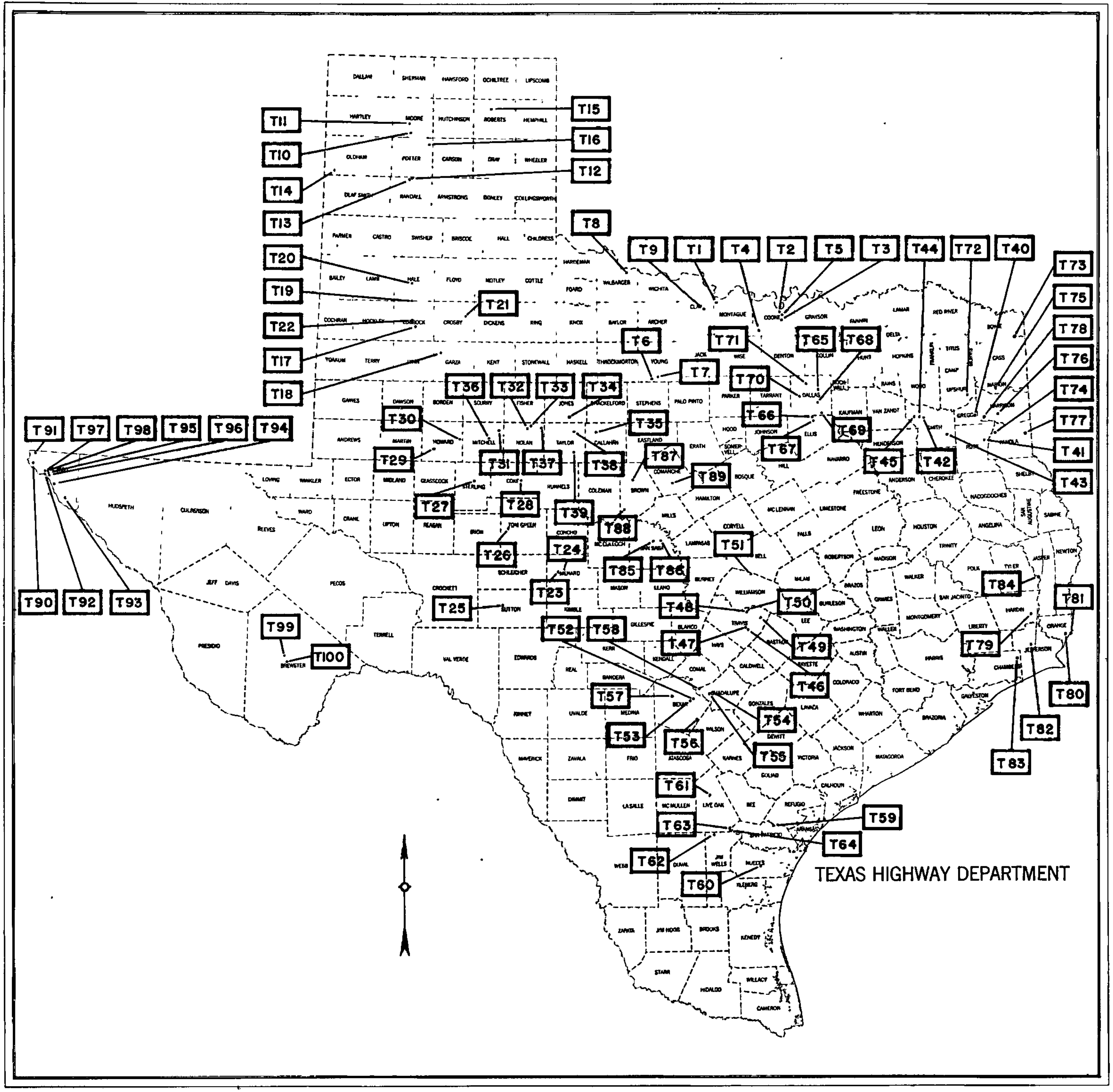
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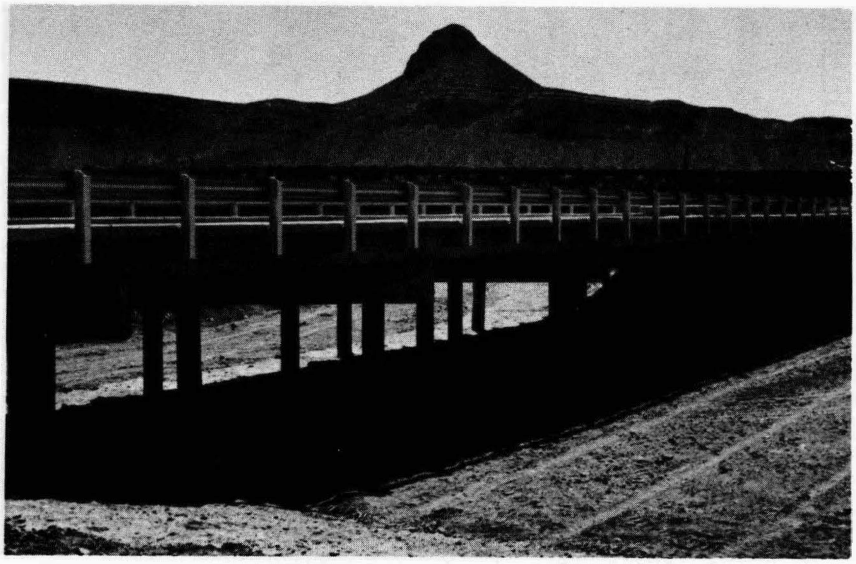
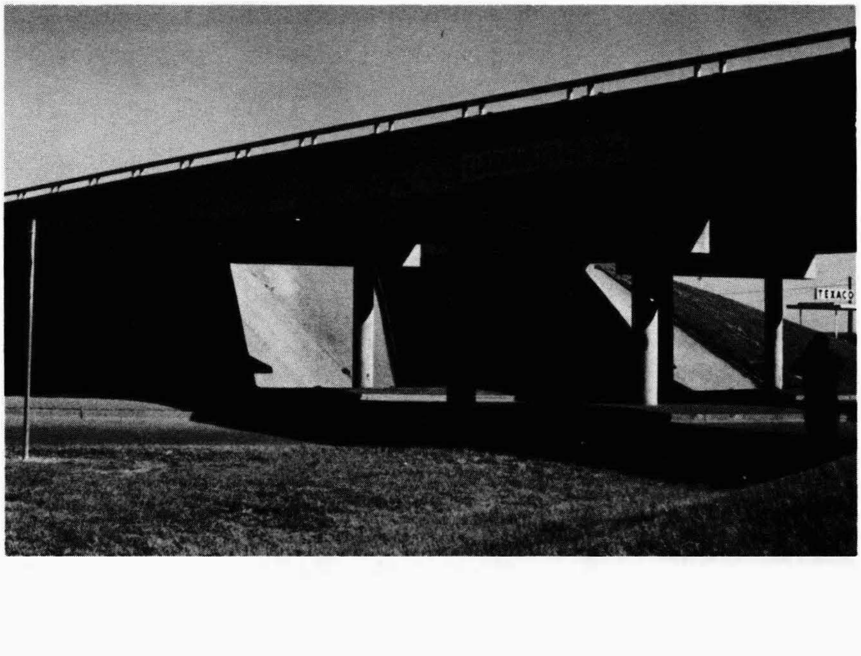
Figure 1.

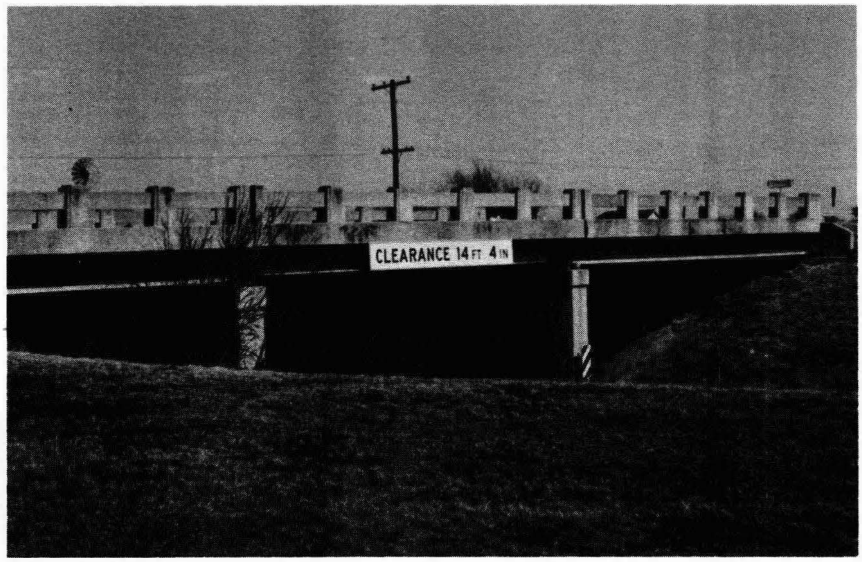


(a) Simple Slab Structure



(b) Pan-Form Slab and Girder Structure

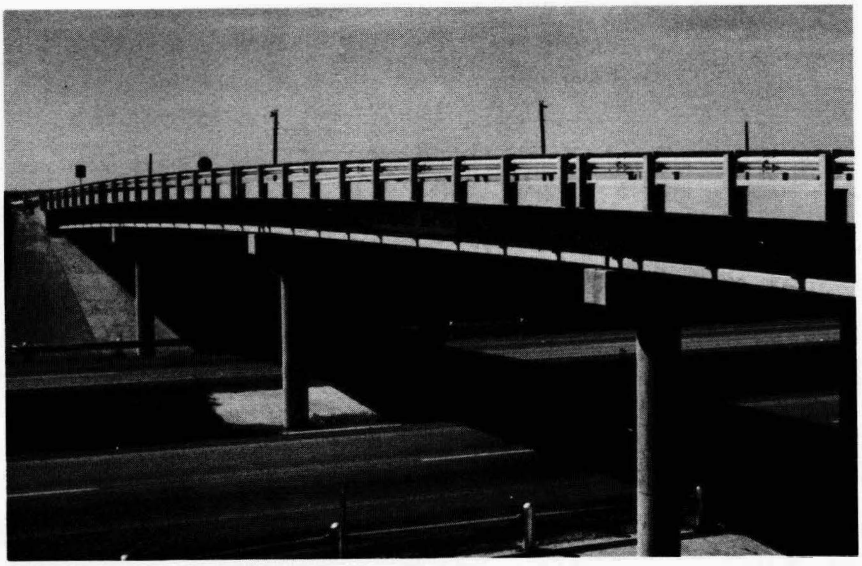
Figure 2



(a) Simple I-Beam Structure

(b) Continuous I-Beam and Pan-Form Structure

Figure 3



(a) Prestressed Beam Structure

(b) Continuous Slab Structure
Note horizontal cracks at joint

Figure 4

and studied visually for microscopic features and evidence of distress. 224 cores were then selected for shipment to consultants for linear traverse and petrographic studies. The remainder of the cores were retained for chemical testing, x-ray diffraction analysis and physical testing for density, absorption and compressive strength. The results of these tests will be discussed later in the report.

RESEARCH OF CONSTRUCTION RECORDS:

District office records, permanent file records, job diaries and concrete pour books were researched for all records of materials, concrete design, concrete placement and weather data. Extremely few records were kept and these were completely inadequate for determining any unusual events, the concrete design used, actual slump, entrained air, yield, or control specimen strengths. Judging from the few records and diaries found, it is doubtful whether any notation ever was made on most projects. The average job diary entry on a day of pouring merely stated that concrete was placed in a particular span on that day. Many average project designs were located and subsequently used in this study. This gave some basis for comparison with results obtained from the analysis of the core samples.

TYPES OF DISTRESS IN TEXAS STRUCTURES:

In the examination of the core samples, microscopically and macroscopically, and visual examination of the bridge deck, the following types and patterns of distress were found in Texas structures:

1. Transverse Cracking:

   Two major forms of transverse cracking were found on Texas structures.

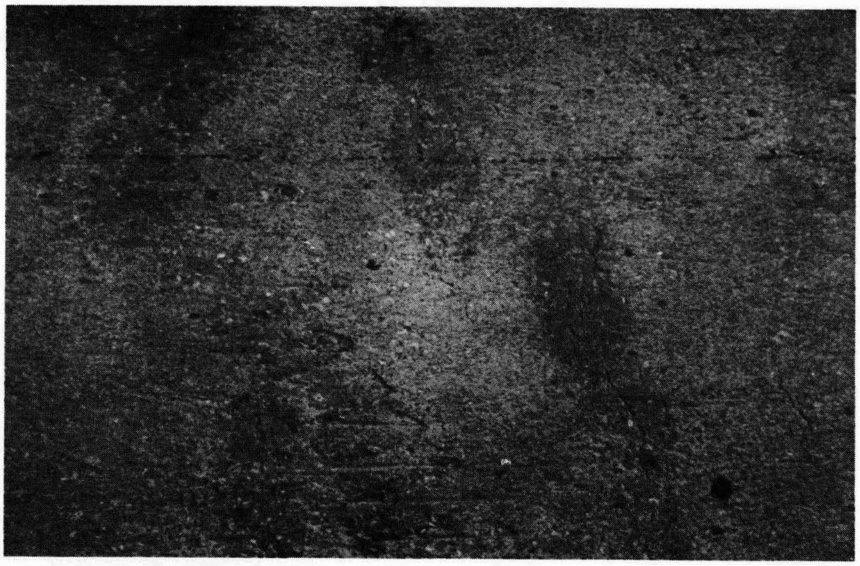
   a. Shrinkage cracks, Figures 5 and 6, formed early while the concrete was still semi-plastic or low in bond strength. Minor cracks 1/8 to 1-inch in depth and major cracks through the full depth of the slab were found. Microscopic examination of the crack pattern showed that the crack had formed around the coarse aggregate particles and in some instances trowel and brush marks were visible on the surface where attempts had been made to close the cracks before the concrete had attained final set. In some instances, shrinkage cracks were found on both surfaces of the deck.

   b. Tension or deflection cracks formed on the bottom surface of the structure and extended up into the slab to the bottom level of steel. In some cases the tension crack joined with a shrinkage crack to extend the fracture completely through the slab. Fractured coarse aggregate particles in the crack face indicated bond strength had at least partially developed when the crack was formed. On some structures this type of transverse cracking was found more closely spaced near the dents on the top surface and near the center of the span on the underside.

Plastic Shrinkage Cracks

Figure 5

(a)



(b) Attempted to close cracks while
Semi-plastic

Plastic Shrinkage Cracks
Figure 6

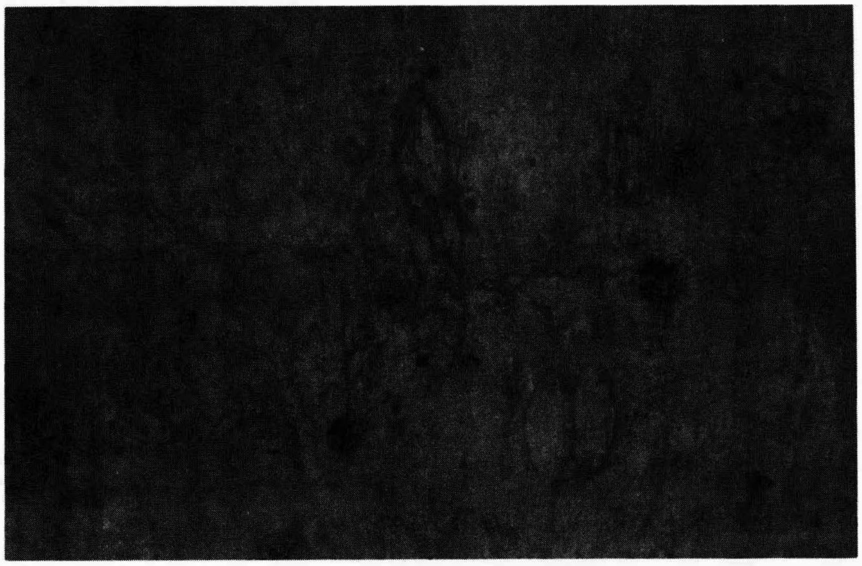
Figure 7 and Figure 8 show examples of bridge decks and core samples with this type damage.

2. Longitudinal cracking was found in some slab structures, all pan form type structures, and in the more seriously deteriorated structures of all types. The cracks in the pan form structures were located at the thin section of the structure and on both surfaces. In many instances evidence provided by examination of the cores indicated the cracks had formed early by plastic shrinkage, in some cases from the bottom and in other cases from the top.

   Cracks associated with slab structures formed at the center line of most structures and were mostly plastic shrinkage type cracks extending a short distance into the slab. However, evidence was seen on the underside of the slab that the crack was working under live loads and in some instances extended through the deck.

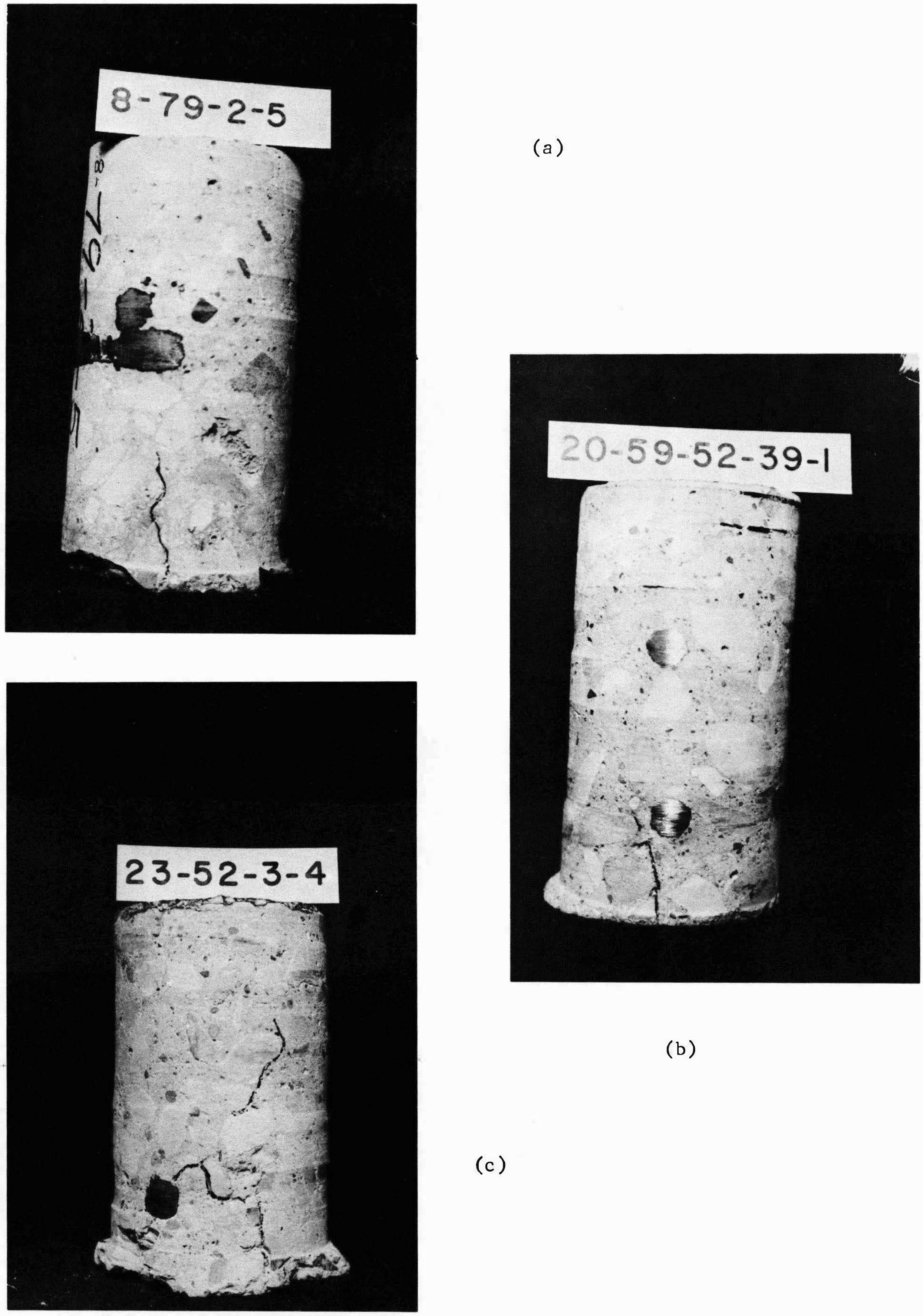
   Longitudinal cracks in the more severely deteriorated structures appeared to be the progression of serious transverse cracking following the line of the reinforcing steel until the checkerboard type of pattern developed. In some instances, the longitudinal cracks were aligned with the beam flange.
3. Diagonal cracks were located primarily at the slab corners of pan form type structures, and most of the cracks found

(a) Transverse Cracks on
Bottom Surface



(b) Deflection Cracks on Bottom Surface

Figure 7



(a)

(b)

(c)

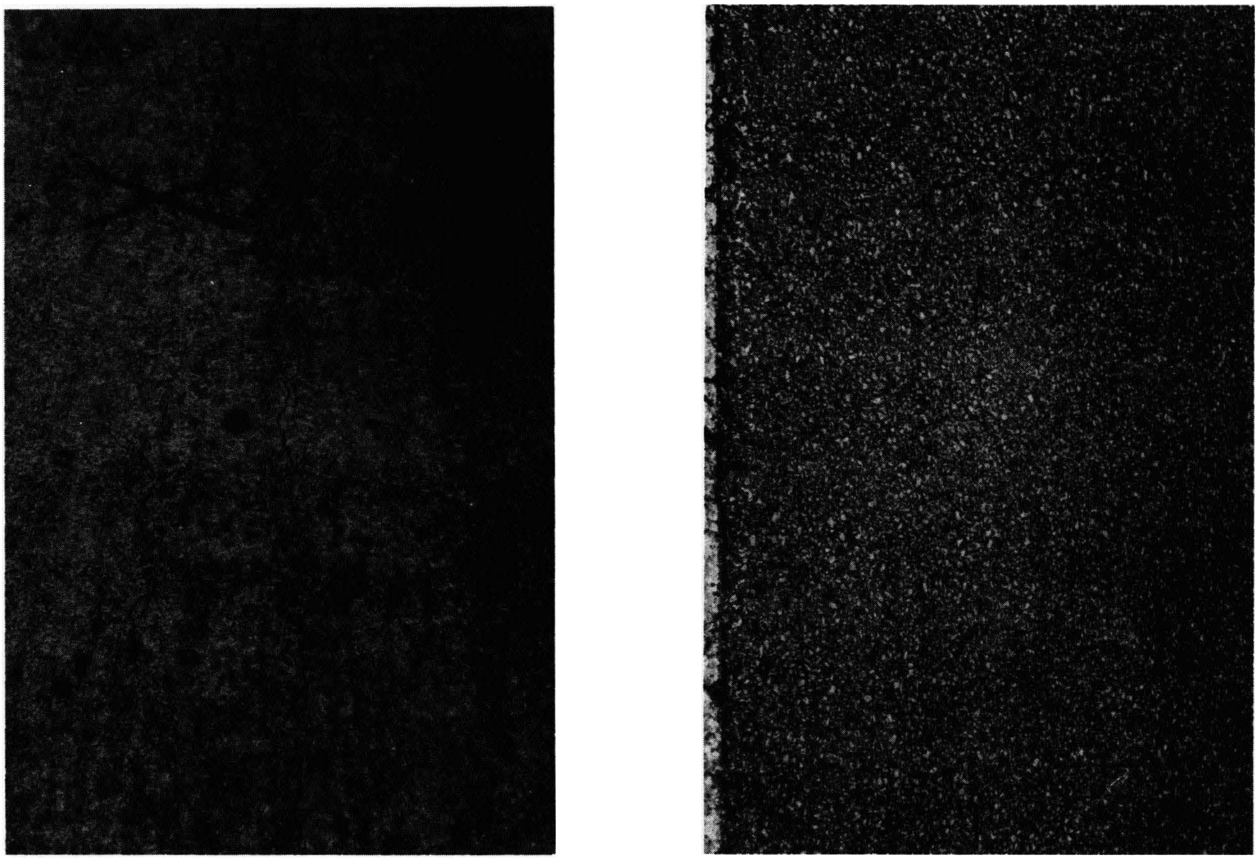
Deflection Cracks on Bottom of cores

Figure 8

at the slab corners were tight and shallow with little relation to other forms of deterioration. Another form of diagonal cracking was found in skew structures where the transverse reinforcing steel was placed parallel to the bents. This cracking is actually a form of transverse cracking and has been considered as such.

4. Checkerboard cracking was found in severely affected structures. This type of cracking was apparently formed by the progression of serious transverse and longitudinal cracking until the perimeter of an area was completely broken through and the integrity of that portion of the deck was destroyed. Figure 9 shows examples of this type of damage.
5. Scaling, Figures 10 and 11, of all forms and degrees was found on all types of structures. Freeze-thaw action and action by solutions were found to have occurred over a wide area of the State. There were numerous instances of the integrity of the deck being destroyed by the loss of as much as two-thirds of the depth of the concrete over a wide area of the slab. Scaling did not necessarily affect every slab, but in some instances a scaled slab was found between two sound slabs. Scaling was found on structures which do not receive de-icing treatment and are not subjected to extensive freeze-thaw action.

   Included in this type of deterioration, by definition used in the BDC survey, is a condition more commonly

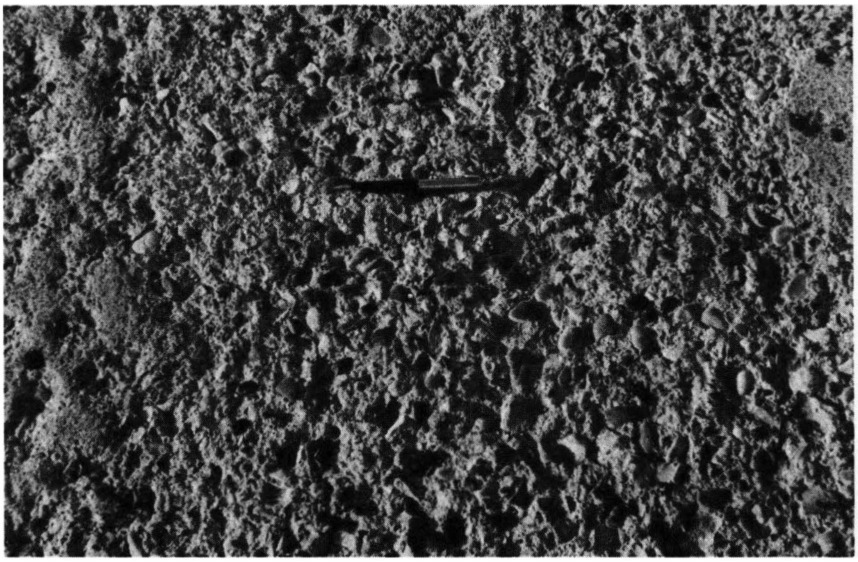


(a) Top Surface of Deck

(b) Top Surface of Slab in (c)

(c) Bottom Surface of Slab in (b)
Checkerboard Cracking
Figure 9

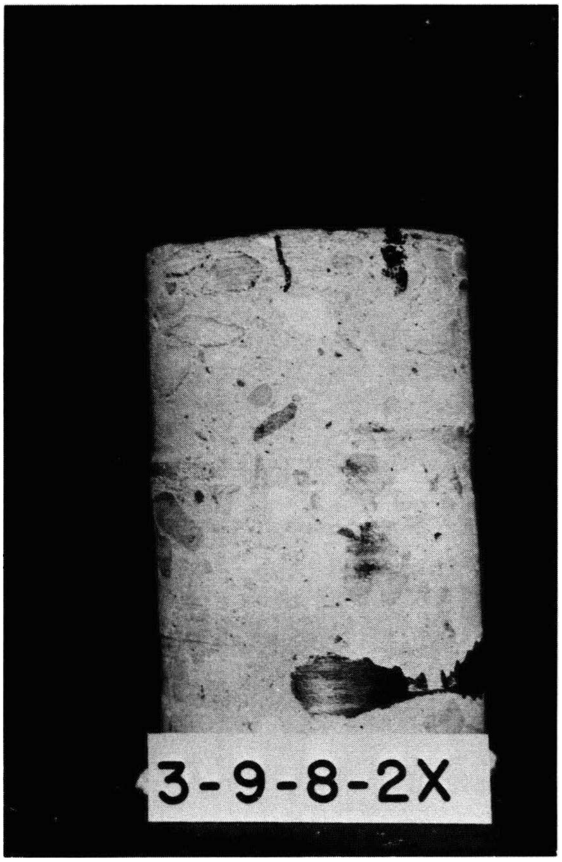
(a)



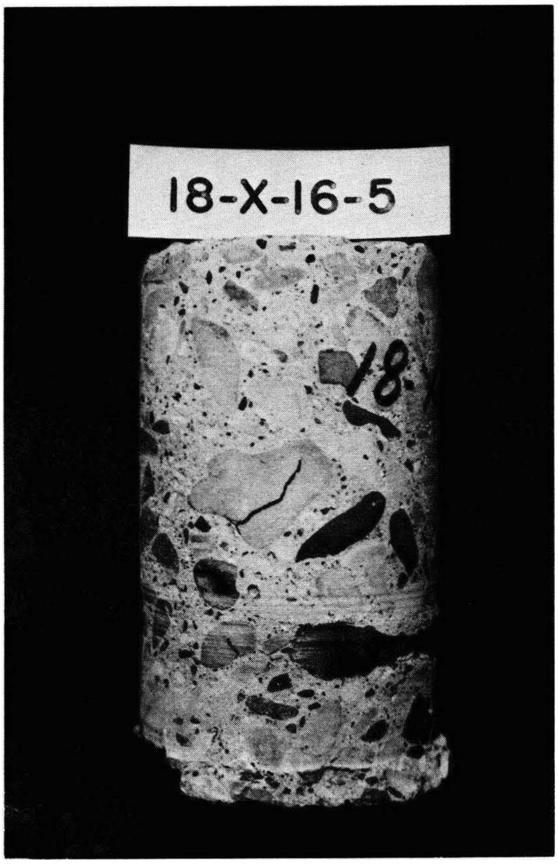
(b)

Scaling on Bridge Deck

Figure 10



(a)

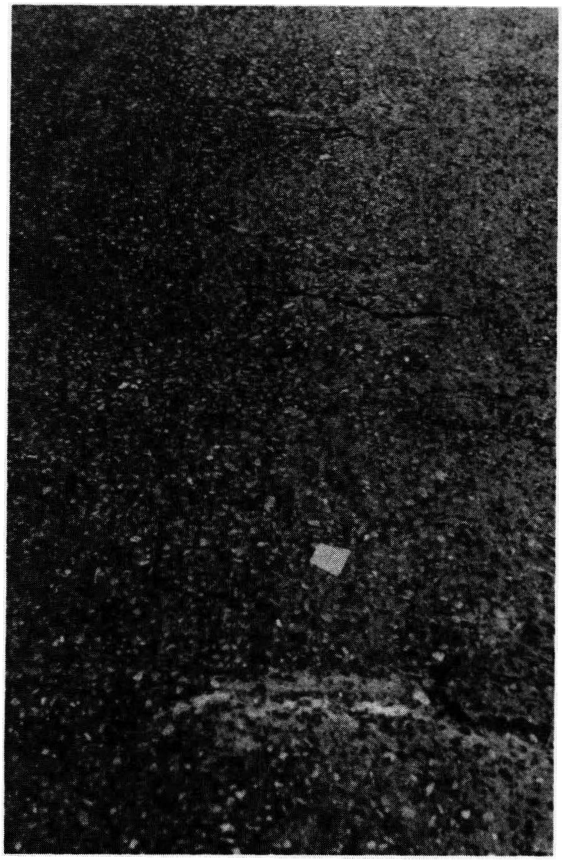


(b)

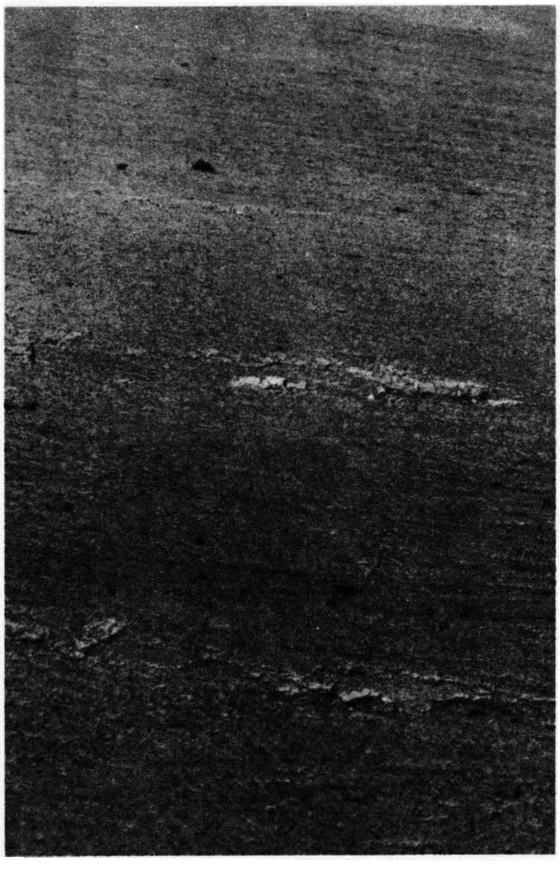
Scaling on Bridge Deck
Figure 11

referred to as spalling, resulting from either delamination or outside physical pressure. The type caused by delamination is the only one of interest in this report. Spalling in Texas structures, Figure 12, ranged from the relatively small popouts caused by loss of individual aggregate particles to the large continuous areas of several square feet of rough depressions in the deck wearing surface, many times with reinforcing steel exposed.

6. Planes of delamination of concrete in the bridge decks have been found at all levels down to the bottom reinforcing steel, Figure 13. The action of wetting-drying, freezing-thawing and solutions entering through channels provided by cracks to susceptible aggregates, or to the reinforcing steel, play a large part in this type of deterioration.
7. A form of deterioration was found to exist in thin-slab and pan form type structures that was closely associated with cracking and heavy scaling but was exhibited on the under surface of the structure as large discolored and porous appearing areas. In many of these, evidence of leakage was apparent but no visible means of egress was seen. Most of this type of damage was located in the close proximity of extensive deterioration on the wearing surface and in structures treated with de-icing salts. Figure 14 reflects this condition.

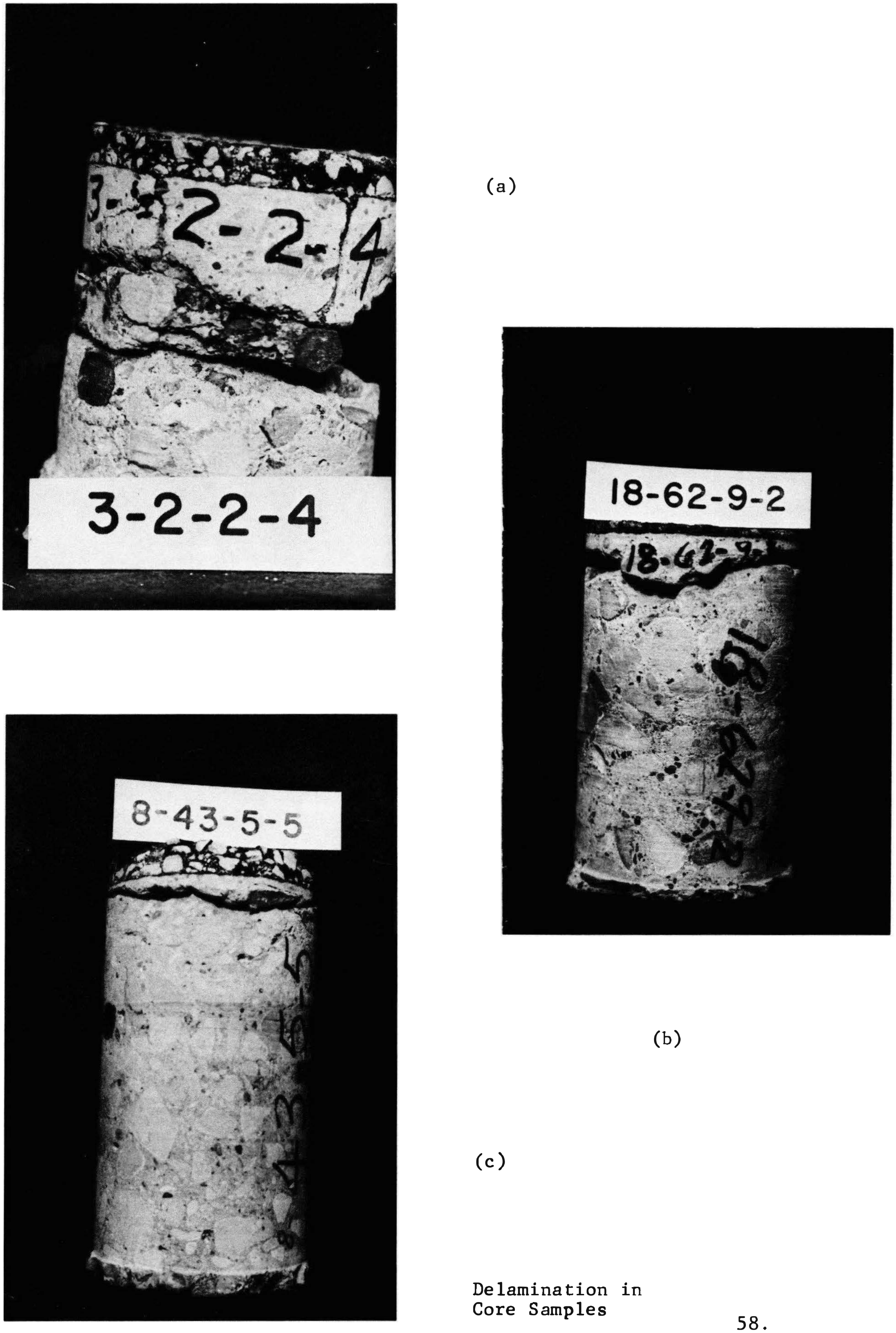


(a) Incipient Spall adjacent to Transverse Reinforcing Steel on Bridge Deck



(b) Spalling adjacent to Longitudinal Reinforcing Steel on Pan Form Bridge

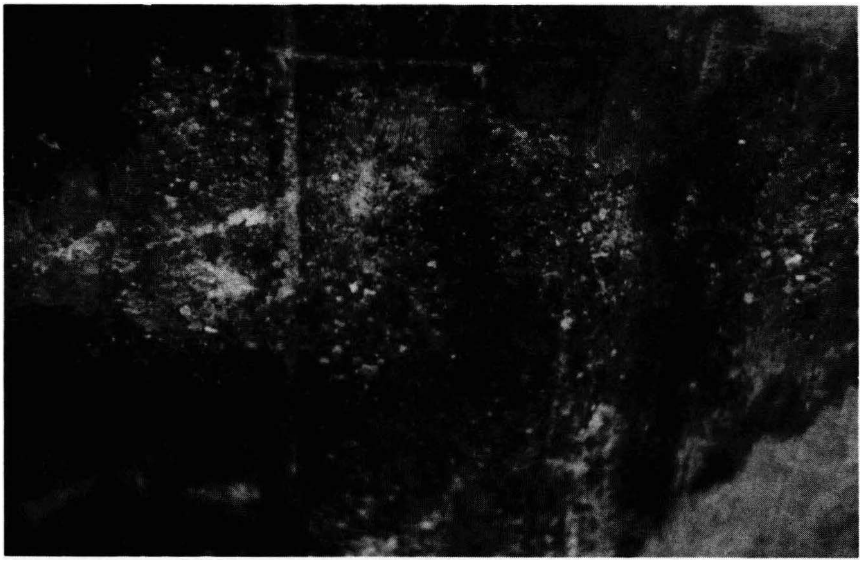
Figure 12



Delamination in
Core Samples

Figure 13

(a)



(b)

Discolored and Scaled Area
On Underside of Bridge Deck

Figure 14

MATERIALS:

Petrographic studies on core samples did not indicate any reactivity of aggregates and cement that would be harmful to the concrete. Six cores representing two simple slab structures constructed in 1959 in the El Paso area had evidence of a mild alkali-silica reaction that could not be associated with any deterioration problems.

Some aggregates examined in the core sections exhibited freeze-thaw susceptibility. These materials, along with low percentages of soft particles of coarse aggregate, would not be expected to be a problem provided they are prevented from becoming saturated.

CONSTRUCTION PRACTICES:

The few job records plus microscopic analysis of core samples revealed a number of variances with good concrete design, control, and placement in a large percentage of the structures studied. The most prevalent discrepancies were:

1) The use of excess mixing water in batching and placing the concrete was evidenced by excess water voids, soft, dull colored paste, and settlement of fine aggregate beneath coarse aggregate particles and reinforcing bars. Field notes reflected up to 6" slump having been used during construction of 66 of the 100 structures studied.

2) Job records were found where low strengths in flexural beams used for quality control had been below specification

requirements. In some instances, these continued low over an extended period of time before corrections were made in either materials or design, or both.

3) Carelessness in placing reinforcing steel or in placing the concrete resulted in the bars having insufficient top or bottom cover. (Figures 15 and 16). Deck slabs were found with the reinforcing steel flush with or partially above the wearing surface of the deck. Measurements made on core samples disclosed numerous structures with the rebars located from 3/8" to 1-inch from the deck surface. This was particularly true with the pan form type structures. The thin section of 3½" in this structure with a requirement for a ½" longitudinal bar and transverse bar made proper placement very critical. Curb sections of all types of structures were also found with the reinforcing bars close to the surface. Forms of cracking and delamination associated with reinforcing steel were more pronounced where the cover was reduced by improper placement. Figure 17 shows the association of the crack and the steel.

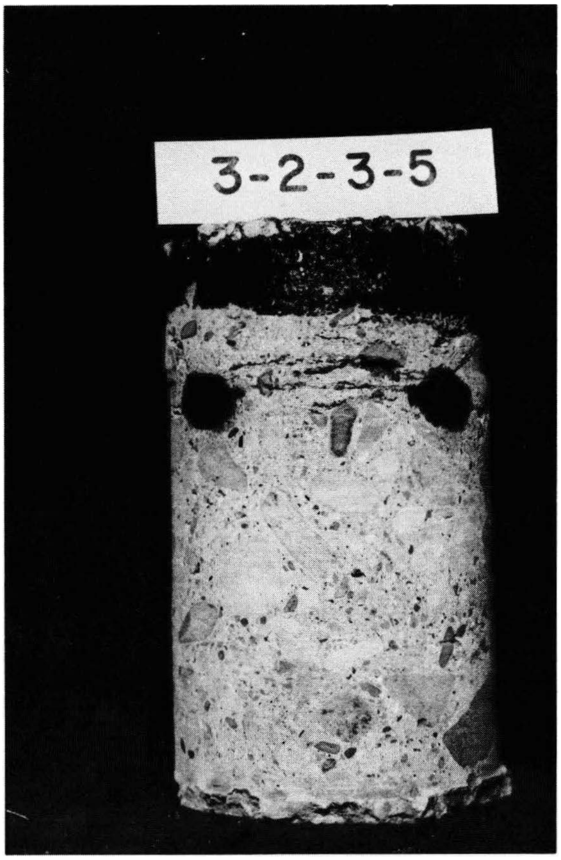
4) Improper mixing or placement was evidenced by the non-uniform distribution of coarse aggregates observed in individual core samples and the varying entrained air content, compressive strengths, densities, in some instances, from the same pour.

a. The measurements taken from prepared core faces of the aggregate, air void and hydrated paste fractions

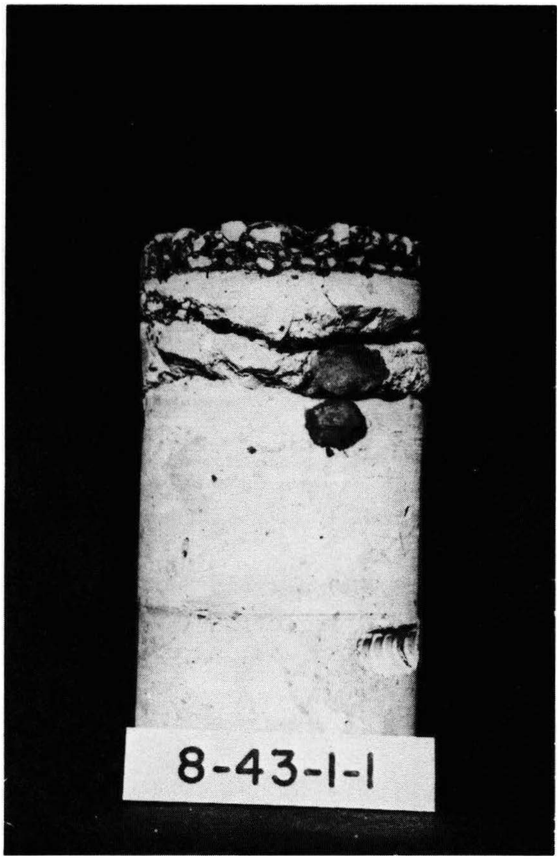
(a) Steel Exposed on Surface
at Construction

(b) Spalled Areas exposing
Reinforcing Steel in Curb

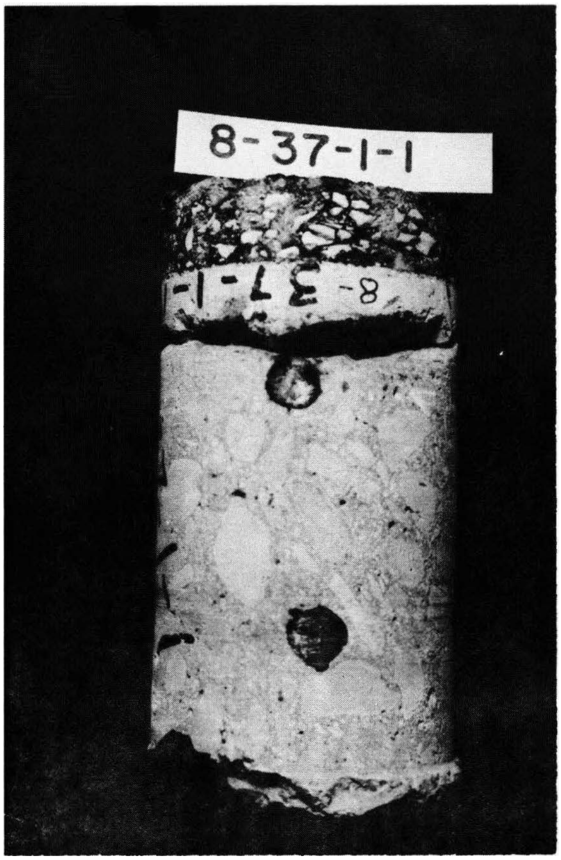
Figure 15



(a)



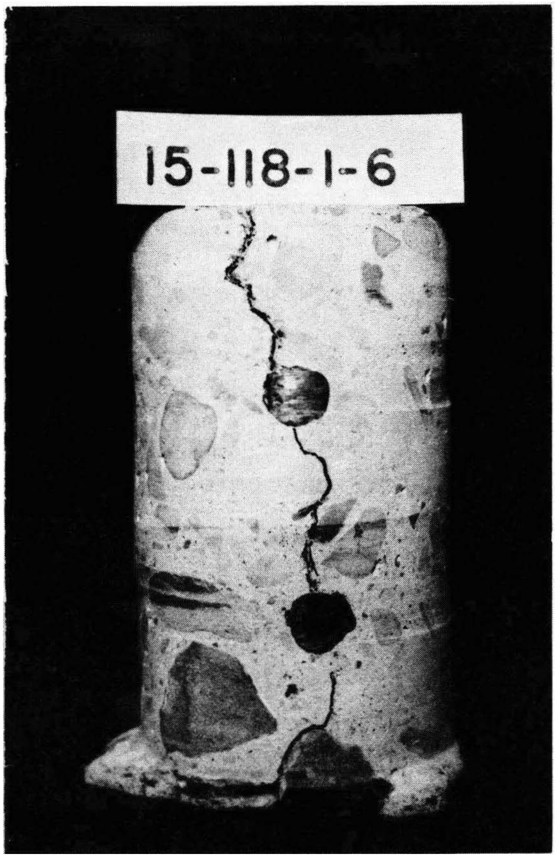
(b)



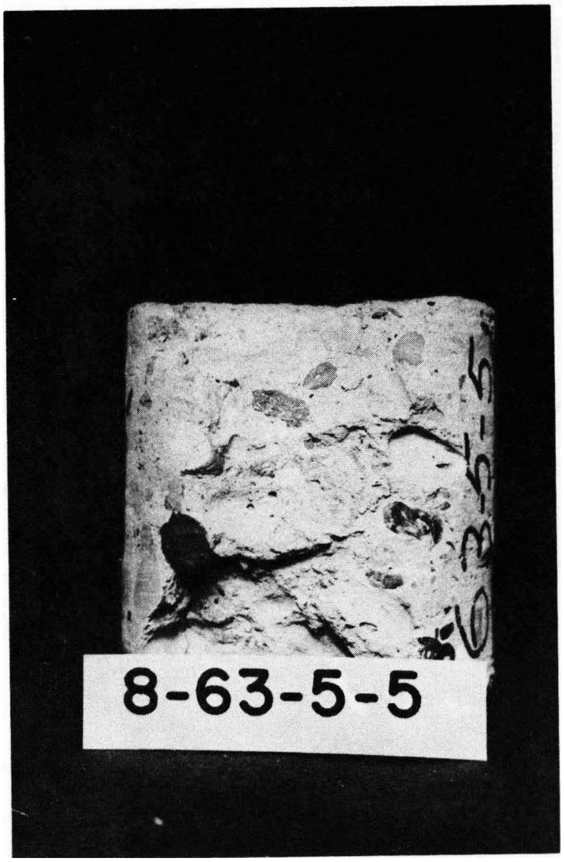
(c)

Delamination with Reinforcing Steel
Placed Close to Surface

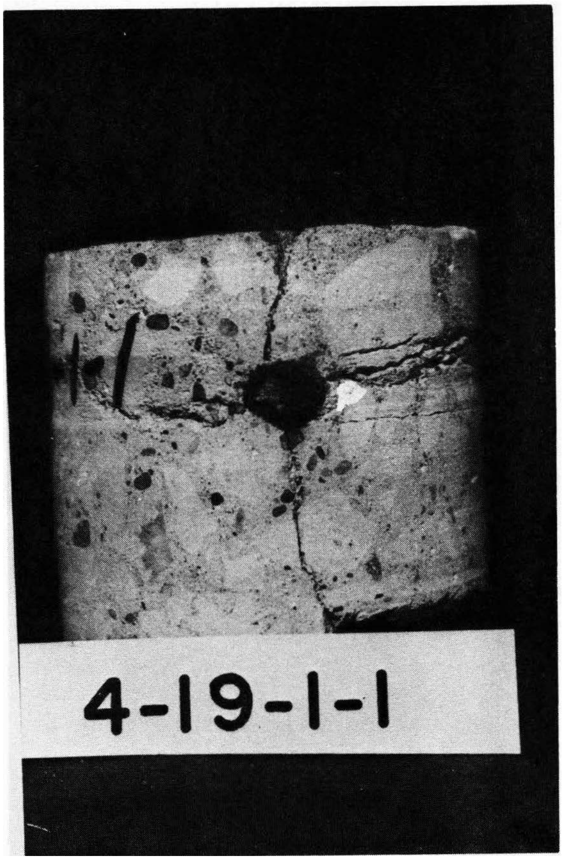
Figure 16



(a)



(b)



(c)

Cracks Adjacent to
Reinforcing Steel

Figure 17

of the concrete disclosed the existence of areas of the sampled deck slab which either contained a small portion or not any of the intermediate sized coarse aggregates. In some instances the coarse aggregates could be seen to be located in the lower portion of the core. Core samples were also taken that were heavily over-sanded with reduced coarse aggregates and paste fractions in evidence.

b. Linear traverse measurements of entrained air performed on different samples taken from the same structure varied by 2.0 to 5.2 per cent. In some cores from concrete designed to have 4.0% entrained, only 2.0 to 3.0% was found. A more serious condition was found where project information reported that air-entraining admixtures were included in the batch design for 32 structures; however, when cross-sections of the concrete were examined, 20 of these 32 structures represented <u>did</u> <u>not</u> contain entrained air or had measured amounts of less than the 2% considered normal for entrapped air, but not adequate in amount or pattern of dispersement to provide any protection to the concrete.

c. Per cent absorption and saturated-surface-dry density values were determined on core samples which were sound enough for testing and which had been retained in the Materials and Tests Laboratory. The cores were oven dried at moderate temperatures to a constant weight and then placed in a pressure pycnometer for complete saturation. The saturated-surface-dry weight and the displaced volume by weighing in water were determined. The density and absorption based on the dry weight of the core were then calculated by the following:

$$D_D = \frac{W_D}{W_{W_1} - W_{W_2}} \quad (62.4)$$

$$A = \frac{W_{W_1} - W_D}{W_D} \quad (100)$$

Where: D_D = Density in lbs. per cu. ft.

W_D = Oven dry weight in grams.

W_{W_1} = Saturated surface-dry weight in grams.

W_{W_2} = Weight of saturated sample immersed in water in grams.

62.4 = Unit weight of water in lbs. per cu. ft.

A = Absorption in per cent.

Where original design data were available, the density was calculated from these data. The design density and the core density are compared in Table 6, Appendix A. The original design data generally were stated as the average used on a complete project and did not therefore necessarily reflect the composition of the concrete as placed. This does, however, provide some basis of comparison between what should have been obtained and that actually found. A wide variation of as much as 12 lbs./cu.ft. was found in the comparison. The cores taken from the same structure varied as much as 13 lbs./cu.ft., even though all information indicated that the same materials, design, and method of placement were used with both, again accentuating the existing lack of uniformity.

d. Compressive strengths were determined on the core samples and the results are listed in Table 6, Appendix A. Little emphasis is given to values obtained with this test since most of the deteriorated material must be removed from the sample prior to testing. It is of interest to note that out of 118 cores tested, 13 cores yielded strengths below the 3000 psi. required of structural concrete and that 27 others tested lower than 3500 psi. A variation of more than 1500 psi. between samples from the same structure was found.

5) Weather data obtained from job diaries supplemented by a compilation of data obtained from the weather station nearest the project site provided a picture of the environment existing at and following the period of construction. Extreme temperature and weather conditions occurred during and following construction often enough to appear almost routine. Temperatures of 109°F. and -4°F. are two extreme examples found to have occurred on pouring dates. The humidity and wind data were not available but the common occurrence of +100°F. and -32°F. days during pouring and curing, coupled with field note references

to rain, sandstorms and extremely high winds reaching 60 mph., clearly illustrate the disadvantages to which the concrete in many structures was subjected.

Two illustrations of the abuse of concrete to correct for adverse weather conditions during the pouring operation are taken from the job diaries on two separate projects in different Districts.

a. Extremely hot temperatures made it difficult to finish the concrete properly so an air-entraining agent was used to compensate. The yield was off for two days until corrections for the air content could be made.

   The examination of cores from this structure revealed no entrained air present and there was evidence of excessive water, soft paste and a low density.

b. Rain commenced during pouring operation so the slump of the concrete was reduced to 1" and the pour completed.

6) Improper curing added to excess amounts of mixing water aided the formation of shrinkage cracks ranging in magnitude from ½ to 2 inches in depth in most cases.

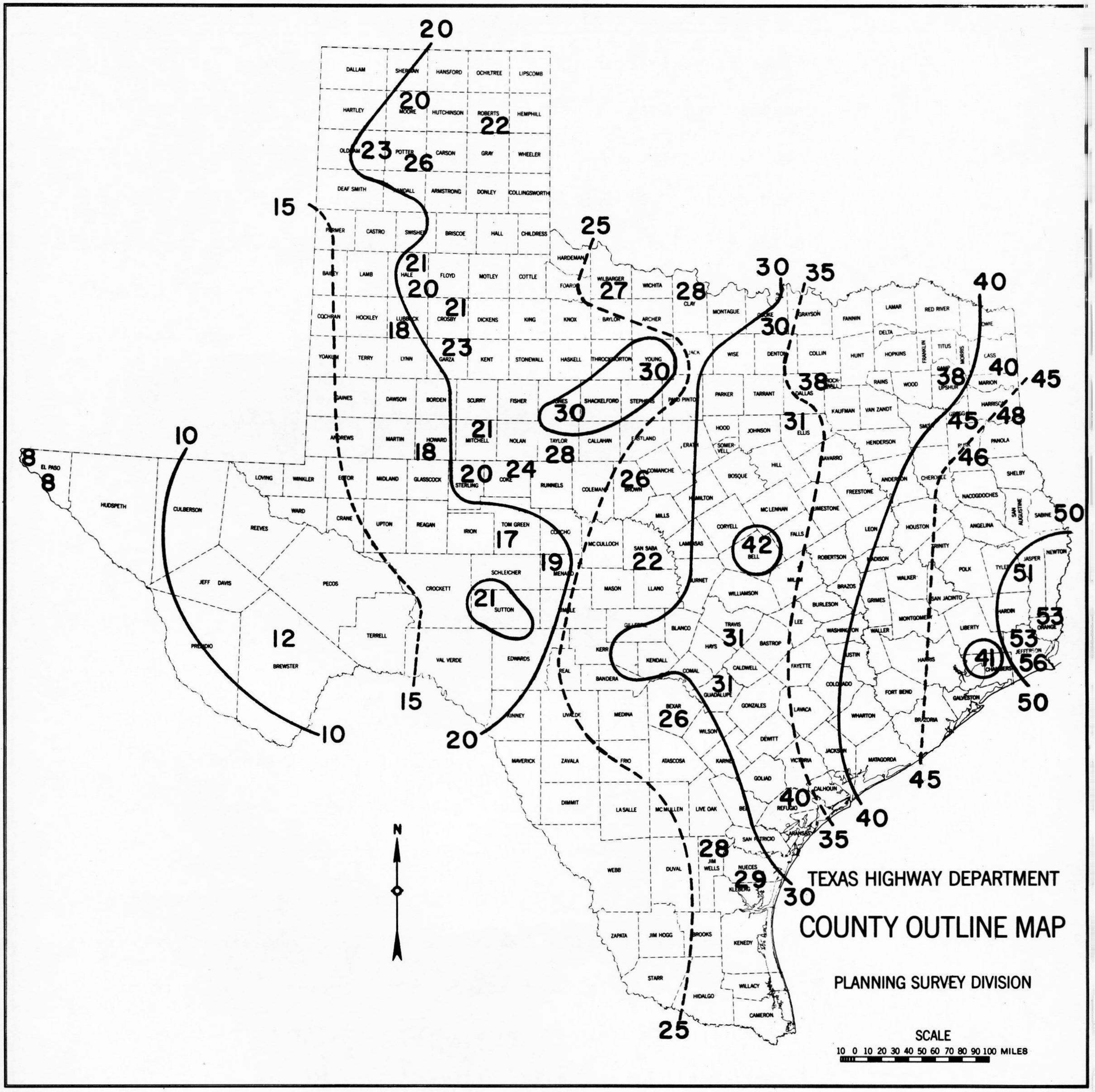
7) Several structures were observed to have areas or pockets of poor drainage where water or solutions containing de-icing salts could stand until evaporation. Extreme examples in which the entire span dropped below the elevation of the deck over the piers were found on two structures which are severely damaged.

WEATHER ENVIRONMENT:

The compilation of weather data for U.S. Weather Stations in close approximation to structure sites was extended to list the monthly temperature extremes and precipitation amounts, and the yearly summary of wet-dry cycles, total precipitation, freeze thaw cycles, wet freeze-thaw cycles, and days with temperatures below 32° plus precipitation. The values obtained for the number of cycles were based on the number of days in which the designated parameters occurred. The cycles, particularly wet-dry, actually might have repeated within a 24-hour period and would not have been counted, but the limited number of such occurrences are considered insignificant.

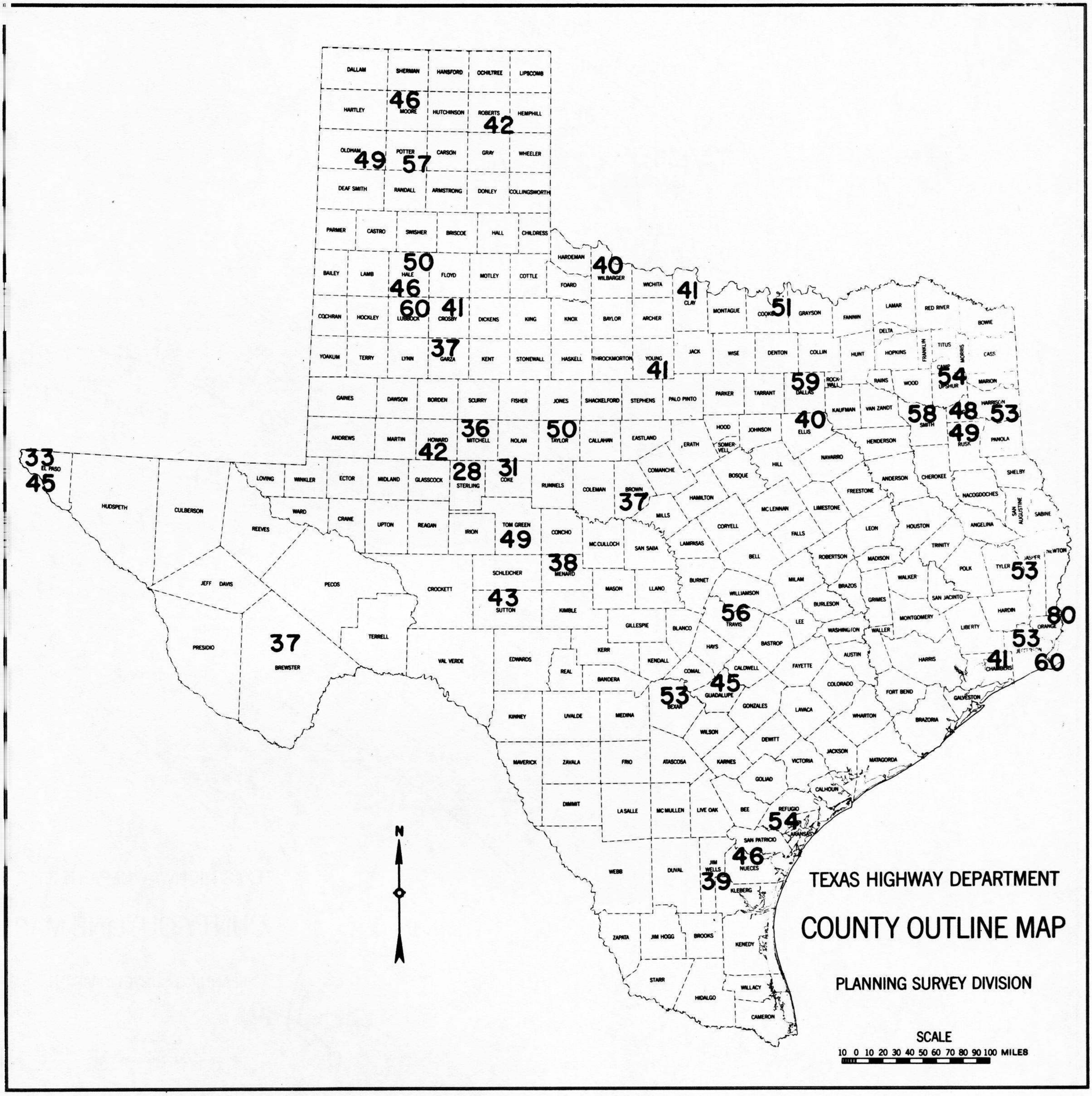
The range of 26° to 34° was selected as a freeze-thaw cycle based on the investigations performed and reported by Larson and Malloy. (3)

Figures 18 through 22 show the patterns of the various weather conditions primarily affecting the service life of exposed concrete. It is of interest to note the pattern of freeze-thaw cycles shown by Figure 20. Large sections of the State annually experience the number of cycles popularly associated with States in the Northern portions of the country. Also of interest is the lack of any definite pattern of wet-dry cycles in the State. Regardless of the average total precipitation approximately the same number of wet-dry cycles are experienced throughout the State.



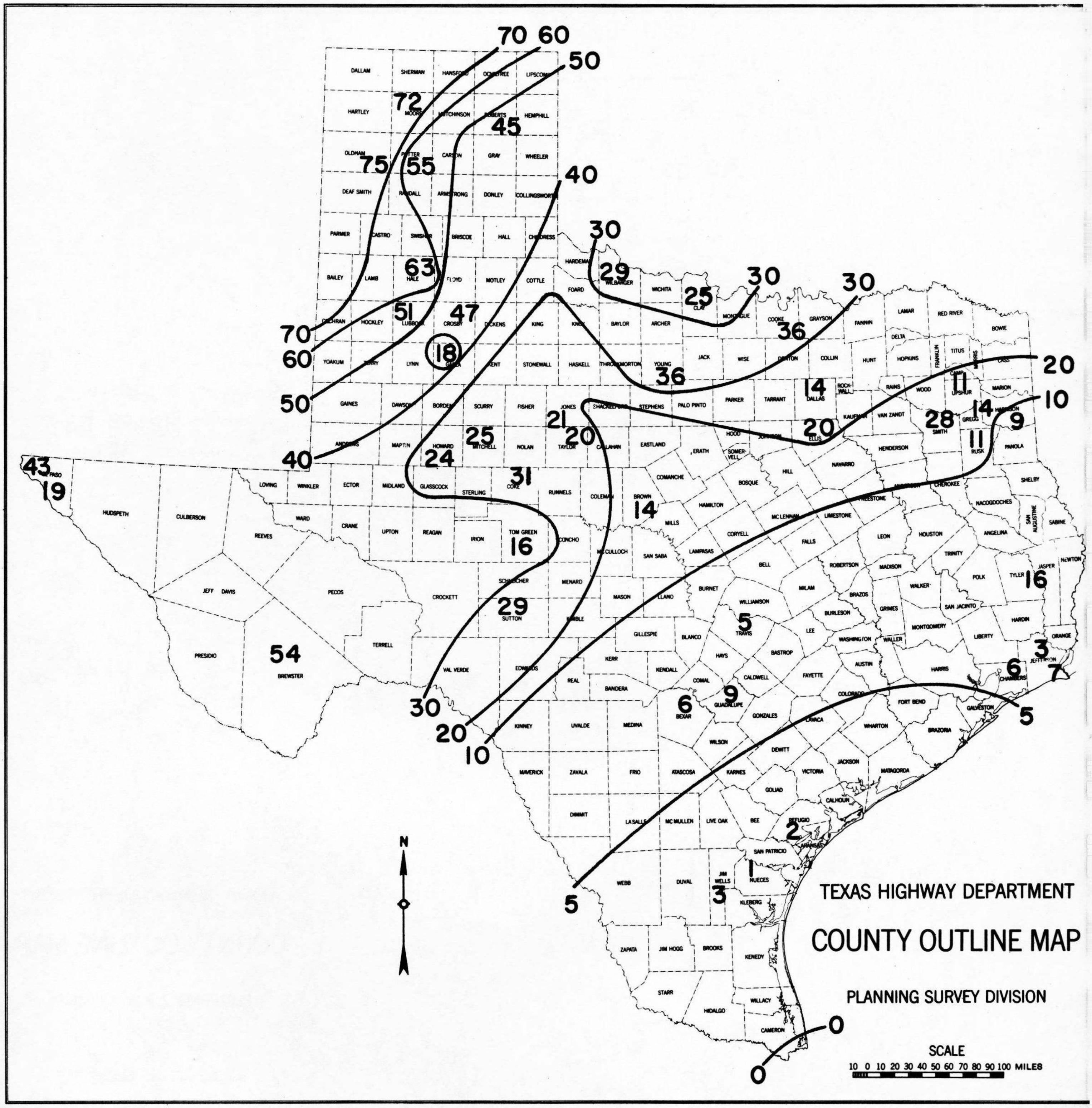
Average Annual Precipitation
in inches.

Figure 18



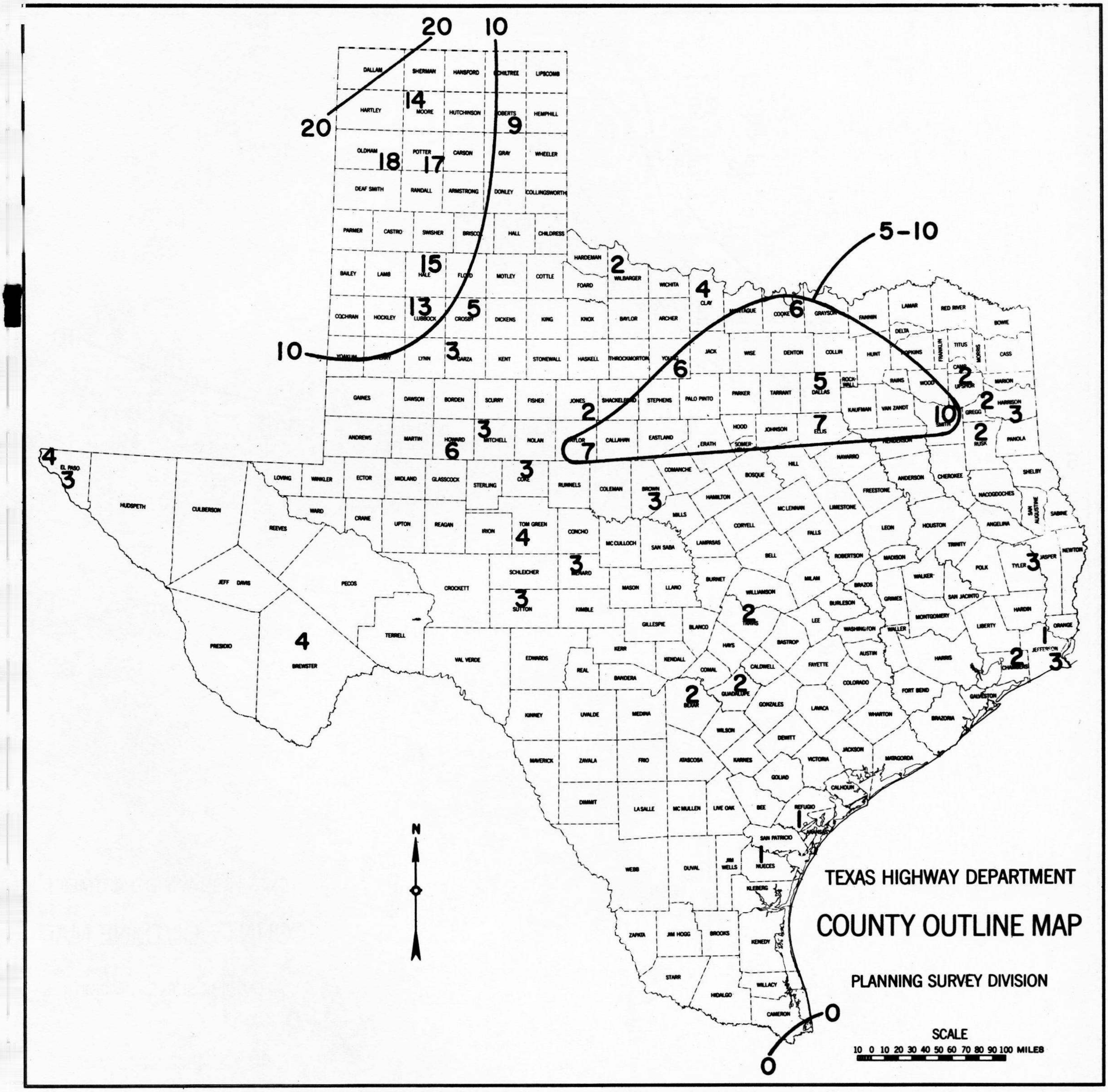
Average Annual Number of
Wet-Dry Cycles.

Figure 19



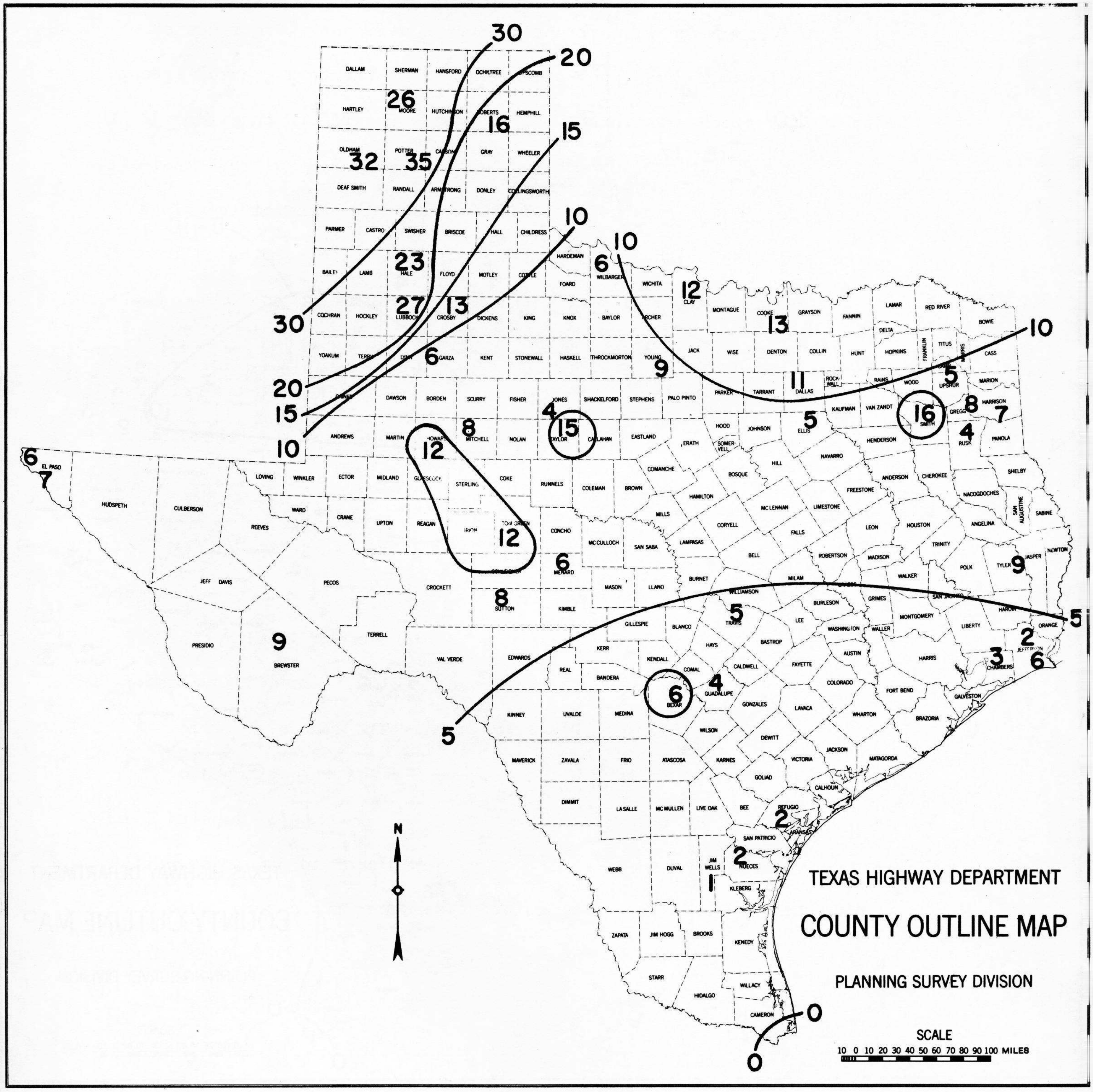
Average Annual Number of
Total Freeze-Thaw Cycles (26°-34°F.)

Figure 20



Average Annual Number of
Freeze-Thaw Cycles with Precipitation
(26°-34°F.)

Figure 21



Average Annual Number of
Days with Temperatures 32°F. and
Below with Precipitation.

Figure 22

MAINTENANCE PRACTICES:

1. Structures which had been treated with de-icing salts, when compared with structures which were not, were found to suffer the same types of deterioration but to a greater extent. Deck slabs were found with no damage under both conditions. Some of the decks which had been treated with salt had individual slabs which were undamaged next to deteriorated slabs, pointing to the probability of the damage being originally caused by other action and accelerated through the effect of the salt.

2. Linseed oil treatment has been used on Texas bridge decks and is an optional form of protection. The treatment consists of two coats of 50% linseed oil and 50% mineral oil spirits.

Observation of structures sealed with solutions of linseed oil indicated that the primary effectiveness of this type of treatment was in the reduction of scaling caused by cycles of wetting-drying and freeze-thaw, and salt action. Little benefit was found where other types of deterioration had opened up inner surfaces of the slab. The use of linseed oil on surfaces was most effective when placed on new construction. Bridge surfaces which had begun to deteriorate were aided somewhat by the treatment, but not cured. The non-uniformity of density within bridge slabs was visibly apparent on many structures after linseed oil had been used. The dense concrete held the solution on the surface as evidenced by the bright shiny appearance, while the adjacent, more porous concrete absorbed the oil, leaving a dull lusterless effect.

3. Deterioration was found to be more severe where bituminous materials were used to overlay the concrete surface.

D. Laboratory Investigations:

The following investigations were undertaken in the Materials and Tests Laboratory to complement the results of the field investigations:

1. The Effect of Varying Cement Content on the Physical Properties of Concrete.
2. The Effect of Cement Composition on the Physical Properties of Mortars Containing Various Admixtures.
3. Investigation of Various Chemical Characteristics of Deteriorated Portland Cement Concrete.

The reports of these investigations in discussion form are attached and are a part of this report as Appendices B through D.

X-ray diffraction tracings on samples chipped from the top and bottom surfaces of concrete bridge decks were made by consultants in the field. The results of these tests are included as a part of this report in Appendix E. No conclusions of merit were made as a result of this investigation, primarily because of the lack of experience of the consultants in concrete technology. Subsequent discussions held with competent authorities in the field of concrete technology and the use of X-ray diffractometer and infra-red spectrophotometer equipment as investigative tools, reaffirmed the use of this equipment for analytical studies of this type. Insufficient time remained for this approach to be reactivated.

VII. REFERENCES:

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(3) Durability of Bridge Deck Concrete, Report No. 3, Volume 1, by T. D. Larson and J. J. Malloy of the Pennsylvania State University College of Engineering, March 1966.

(4) A Study of Deterioration in Concrete Bridge Decks by Missouri State Highway Department Division of Materials and Research in cooperation with Bureau of Public Roads, October 1965.

(5) Durability of Concrete Bridge Decks, Report 4 Second Draft, A Cooperative Study by Missouri State Highway Commission; U.S. Dept. of Commerce, Bureau of Public Roads, and Portland Cement Association, 1967.

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(7) A Study of the Mechanism of Concrete Fatigue and Fracture by Don A. Linger and H. Aldridge Gillespie, Department of Civil Engineering, University of Arizona, published in Highway Research News, Number 22, February 1966.

(8) Highway Research Bulletin No. 323, "The Effect of De-Icing Salts on Structures - A Symposium".

(9) "Bridge Deck Repair Techniques on the New Jersey Turnpike" by Orrin Riley, published in Highway Research Record No. 11, 1963.

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(11) Texas State Highway Department Standard Specifications for Road and Bridge Construction, adopted January 13, 1938.

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(14) Corrosion of Reinforcing Steel, by Bailey Tremper, Concrete and Concrete-Making Materials, STP 169A, ASTM, 1966.

(15) Recommended Practice for Selecting Proportions for Concrete, by ACI Committee 613, ACI Proceedings, Vol. 50, 1954.

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APPENDIX A

TABLE 1

COMPARISON OF STRUCTURE TYPES BY PERCENTAGE OF OCCURRENCE OF DETERIORATION

Structure Type	Structures with No Damage	Cracking	Scaling	Delamination
Continuous I-Beam	1.05	65.1 (26.3)*	50.6 (25.9)	28.6 (19.4)
Continuous Slab & Girder	4.90	53.7 (17.6)	36.3 (15.9)	30.7 (19.3)
Simple I-Beam	3.53	43.5 (16.2)	34.9 (13.5)	14.1 (11.9)
Pan Form Slab & Girder	4.56	35.0 (6.1)	30.1 (10.2)	13.7 (9.7)
Prestressed Beam	8.33	26.5 (3.2)	22.9 (9.3)	16.0 (10.7)
Continuous Slab	2.95	49.3 (8.3)	24.6 (8.9)	10.2 (5.8)
Simple Slab & Girder	9.75	40.8 (8.8)	20.7 (8.7)	8.14 (4.8)
Simple Slab Span	10.37	33.7 (4.1)	21.53 (5.1)	4.71 (1.4)

* Top figure indicates the percentage of all structures of that type with any deterioration above minor classification. Figure in parenthesis is the percentage of structures of that type with extensive and severe deterioration.

TABLE 2

COMPARISON OF AIR-ENTRAINED VS. NON-AIR-ENTRAINED CONCRETE DECKS BY PERCENTAGE OF OCCURRENCE OF DETERIORATION

Structure Type	Structures with No Damage		Cracking		Scaling		Delamination	
	Non-Air	Air	Non-Air	Air	Non-Air	Air	Non-Air	Air
Continuous I-Beam	0.0	3.15	67.2 (21.3)*	33.3 (2.4)	51.7 (23.3)	11.2 (1.6)	18.8 (4.4)	7.3 (0.8)
Continuous Slab & Girder	(-)	12.77	(-) (-)	12.2 (2.43)	(-) (-)	7.1 (-)	(-) (-)	5.0 (5.0)
Simple I-Beam	9.09	13.16	45.0 (20.0)	9.1 (3.0)	15.0 (-)	6.3 (-)	(-) (-)	6.1 (6.1)
Pan Form Slab & Girder	0.0	8.21	27.5 (4.4)	9.8 (1.6)	22.1 (7.0)	6.5 (3.3)	7.3 (1.0)	4.9 (4.9)
Prestressed Beam	2.88	22.0	26.7 (3.0)	18.6 (0.6)	11.1 (3.7)	5.8 (-)	1.5 (0.8)	1.3 (0.7)
Continuous Slab	4.76	0.0	30.0 (7.5)	30.0 (7.5)	21.2 (13.2)	(-) (-)	11.1 (-)	5.1 (2.6)
Simple Slab & Girder	0.0	14.28	22.2 (-)	8.3 (-)	11.1 (11.1)	(-) (-)	15.4 (7.7)	(-) (-)
Simple Slab Span	2.63	43.75	18.9 (-)	33.3 (11.1)	19.4 (5.5)	16.7 (-)	2.6 (-)	5.6 (-)

* Top figure indicates the percentage of all structures of that type with any deterioration above minor classification. Figure in parenthesis is the percentage of structures of that type with extensive and severe deterioration.

TABLE 3

COMPARISON OF STRUCTURES TREATED AND NON-TREATED WITH DE-ICING SALTS BY PERCENTAGE OF OCCURRENCE OF DETERIORATION

Structure Type	Structures with No Damage		Cracking		Scaling		Delamination	
	Salt	Non-Salted	Salt	Non-Salted	Salt	Non-Salted	Salt	Non-Salted
Continuous I-Beam	9.23	1.47	63.5 (29.8)*	49.2 (14.9)	63.7 (31.4)	39.7 (17.9)	48.1 (34.1)	23.4 (18.2)
Continuous Slab & Girder	1.72	8.51	77.3 (33.3)	16.3 (4.65)	63.2 (33.3)	11.6 (2.33)	59.6 (33.3)	11.6 (11.6)
Simple I-Beam	.90	1.67	38.9 (14.1)	28.8 (16.9)	37.6 (15.7)	22.0 (3.4)	23.8 (22.4)	7.1 (6.5)
Pan Form Slab & Girder	3.33	4.27	42.4 (10.0)	36.6 (6.3)	45.1 (15.0)	21.0 (5.3)	24.7 (16.9)	7.3 (7.3)
Prestressed Beam	8.79	7.27	27.5 (5.0)	15.0 (2.0)	35.8 (17.2)	27.5 (9.2)	28.1 (19.4)	19.6 (13.1)
Continuous Slab	1.79	5.0	60.8 (11.4)	39.5 (7.9)	24.8 (7.8)	30.6 (5.6)	13.3 (7.9)	11.4 (11.4)
Simple Slab & Girder	5.41	11.54	60.9 (18.1)	34.8 (4.3)	31.6 (15.3)	10.0 (10.0)	14.3 (8.9)	5.0 (-)
Simple Slab Span	2.72	16.67	40.6 (5.6)	51.0 (4.0)	22.8 (7.4)	24.0 (5.0)	6.3 (4.2)	7.9 (2.0)

* Top figure indicates the percentage of all structures of that type with any deterioration above minor classification. Figure in parenthesis is the percentage of structures of that type with extensive and severe deterioration.

TABLE 4

COMPARISON OF STRUCTURES BY AGE GROUP BY PERCENTAGE OF OCCURRENCE OF DETERIORATION

Structure Type	Structures with No Damage			Cracking			Scaling			Delamination		
	-1950	1951-60	1961-64	-1950	1951-60	1961-64	-1950	1951-60	1961-64	-1950	1951-60	1961-64
Continuous I-Beam	.92	.66	2.17	65.9 (20.4)*	71.7 (35.3)	44.6 (8.7)	49.0 (17.7)	60.5 (35.3)	23.5 (8.7)	31.8 (23.1)	36.2 (25.5)	7.8 (2.1)
Continuous Slab & Girder	7.14	0.0	10.20	69.2 (53.8)	76.3 (18.0)	18.2 (4.54)	61.5 (46.1)	50.0 (20.5)	8.9 (2.2)	45.2 (37.5)	40.0 (22.5)	4.7 (4.7)
Simple I-Beam	2.79	3.68	11.67	48.4 (16.8)	43.9 (18.5)	22.6 (9.4)	37.3 (16.2)	31.1 (11.8)	9.6 (-)	14.6 (11.5)	16.1 (14.3)	3.8 (3.8)
Pan Form Slab & Girder	0.0	3.71	4.91	33.3 (-)	48.2 (9.9)	17.4 (2.8)	12.5 (-)	39.0 (13.1)	13.4 (5.3)	16.7 (16.7)	17.8 (12.6)	6.0 (3.2)
Prestressed Beam	(-)	2.30	14.16	(-) (-)	30.3 (4.7)	22.3 (1.7)	(-) (-)	39.5 (17.6)	8.3 (1.7)	(-) (-)	27.6 (18.9)	1.4 (6.7)
Continuous Slab	9.20	1.19	2.50	54.4 (11.4)	60.0 (7.88)	30.8 (7.7)	63.2 (38.2)	25.2 (7.8)	10.5 (6.58)	18.3 (13.4)	8.0 (4.8)	8.3 (1.2)
Simple Slab & Girder	9.52	8.64	8.70	50.0 (11.8)	31.1 (5.4)	14.3 (-)	19.4 (8.3)	26.4 (9.7)	4.8 (4.8)	8.1 (5.6)	8.6 (3.7)	8.0 (4.0)
Simple Slab Span	11.62	8.14	21.74	30.8 (4.6)	41.3 (2.9)	24.1 (3.7)	15.5 (8.6)	17.5 (3.6)	18.5 (3.7)	7.1 (2.0)	3.6 (1.45)	3.6 (-)

* Top figure indicates the percentage of all structures of that type with any deterioration above minor classification. Figure in parenthesis is the percentage of structures of that type with extensive and severe deterioration.

TABLE 5

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
District 3						
T-1	3-13-21(x)	Montague	C-13-3-4	U. S. 81	21(x)	U. S. 82 Op.
T-2	3-1356-9(x)	Cooke	C-1356-2-?	FM 1202	9(x)	FM 1202 Op. (Over IH 35)
T-3	3-195-96	Cooke	C-195-1-30	I.H. 35	96	FM 1306 Op.
T-4	3-845-12	Cooke	C-845-3-9	FM 922	12	Clear Creek Bridge (West Bound)
T-5	3-45-107	Cooke	C-45-1-15	U. S. 82	107	G.C.&S.F.R.R. Op.
T-6	3-2217-2	Young	C-2217-1-1	FM 1974	2	Clear Fork of the Brazos River. #3
T-7	3-570-9	Young	C-570-3-7	FM 701	9	Clear Fork of the Brazos River. #1
T-8	3-43-72	Wilbarger	C-43-6-21	U. S. 70	72	U. S. 287, 70 & 183 Op. (East Bound)
T-9	3-224-23	Clay	C-224-1-7	U. S. 287	23	East Fork of the Little Wichita River.
District 4						
T-10	4-41-24	Moore	C-41-4-11	FM 1913	24	4-way (Grade Separation)
T-11	4-66-19	Moore	C-66-5-15	U. S. 87	19	Little Blue Creek Bridge

TABLE 5, CONT'D.

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
District 4, Cont'd.						
T-12	4-168-34	Randall	C-168-9-32	U. S. 60	34	McCormick Road Up.
T-13	4-168-32	Randall	C-168-9-32	U. S. 60	32	Bell Street Up.
T-14	4-90-27	Oldham	C-90-2-18	I. H. 40	27	Mujares Creek
T-15	4-490-7	Roberts	C-490-4-7	S. H. 70	7	Canadian River Br.
T-16	4-379-15	Potter	C-379-2-6	S. H. 136	15	Turkey Creek Br.
District 5						
T-17	5-783-1(x)	Lubbock	C-783-1-3	Lp. 289	1(x)	Double Mountain Fork of the Brazos River Br. (South Bound)
T-18	5-2498-1	Garza	C-2498-1-2	FM 211	1	P. & S.F.R.R. Op.
T-19	5-67-45	Hale	C-67-7-13	U. S. 87	45	Op. at Abernathy (South Bound & North Bound)
T-20	5-67-47	Hale	C-67-6-14	U. S. 87	47	Cleveland Street Op.
T-21	5-131-2	Crosby	C-131-5-9	U. S. 82	2	White River Br.
T-22	5-67-23	Lubbock	C-67-7-17	U. S. 87	23	P. & S.F.R.R. Op.
District 7						
T-23	7-396-24	Menard	C-396-5-5	S. H. 29	24	Rocky Creek Br.

TABLE 5, CONT'D.

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
District 7, Cont'd.						
T-24	7-396-25	Menard	C-396-5-5	S. H. 29	25	Dry Creek Br.
T-25	7-160-53	Sutton	C-160-1-13	U. S. 277	53	Sawyer Draw Br.
T-26	7-77-46	Tom Green	C-77-6-21	U. S. 67	46	Middle Concho River Br.
T-27	7-405-17	Sterling	C-405-2-6	U. S. 87	17	State Highway 158 Op. (West Bound)
T-28	7-454-40	Coke	C-454-1-15	S. H. 208	40	Colorado River Br.
District 8						
T-29	8-5-37	Howard	C-5-5-19	I. H. 20	37	Texas & Pacific R. R. Op.
T-30	8-5-43	Howard	C-5-5-25	I. H. 20	43	Texas & Pacific R. R. Op.
T-31	8-6-79	Mitchell	C-6-1-20	I. H. 20	79	Texas & Pacific R. R. Op.
T-32	8-6-63	Nolan	C-6-3-25	U. S. 80	63	Sweetwater Creek (East Bound)
T-33	8-6-66	Nolan	C-6-3-26	U. S. 80	66	Plum Creek
T-34	8-33-31	Jones	C-33-5-17	U. S. 83	31	Clear Fork of the Brazos River Br.
T-35	8-6-283	Callahan	C-6-7-25	I. H. 20	283	FM 604 Op.

TABLE 5, CONT'D.

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
District 8, Cont'd.						
T-36	8-454-56	Mitchell	C-454-3-9	S. H. 208	56	North Champion Creek Br.
T-37	8-6-176	Nolan	C-6-3-31	I. H. 20	176	White Flat Road Up.
T-38	8-33-54	Taylor	C-33-6-20	U. S. 83	54	U. S. 277 Op. (North Bound)
T-39	8-34-36	Taylor	C-34-1-21	U. S. 83	36	FM 613 Op. (North Bound)
District 10						
T-40	10-1763-2	Gregg	C-1763-3-1	FM 1845	2	Graces Creek Br.
T-41	10-1388-1(x)	Rusk	C-1388-1-2	FM 1251	1(x)	Martin's Creek Br.
T-42	10-495-143	Smith	C-495-5-1	I. H. 20	143	Saline Creek Road Op. (East Bound)
T-43	10-2623-1	Smith	C-2623-1-1	FM 2607	1	Caney Creek Bridge
T-44	10-495-57	Smith	C-495-4-2	I. H. 20	57	County Road Op.
T-45	10-495-56	Smith	C-495-4-2	I. H. 20	56	FM 849 Op.
District 14						
T-46	14-265-59	Travis	C-265-1-37	U. S. 183	59	Colorado River Br. (North Bound)

TABLE 5, CONT'D.

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
T-47	14-414-2	Travis	C-414-2-9	Lp. 343	2	First Street Op.
T-48	14-15-92	Travis	C-15-13-8	I. H. 35	96	Dessau Road Op. (North Bound)
T-49	14-114-81	Travis	C-114-2-13	U. S. 290	81	Wilbarger Creek Br.
T-50	14-15-166	Travis	C-15-10-12	I. H. 35	166	Three Point Op. (North Bound)
T-51	14-15-219	Williamson	C-15-8-42	I. H. 35	219	Yankee Road Up.
District 15						
T-52	15-25-96	Bexar	C-25-2-33	I. H. 10	96	Rosillo Creek Br. (East Bound)
T-53	15-25-94	Bexar	C-25-2-33	I. H. 10	94	Rosillo Creek Br. (West Bound)
T-54	15-25-118	Guadalupe	C-25-3-24	I. H. 10	118	Santa Clara Road Up. (East Bound)
T-55	15-25-119	Guadalupe	C-25-3-24	I. H. 10	119	Santa Clara Creek (West Bound)
T-56	15-100-83	Bexar	C-100-2-30	U. S. 181	83	Calaveras Creek Br.
T-57	15-72-89	Bexar	C-72-12-20	I. H. 10	89	Huebner Road

TABLE 5, CONT'D.

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
T-58	15-16-142	Guadalupe	C-16-6-19	I. H. 35	142	Live Oak Road Op.
District 16						
T-59	16-371-34	Refugio	C-371-3-22	U. S. 77	34	Aransas River (County Line)
T-60	16-1052-31	Nueces	C-1052-2-12	FM 665	31	Drainage Ditch (East of Driscoll)
T-61	16-254-44	Live Oak	C-254-1-30	U. S. 281	44	Nueces River Br. (South Bound)
T-62	16-2373-7	Jim Wells	C-2373-5-1	FM 624	7	Lagarto Creek Br.
T-63	16-1808-4	Live Oak	C-1808-2-1	FM 2287	4	Molinero Creek Br.
T-64	16-1808-3	Live Oak	C-1808-2-1	FM 2287	3	No Name Creek
District 18						
T-65	18-9-"x"	Dallas	C-9-11-18	I. H. 20	"x"	St. Francis Road Up. (Lottle Road)
T-66	18-442-26	Ellis	C-442-3-13	I. H. 35 E	26	Red Oak Creek (West Frontage)
T-67	18-48-62	Ellis	C-48-4-26	I. H. 35 E	62	U. S. 77 Up. (South Bound)

TABLE 5, CONT'D.

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
District 18, Cont'd.						
T-68	18-92-96	Dallas	C-92-2-41	I. H. 45	96	Dowdy Ferry Op. (South Bound)
T-69	18-92-142	Dallas	C-92-2-35	I. H. 45	142	Mars Road Up.
T-70	18-442-28	Dallas	C-442-2-25	I. H. 35 E	28	Beckley Ave. Up.
T-71	18-353-49	Dallas	C-353-5-43	Lp 12	49	Greenville Ave. Up.
District 19						
T-72	19-402-30	Upshur	C-402-2-2	S. H. 154	30	Cypress Creek Relief Br.
T-73	19-218-32	Bowie	C-218-1-9	U. S. 59	59	Sulphur River Br.
T-74	19-393-27	Panola	C-393-3-1	S. H. 149	27	Hogan's Creek Br.
T-75	19-1018-1	Marion	C-1018-3-1	FM 729	1	French's Creek Br.
T-76	19-207-15	Harrison	C-207-5-1	S. H. 43	15	Potter's Creek Br.
T-77	19-1221-5	Panola	C-1221-2-1	FM 123	5	Socagee Creek Relief Br.
T-78	19-1575-2	Harrison	C-1575-2-1	FM 968	2	Clark's Creek Br.
District 20						
T-79	20-65-59	Hardin	C-65-5-23	U. S. 96	59	Village Creek Br.

TABLE 5, CONT'D.

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
District 20, Cont'd.						
T-80	20-306-17	Orange	C-306-1-3	S. H. 87	17	Cow Bayou Br.
T-81	20-28-70	Orange	C-28-14-3	U. S. 90	70	Sabine River Relief Br.
T-82	20-739-5	Jefferson	C-739-2-3	I. H. 10	5	Boyt's Ranch Road Up.
T-83	20-508-147	Chambers	C-508-3-6	I. H. 10	147	S. H. 73 Op.
T-84	20-1237-10	Tyler	C-1237-1-5	FM 1013	10	Neches River Relief Br.
District 23						
T-85	23-272-55	San Saba	C-272-3-8	U. S. 190	55	First Slough to the San Saba River Br.
T-86	23-289-48	San Saba	C-289-4-10	S. H. 16	48	San Saba River Br.
T-87	23-2541-1	Brown	C-2541-2-1	FM 2559	1	Pecan Bayou Br.
T-88	23-1365-8	Brown	C-1365-5-3	FM 1176	8	Clear Creek Br.
T-89	23-183-52	Comanche	C-183-1-10	S. H. 36	52	U. S. 67 Up.
District 24						
T-90	24-2121-20	El Paso	C-2121-1-1	I. H. 10	20	Op. Between U. S. 180 & FM 1905

TABLE 5, CONT'D.

LIST OF STRUCTURES SAMPLED AND INVESTIGATED IN-DEPTH

Code No.	ID Number	County	Project No.	Highway No.	Structure No.	Name or Location
District 24, Cont'd.						
T-91	24-2121-39	El Paso	C-2121-1-1	I. H. 10	39	Op. Between U. S. 180 & FM 1905
T-92	24-2-79	El Paso	C-2-1-19	U. S. 80	79	Separation of Sp. 16 & U. S. 80
T-93	24-2121-113	El Paso	C-2121-4-2	I. H. 10	113	Op. Between Sp. 375 & FM 793
T-94	24-2121-121	El Paso	C-2121-4-2	I. H. 10	121	Op. Between Sp. 375 & FM 793
T-95	24-2121-96	El Paso	C-2121-3-4	I. H. 10	96	Op. Between S. H. 659 & Sp. 16
T-96	24-2121-97	El Paso	C-2121-3-4	I. H. 10	97	Op. Between S. H. 659 & Sp. 16
T-97	24-2121-100	El Paso	C-2121-3-4	I. H. 10	100	Hawkin's Blvd. Op.
T-98	24-2121-137	El Paso	C-2121-3-6	I. H. 10	137	Fort Bliss Spur Op.
T-99	24-485-9	Brewster	C-485-1-3	FM 385	9	Reynold's Creek Br.
T-100	24-485-12	Brewster	C-485-1-7	FM 385	12	Spring Creek

TABLE 6

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density (Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-2	3-9-8-3(x)	6.24	142.90		4341
T-3	3-96-2-1	5.79	154.65		3571
T-4	3-12-24	7.26	135.39	149.23	3166
T-4	3-12-7-2	6.01	144.77	149.23	3744
T-5	3-107-15-2	6.08	150.38	150.12	4345
T-6	3-2-3-1	4.44	149.76	150.34	5260
T-7	3-9-1-4	5.36	145.39	150.34	4197
T-7	3-9-9-1	4.51	154.75	150.34	4700
T-8	3-72-1-1	4.02	151.63	151.47	4391
T-9	3-23-4-1	4.73	152.26	-	3993
T-10	4-24-2-1	5.97	154.13	150.71	3199
T-10	4-24-6-3	5.79	151.63	150.71	4704
T-11	4-19-3-3	(Fell Apart)		150.71	
T-12	4-34-5-4	4.89	152.88	150.9	3944
T-13	4-32-1-1	4.94	144.14	150.9	3680
T-13	4-32-2-6	(Fell Apart)		150.9	

TABLE 6, CONT'D.

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density (Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-14	4-27-6-2	5.0		148.77	4719
T-15	4-7-19-4	4.17	157.87	150.00	3533
T-16	4-15-2-2	5.53	138.75	149.23	3349
T-18	5-1-3-4	6.11	144.77	142.9	2540
T-19	5-45-1-3	5.47	142.27	150.95	3019
T-19	5-45-3-6	4.80	144.14	150.95	3395
T-20	5-47-4-4	4.55	144.14	150.95	3551
T-21	5-2-2-2	5.88	138.33	138.90	4284
T-22	5-23-3-5	5.19	143.52	150.92	Too small for test.
T-22	5-23-10-1	4.87	148.51	150.92	3319
T-23	7-24-4-4	4.14	150.98	150.49	3226
T-24	7-25-4-1	5.37	142.91	150.49	4070
T-24	7-25-1-5	4.02	155.38	150.49	3467
T-25	7-53-4-2	3.73	146.64		5372
T-25	7-53-1-4	3.73	152.26		3821

TABLE 6, CONT'D.

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density (Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-26	7-46-4-3	3.09	151.94		3618
T-26	7-46-3-2	3.11	154.81		3886
T-26	7-46-1-7	3.09	154.81		-
T-26	7-46-8-5	3.11	151.94		-
T-26	7-46-2-6	3.68	154.69		-
T-27	7-17-1-5	3.86	153.5	143.89	4734
T-28	7-40-8-1	4.49	145.39	-	3675
T-28	7-40-4-3	3.07	158.50		4364
T-29	8-37-5-5	5.23	151.01	151.68	3465
T-30	8-43-3-2	3.92	152.26	152.26	3903
T-31	8-79-3-6	3.66	148.51	152.27	3462
T-32	8-63-1-2	3.54	152.26	151.57	4629
T-32	8-63-5-5	5.06	151.63	151.57	Too small for test.
T-33	8-66-3-1	4.46	158.13	151.57	4389
T-35	8-283-4-4	4.37	156.66	151.74	4037

TABLE 6, CONT'D.

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density (Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-36	8-56-2-4	4.42	150.38	152.3	3531
T-37	8-176-3-4	4.54	153.50	150.57	3926
T-38	8-54-2-2	4.53	147.89	152.25	2667
T-38	8-54-1-4	3.83	148.51	152.25	3724
T-39	8-36-5-2	4.58	147.34	152.25	2794
T-40	10-2-8-3	3.18	146.64	149.86	4621
T-41	10-1-8-1(x)	3.83	146.02	142.61	4470
T-41	10-1-6-4(x)	4.80	143.52	142.61	Too Small for test.
T-42	10-143-6-1	4.58	148.51	146.37	3654
T-43	10-1-4-1	5.04	143.52	150.68	3828
T-44	10-57-5-4	6.23	139.15	150.91	3074
T-45	10-56-1-1	4.74	119.18	150.85	4120
T-45	10-56-7-4	5.07	146.64	150.85	3913
T-46	14-59-12-3	4.79	148.51	144.45	4048
T-47	14-2-2-5	4.91	146.20	144.45	3785

TABLE 6, CONT'D.

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density (Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-47	14-2-2-4	4.19	145.95	144.45	
T-48	14-92-3-1	4.58	143.71		2778
T-48	14-92-4-4	4.76	143.96		
T-49	14-81-8-5	4.84	149.14		3828
T-49	14-81-14-6	3.73	146.64		4281
T-50	14-166-1-2	4.82	144.77	144.84	3511
T-51	14-219-4-4	5.0	147.26	146.34	3511
T-52	15-96-3-3	6.06	140.40	149.03	2951
T-53	15-94-1-3	4.81	143.52	149.03	3671
T-53	15-94-3-4	5.85	139.15	149.03	2777
T-54	15-118-3-2	6.43	151.01	149.09	3517
T-54	15-118-2-3	4.75	156.0	149.09	3769
T-55	15-119-3-4	5.63	141.02	149.09	4367
T-56	15-83-4-2	5.29	116.69	148.26	2999
T-56	15-83-3-5	5.02	144.14	148.26	2989

TABLE 6, CONT'D.

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-57	15-89-2-1	5.11	149.14		4360
T-57	15-89-4-2	5.60	140.40		4383
T-58	15-142-5-5	4.83	143.52	142.19	3375
T-58	15-142-1-6	4.96	145.45	142.19	4953
T-59	16-34-8-5	4.03	161.62	150.26	Too small for test.
T-61	16-44-23-1	5.43	139.78	150.41	3219
T-62	16-7-6-1	4.30	144.77	150.41	3461
T-63	16-4-1-2	4.76	141.68	151.46	3263
T-64	16-3-1-1	4.43	142.27	151.46	Too small for test.
T-65	18-4-8-6	5.31	153.50	152.46	3992
T-66	18-26-3-4	5.03	144.14	149.91	2797
T-67	18-62-9-2	4.75	146.64	149.91	2936
T-68	18-96-2-2	4.82	149.14	151.49	3269
T-69	18-142-6-4	4.95	154.75	151.13	3752

TABLE 6, CONT'D.

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density (Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-70	18-28-6-4	5.51	156.62	151.45	3589
T-71	18-49-4-2	5.29	157.87	152.07	3699
T-72	19-30-2-3	4.61	150.38	-	4358
T-72	19-30-5-5	4.54	143.52	-	5261
T-73	19-32-25-3	4.48	143.52	151.08	4551
T-73	19-32-24-4	4.18	146.02	151.08	3229
T-74	19-27-5-6	3.88	144.77	151.11	5515
T-75	19-1-1-3	5.41	140.02	151.11	3246
T-76	19-15-2-3	4.89	143.5	149.98	3508
T-77	19-5-3-2	4.60	138.75	149.98	3303
T-79	20-59-37-4	3.50	151.76	-	3008
T-79	20-59-38-2	3.67	150.45	-	3954
T-80	20-17-2-4	3.03	147.26	-	5186
T-81	20-70-3-1	4.12	144.14	147.07	4833
T-82	20-5-7-3	4.42	144.14	150.15	5545

TABLE 6, CONT'D.

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density (Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-83	20-147-5-1	4.54	142.27	-	4553
T-84	20-10-1-1	2.92	160.18	149.56	5866
T-85	23-55-15-3	4.78	149.76	149.26	4300
T-85	23-55-4-1	4.59	151.04	149.26	5089
T-86	23-48-4-2	4.20	147.89	150.19	3645
T-87	23-1-10-1	5.06	146.64	-	3398
T-87	23-1-3-3	4.52	149.76	-	4436
T-88	23-8-1-3	4.92	144.14	-	4403
T-89	23-52-1-1	5.93	151.63	150.05	2327
T-89	23-52-8-6	5.77	141.65	150.05	2870
T-90	24-20-6-6	4.12	148.51	153.96	3256
T-90	24-20-2-4	4.33	147.26	153.96	3467
T-91	24-39-2-1	3.96	148.5	153.96	3639
T-92	24-79-2-2	3.74	159.87	-	3338
T-92	24-79-8-4	3.37	156.62	-	3500

TABLE 6, CONT'D.

PHYSICAL PROPERTIES OF CORE SAMPLES

Code No.	Core ID Number	Absorption %	Density (Pounds per Cubic Foot)	Design Density (Pounds per Cubic Foot)	Compressive Strength P.S.I.
T-93	24-113-4-1	4.97	146.64	152.82	3200
T-94	24-121-5-1	5.47	145.39	152.82	3445
T-94	24-121-4-3	4.89	152.88	152.82	3307
T-95	29-96-3-6	4.33	149.14	153.0	5490
T-96	24-97-2-4	4.42	157.87	153.0	5214
T-97	24-100-1-2	4.72	145.39	153.0	4685
T-97	24-100-3-5	4.34	157.63	153.0	5413
T-98	24-137-5-3	4.31	147.26	146.50	3825
T-99	24-9-3-2	4.78	140.4	148.47	3706
T-100	24-12-6-5	7.67	132.29	-	1733

TABLE 7

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (Pre. 1951)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-1	U. S. 82 Op.	Jan.-Apr. 1936	No	-	2550	Simple I-Beam	Severe Scaling - Down to 4" depth
T-21	White River	Jul.-Aug. 1930 (Old)	No	No	2010	Simple Slab & Girder	Moderate Scaling
T-21	White River	Feb. 8-23, 1949 (New)	No	-	2010	Simple Slab & Girder	Moderate Scaling
T-22	P. & S.F.R.R. Op.	1947	3-1/2%	No	5790	Simple I-Beam	Extensive Scaling over & under deck all slabs.
T-49	Wilbarger Ck.	Feb. 1947	No	-	4090	Simple I-Beam	Minor Scaling
T-72	Cypress Ck.	Sept. 1935	No	-	870	Simple I-Beam	Scaling under curb, pop-outs.
T-74	Hogan's Ck.	Sept. 1949	No	-	1660	Continuous Slab	-
T-75	French's Ck.	Sept. 1949	No	-	510	Simple Slab Span	-
T-76	Potter's Ck.	Sept.-Oct. 1930	No	-	1680	Simple Slab & Girder	Steel exposed on underside
T-77	Socagee Ck.	Aug. 8-11, 1950	No	-	1660	Simple Slab Span	Pop-outs
T-79	Village Ck.	Jul.-Dec., 1948	No.	-	5080	Simple I-Beam & Continuous I-Beam	Minor Scaling (worn surface)
T-80	Cow Bayou	Apr.-Aug., 1940	No	No	10350	Simple I-Beam	Moderate Scaling

* VPD: Vehicles per day.

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (Pre. 1951)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-92	U. S. 80 at Lp. 16 Sep.	Dec. 1948	No	3.0-5.2%	22930	Simple I-Beam & Continuous I-Beam	Extensive scaling, pot holes
T-99	Reynold's Ck.	Apr. 1947	No	No	260	Simple Slab Span	Extensive scaling
	Bridge ID (1951-1960)						
T-2	FM 1202 Op.	Sept.1958	No	2%	200	Continuous Pre-stressed Beam	Steel close to surface - causing extensive scaling
T-4	Clear Ck.	Oct. & Nov., 1959	No	1%	210	Pan Form Slab & Girder	Minor Scaling
T-5	G. C. & S. F. R. R. Op.	Jan.-Mar., 1958	No	1.5%	6700	Continuous I-Beam	Extensive Scaling on some slabs & curbs - light scaling on others
T-6	Clear Fk., Brazos	Jan-June, 1958	No	2.2%	140	Pan Form Slab & Girder, & Continuous I-Beam	Extensive scaling
T-7	Clear Fk., Brazos # 1.	May-Aug., 1958	No	2.4%	240	Continuous I-Beam & Simple I-Beam	Minor scaling on simple I-Beam and Moderate scaling on continuous I-Beam
T-8	U. S. 287, 183 Op.	Oct. 1958	No	1.6%	2035	Continuous I-Beam	Extensive scaling in curbs (overlay)
T-9	E. Fk. of Little Wichita	Jan. 1952	20%	2.5%	4060	Simple I-Beam	Extensive scaling - caps scaled to steel curb scaled

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (1951-1960)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-10	4-way Gr. Sep.	Aug. 1958	No	.9%	235	Continuous Slab & Girder	Extensive scaling - 3" hole left by foreign matter
T-11	Little Blue Ck.	July 1958	No	.9%	1690	Pan Form Slab & Girder	Severe scaling - 1" holes
T-12	McCormick Rd. Up.	June-July, 1959	No	1%	115	Continuous Slab & Girder	Minor scaling
T-13	Bell St. Up.	Aug.-Sept., 1959	No	1.4%	830	Continuous Slab	Heavy scale near cracks to top of large aggregate. Steel exposed at drains.
T-14	Mujares Ck.	Jan.-Feb., 1960	No	1%	2045	Pan Form Slab & Girder	Extensive scaling - 1/4" scaling on 1 slab.
T-15	Canadian R.	Nov., 1954 - Feb., 1955	20%	7.4%	790	Continuous I-Beam	Moderate scaling - some slabs
T-17	Double Mountain Fk. of the Brazos River	Oct., 1960	No	1%	1490	Pan Form Slab & Girder	Extensive scaling on slabs 2 & 4
T-23	Rocky Ck.	May-June, 1958	No	-	430	Prestressed Beam	Scaling at joints - minor
T-24	Dry Ck.	Apr.-June, 1958	No	-	480	Prestressed Beam	Over shredded mortar
T-25	Sawyer Draw Br.	Aug., 1957	No	-	980	Pan Form Slab & Girder	Minor scaling

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (1951-1960)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-26	Middle Concho R.	Oct., 1953	No	-	1760	Continuous I-Beam	Moderate scaling
T-27	S. H. 158 Op.	Aug., 1958	No	-	565	Prestressed Beam	Minor scaling - some on caps.
T-28	Colorado R.	Apr.-May, 1956	No	-	820	Continuous I-Beam	Severe scaling
T-29	T. & P.R.R. Op.	June-Aug., 1956	-	No	2760	Continuous I-Beam	Scaling on curbs. Seepage causing scaling on deck bottom.
T-30	T. & P.R.R. Op.	Mar.-Apr., 1956	-	No	4730	Continuous I-Beam	Caps scaled (overlay)
T-31	T. & P.R.R. Op.	Jun.-Aug., 1956	-	No	4810	Continuous I-Beam	Caps scaled. Scaling on bottom where water & salt seeping through.
T-32	Sweetwater Ck.	Jan.-Feb., 1954	-	No	3520	Pan Form Slab & Girder	Minor scale - underside
T-33	Plum Ck.	Dec., 1953	-	No	3170	Pan Form Slab & Girder	-
T-34	Clear Fk., Brazos	May, 1956	-	No	2635	Simple I-Beam & Continuous I-Beam	Severe scale at curbs
T-36	N. Champion Ck.	Apr.-May, 1956	-	No	700	Pan Form Slab & Girder	Moderate scale at span ends - underside
T-37	White Flat Rd. Up.	Apr.-June, 1958	-	No	6940	Prestressed Beam	Minor scale on beams only

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (1951-1960)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-38	U. S. 277 Op.	March, 1958	-	No	4610	Continuous I-Beam	Minor scale
T-39	U. S. 83 Op.	March, 1958	-	No	2120	Continuous I-Beam	Minor scale
T-40	Grace's Ck.	Feb., 1954	-	No	3540	Continuous Slab	Minor scale on underside
T-41	Martin's Ck.	June-July, 1953	4%	No	140	Pan Form Slab & Girder	Minor scale at drains
T-48	Dessau Rd.	Jan., 1954	No	No	12490	Continuous I-Beam	Extensive - especially East side
T-50	Three Point Rd.	Dec., 1958	3%	-	11300	Prestressed Beam	Minor scale
T-52	Rosillo Ck.	July, 1959	No	No	5000	Pan Form Slab & Girder	Moderate scale
T-53	Rosillo Ck.	July, 1959	No	No	5000	Pan Form Slab & Girder	Moderate scale
T-54	Santa Clara Rd.	Apr.-May, 1960	No	-	500	Prestressed Beam	Severe (1") scale
T-55	Santa Clara Ck.	Jan.-Feb., 1960	No	-	5000	Pan Form Slab & Girder	-
T-59	Aransas R.	Apr.-June, 1956	No	No	3090	Pan Form Slab & Girder, & Continuous I-Beam	Moderate scale

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (1951-1960)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-60	Drainage Ditch	April, 1958	No	No	2160	Simple Slab Span	Deck - good condition
T-61	Nueces R.	May-Aug., 1957 (Pan Form S & G) Jan.-Feb., 1958 (Cont. Plate G.)	No	No	1930	Pan Form Slab & Girder, & Continuous Plate Girder	Minor scale
T-62	Lagarto Ck.	Dec., 1959 - Jan., 1960	No	No	350	Pan Form Slab & Girder	Minor scale
T-63	Molinero Ck.	Oct., 1957	No	3.44%	310	Simple Slab Span	Minor scale
T-64	No Name Ck.	Oct., 1957	No	3.03%	310	Simple Slab Span	
T-65	St. Francis Rd.	Mar.-Apr., 1958	No	No	-	Continuous I-Beam	Extensive to severe scale
T-66	Red Oak Ck.	Feb., 1960	No	No	7930	Pan Form Slab & Girder	-
T-67	U. S. 77 at I. H. 35	March, 1960	No	No	3580	Continuous I-Beam	-
T-68	Dowdy Ferry Rd.	1957	No	No	11440	Pan Form Slab & Girder	Extensive to severe scale
T-69	Mars Rd.	1959	No	No	100	Prestressed Beam	Moderate scale
T-73	Sulphur Rd.	Nov., 1951	No	No	4120	Continuous I-Beam	Extensive scale

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (1951-1960)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-78	Clark's Ck.	Aug., 1952	No		420	Prestressed Beam	
T-81	Sabine R.	Jan.-Mar., 1953	4%	1.2-2.1%	6540	Pan Form Slab & Girder	Moderate scale
T-82	Boyt's Ranch Rd.	Nov., 1960	No	No	42	Continuous I-Beam	Moderate scale
T-83	S. H. 73 Op.	Nov., 1958	No	1.0-3.2%	1560	Continuous I-Beam	Minor to moderate scale
T-84	Neches R.	Nov., 1960	No	-	4100	Pan Form Slab & Girder	Moderate scale
T-85	1st Slough, San Saba R.	Nov., 1953	No	-	1170	Pan Form Slab & Girder	Extensive scale
T-86	San Saba R.	July-Aug., 1952	No	-	1320	Continuous I-Beam	Moderate scale
T-87	Pecan Bayou	Aug.,-Oct., 1960	No	-	100	Pan Form Slab & Girder, & Continuous I-Beam	Extensive scale
T-88	Clear Ck.	Sept., 1958	No	-	90	Pan Form Slab & Girder	Moderate scale
T-89	S. H. 36 Op.	May-June, 1952	No	-	1800	Continuous I-Beam	Extensive scale in curb & gutter
T-90	Sta. 249 + 70 - 251 + 23	July, 1958	No	-	6720	Simple Slab Span	Minor scale

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (1951-1960)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-91	Sta. 588 + 05 - 589 + 30	Nov., 1958	No		6720	Simple Slab Span	
T-93	Sta. 576 + 29 - 577 + 86	Sept., 1959	No	No	3120	Simple Slab Span	
T-94	Sta. 833 + 20	Aug., 1959	No	No	3120	Simple Slab Span	Minor scale. Pot holes - pr. 5
T-95	Geronimo St. Op.	March, 1960	4%	No	28210	Pan Form Slab & Girder	Minor scale.
T-96	Sta. 105 - 748 - 105 + 348	Feb., 1960	4%	No	28210	Pan Form Slab & Girder	Minor scale.
T-97	Hawkins Dr. Op.	Jan., 1960	4%	No	28210	Pan Form Slab & Girder	Minor scale.
	Bridge ID (1961 to Pres.)						
T-3	FM 1306 Up.	May, 1961	No	No	160	Continuous I-Beam & Simple I-Beam	Minor scale.
T-16	Turkey Ck.	Sept., 1946 (Old)	No		1630	Continuous Slab	Minor scale.
T-16	Turkey Ck.	Sept., 1964 (New)		3.82%	1630	Continuous Slab	Minor scale.

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (1961 to Present)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-18	P. & S.F.R.R. Up.	May, 1962	3%	3.7%	100	Continuous I-Beam	
T-19	Op. at Abernathy	July-Aug., 1961	No		4540	Continuous Slab	Extensive scale exposing 1/2 of coarse aggregate.
T-20	Cleveland St. Up.	Oct.-Nov., 1961	No		2010	Continuous Slab	Extensive scale - some popouts
T-35	FM 604 Op.	April, 1964	4.13 to 5.05 %	5.92%	3425	Continuous Slab	
T-42	Saline Ck. Rd.	Sept.-Oct., 1963	4%	7.6-1.9%	2000	Continuous I-Beam	Minor scale
T-43	Caney Ck.	Oct., 1961	4%	No	180	Pan Form Slab & Girder	Minor scale around joints
T-44	County Rd. Op.	June, 1961	4%	No	70	Continuous I-Beam	Minor scale
T-45	FM 849 Op.	Oct., 1961	4%	No	300	Continuous I-Beam	None
T-46	Colorado R.	Nov., 1962 - Feb., 1963	3%	2.9-3.3%	17680	Prestressed Beam & Continuous I-Beam	Extensively worn & eroded. Spalled areas.
T-47	First Street	July-Aug., 1963	3%	2.1-3.9%	5810	Continuous I-Beam	Minor scale
T-51	Yankee Rd.	Aug., 1963	3.5-4.5%		40	Prestressed Beam	Good condition

TABLE 7, CONT'D.

SCALING ON TEXAS BRIDGE DECKS

Code No.	Bridge ID (1961 to Present)	Built	Designed Entrained Air (%)	Actual Air (%)	Traffic Volume (VPD) *	Structure Type	Surface Condition
T-56	Calavera Ck.	May, 1964	4%	4.2-5.3%	3000	Prestressed Beam	Minor scale
T-57	Huebner Rd.	1960-1961	No	No	9000	Continuous I-Beam	Moderate scale
T-58	Live Oak Rd.	July, 1963	4.0%	3.7-6.2%	10000	Continuous I-Beam	Minor scale
T-70	Beckley Ave. Op.	June-Aug., 1961	No	No	10000	Continuous Plate Girder	Minor scale
T-71	Greenville Ave.	May, 1961	No	No	7500	Continuous I-Beam	Moderate scale
T-98	Ft. Bliss Spur	June, 1961	4%	3.0-7.4%	28210	Continuous I-Beam	-
T-100	Spring Ck.	June-July, 1961	-	No	260	Simple Slab Span	Extensive scale

APPENDIX B

THE EFFECT OF VARYING CEMENT CONTENT ON THE PHYSICAL PROPERTIES OF CONCRETE

I. SCOPE:

The disintegration of structural concrete through cracking, delamination and scaling has been blamed in part on the lack of adequate cement content to insure good performance. This laboratory study which is a part of the overall investigation of Bridge Deck Deterioration in Texas has been conducted to evaluate the effect of varying the cement content from 5.0 sacks to 6.0 sacks per cubic yard.

II. LIMITATIONS:

Inadequate time and laboratory space and personnel restricted this investigation to one aggregate and cement source, and allowed only the two control conditions of 5.0 and 6.0 sacks of cement per cubic yard to be compared throughout the range of testing.

The conclusions reached as a result of this investigation cannot be applied in general form to all materials and their combinations but resulting trends can be utilized to base recommendations for changing or adhering to present standards.

III. OBJECTIVES:

To determine and compare the physical properties of 5.0 and 6.0 sacks per cubic yard concrete made in the laboratory with the following test conditions:

1. Plain or Reference
2. Neutralized Vinsol Resin type air-entraining admixture (NVR "D").

3. Lignosulfonate type set-retarding, water-reducing admixture (Retarder A).
4. Condition (3) plus air-entraining admixture.
5. Same as (4) except Admixtures combined prior to addition to batch.
6. Same as (4) except double dosage of air entrainment without compensating the design for additional air or workability.
7. Repeat of (3), (4), (5), and (6) with a Hydroxylated Carboxylic type set-retarding, water-reducing admixture (Retarder B).

IV. SUMMARY:

A. Increasing the cement content from 5.0 to 6.0 sacks per cubic yard resulted in:

1. Equal or increased density of 1 to 4 lbs. per cu. ft. in hardened concrete.
2. Reduced linear shrinkage at 7 and 28 days up to 80%.
3. Increased compressive strengths at age of 28 and 90 days up to 20%.
4. Reduced per cent absorption in hardened concrete by 0.5 to 1.25% for all combinations of air-entraining and set-retarding admixtures. No change or slight increase in per cent absorption for reference, air-entrained, and Retarder A concrete.
5. Increased the durability factor of plain concrete by approximately 100% from 11.0 to 21.5, when tested in tap water.

B. Use of air-entraining and set-retarding, water-reducing admixtures resulted in the following:

1. NVR in the 5.0 sack design yielded the lowest concrete density,

highest shrinkage at 7 days, the lowest compressive strength at 28 days and only a slight reduction in the per cent absorption. Changing to the 6.0 sack design increased the hardened density by 4.0 lbs. per cu. ft., decreased the 7 day shrinkage by 60%, increased the 28 day compressive strengths by 11% and had no effect on the per cent absorption compared to values obtained with the 5-sack mix.

2. Lignosulfonate (Retarder A) and Hydroxylated Carboxylic (Retarder B) set-retarders increased the compressive strengths and slightly reduced the shrinkage of 5.0 and 6.0 sack designs. Retarder B increased the hardened concrete density compared to the reference concrete while Retarder A had little effect.
3. Retarder A or Retarder B, plus NVR "D" resulted in lower compressive strength, density, absorption, and shrinkage with both 5.0 and 6.0 sack design when added in accordance with the manufacturer's recommendation.
4. Retarder A when combined with NVR "D" prior to addition to the concrete mix increased concrete density by 5.0 lbs. per cu. ft., increased compressive strength by 1600 lbs. per sq. in., and reduced absorption by 1% for the 5.0 sack mix and, for the 6.0 sack mix, increased density by 5.5 lbs. per cu. ft., compressive strength by 2450 lbs. per sq. in., and reduced absorption 0.5%, as compared to values obtained by adding the admixtures to the concrete separately.

Retarder B when compared in a similar manner, 5-sack vs. 6-sack mix, yielded a lower density, lower compressive strength and increased shrinkage.

5. Retarder A or Retarder B, when combined with double dosage of NVR "D" without compensation for additional air and workability, resulted in lower densities and compressive strengths, had little effect on shrinkage and absorption, and maintained high durability factors through 240 cycles.

C. Durability tests performed by cycles of freeze and thaw, with companion samples thawing in plain water or brine solution, resulted in:

1. Reference or plain specimens for 5.0 sack mix failed after 78 cycles in brine solution and 55 cycles in tap water. Durability factors of 15.5 and 11.0, respectively.
2. Reference or plain specimens for 6.0 sack mix failed after 94 cycles in brine solution and 103 cycles in tap water. Durability factors of 19.0 and 20.5, respectively.
3. Retarder B specimens for 5.0 sack mix failed after 141 cycles in brine solution and 160 cycles in tap water. Durability factors of 28.2 and 31.9, respectively.
4. Retarder B specimens for 6.0 sack mix failed after 122 cycles in brine solution and 155 cycles in tap water. Durability factors of 24.2 and 30.9, respectively.
5. With a 5.0 sack mix Retarder A or Retarder B, + double NVR "D" had a durability factor of 80 at 300 cycles.
6. All mix conditions containing Retarder A or NVR "D", and combinations of Retarder A with NVR "D", with the exception noted in (5), gave little evidence of weight loss or deterioration

through the planned test life of 300 cycles.

V. CONCLUSIONS:

For these materials, increasing the cement factor from 5.0 to 6.0 sacks per cubic yard increases compressive strength and density, lowers absorption and decreases shrinkage. It ameliorates the adverse effects of entraining air and increases durability.

Hydroxylated Carboxylic type retarder should not be used without using an air entraining agent to increase durability.

Prior mixing of some admixtures may be advantageous to obtain desired concrete quality and should be determined by pilot tests.

Air-Entraining can adversely affect a 5.0 sack per cubic yard mixture.

VI. MATERIALS:

1. Siliceous-Limestone River Gravel and Sand.
2. Type I cement.
3. Job sample of previously approved air-entraining agent.
4. Job samples of previously approved Lignosulfonate and Hydroxylated Carboxylic type set-retarding, water-reducing admixtures.

VII. TEST PROCEDURES:

1. Test procedures and apparatus as outlined in the 400 Series of the Texas Test Methods. See attached copies of these procedures.
2. Test procedure and apparatus as outlined by ASTM Designation C-291, modified to include thawing in a 4.0% brine solution.

VIII. DISCUSSION:

The initial field investigations conducted on problem structures revealed an extensive amount of concrete which gave the appearance of being low in density and having a relatively high porosity. In addition, some types of damage reflected possible low strengths or high shrinkage, or both, as contributory causes of distress.

This laboratory investigation was set up to explore the effect of increasing the cement content from 5.0 sacks to 6.0 sacks per cubic yard on the physical properties of plain and admixed concrete. The parameters as stated in Part II, Objectives, of this report were established to accomplish three purposes:

1. To investigate the possible benefits of increasing the cement content to 6.0 sacks per cubic yard by measuring the compressive strength, density, absorption and shrinkage.
2. To investigate the effect of adding an air-entraining agent, a Lignosulfonate type set-retarder or a Hydroxylated Carboxylic type set-retarder to both 5.0 and 6.0 sack designs, measured by the same characteristics as in (1).
3. To measure the durability in (1) and (2) by freeze and thaw action with 300 cycles of freeze and thaw as outlined in ASTM Designation C-291, "Resistance of Concrete to Rapid Freeze in Air and Thaw in Water", modified to include thaw of companion specimens in brine.

The materials used in casting test specimens consisted of Siliceous-Limestone sand and gravel, Type I cement and previously submitted samples of admixtures approved for use on State Highway Construction. Lack of time and space prevented repeating the tests with other materials.

A 1.5 cubic foot Lancaster Laboratory Mixer was used to perform the mixing operation. Standard 6 in. x 12 in. cylinders and 3 in. x 3 in. x 11¼ in. specimens were fabricated to represent each test condition in accordance with current Texas Test Methods. The design for each test condition was adjusted to allow for water reduction, entrained air and increased workability to maintain the slump within + ½" and entrained air, where applicable within + 1% except for the condition of purposely doubling the dosage of air entraining agent without adjusting the design.

The fabricated specimens were cured and held in a 100% humidity room for the duration of the testing phase, with the exception of the specimens made for durability testing by freeze and thaw cycles. Durability specimens were removed from the curing room at 14 days and placed in the water baths, with companion specimens in 4% brine solution or tap water to begin the cycles.

A. Effect of cement content (C/F) of 5.0 vs. 6.0 sacks per cu. yd.: Fig. B-1 is a graphic picture of the compressive strengths as measured on 6" x 12" standard cylinders at the age of 28 and 90 days for 5.0 and 6.0 cement factors for all test conditions with the exception of doubling the air content. The effect of increasing the cement content is readily seen from the increase in compressive strength of 500 up to 1300 psi., for each test condition, except that at 90 days for Retarder A, and for Retarder A + NVR "D" (added separately) the reverse is true. The excess of entrained air explains the slight increase in the 7 day shrinkage as shown on Figure B-2.

The shrinkage values were determined by testing 3" x 3" x 11¼" specimens equipped with gage plugs having an effective gage length of 10.0". The results obtained are shown on Figure B-2 and, with the exception previously noted, increasing the cement factor to 6.0 reduced these values by amounts up to 80%.

The density and absorption of concrete was determined with standard compression cylinders at the age of 28 days. These values are plotted in Figures B-3 and B-4. With the same exception above noted for compressive strengths, the density of the concrete has increased with the additional cement. Per cent absorption increased slightly or remained approximately the same for plain, air-entrained, and Retarder A concrete, but was reduced up to 24% for all other combinations.

B. Effect of Admixtures.

Figures B-5, B-6, B-7, and B-8 depict comparisons of each mix condition for compressive strength, absorption, shrinkage and density at the two cement contents investigated.

It is readily seen, on viewing these figures, that the addition of the air-entraining agent to the concrete with a cement factor of 5.0 results in a relatively high absorption, density, low compressive strength and a high 7 day shrinkage value. Increasing the cement factor to 6.0 improves many of the low values, placing them in a more acceptable range.

Retarders A and B, when used alone, increased the compressive strength well over that of the plain concrete and decreased the shrinkage slightly for both cement factor. Retarder A decreases the absorption and lowers the density somewhat for both 5.0 and 6.0 sack mixes while Retarder B increases the absorption for the 5.0 sack mix and lowers it significantly for the 6.0 sack mix. Retarder B also increases the density over that of the reference concrete for 5.0 and 6.0 sack cement factor.

When NVR "D" and the two retarders were added to the mixture in the accepted manner a loss of strength, density, shrinkage and absorption occurred, with Retarder A being slightly more adversely affected.

Figures B-9 and B-10 show a comparison of values obtained by adding Retarder A or Retarder B, and the air-entraining agent to the concrete separately in the recommended manner vs. prior mixing of the retarder with the air-entraining agent before placing in the concrete.

For Retarder A and NVR "D", prior mixing of the admixtures reduces the entrained air by almost 50% below that obtained when admixtures were added separately. The compressive strength and density increased considerably, while the absorption and shrinkage were lowered for both 5.0 and 6.0 sack concrete. Retarder B was not affected as extensively but all changes were adverse to the quality of the concrete.

Double dosage of NVR "D" was added without compensation in the design to each of the retarders to simulate accidental overdoses during the mixing action. Previous work performed in the laboratory had indicated a possible decrease in compressive strength of 50%. This was confirmed by this investigation by strength losses of 41.0% with Retarder A, and 39.0% with Retarder B, measured at the age of 28 days, with a cement factor of 5.0. The percentage loss was reduced with a cement factor of 6.0.

C. Durability by Freeze and Thaw Cycles.

Cycles of freeze and thaw were performed on 3" x 3" x 11¼" concrete specimens representing each test condition. To simulate the action occurring in those portions of the State using de-icing salts, two series of specimens were cast, one for thawing in tap water and one for thawing in a 4% NaCl brine solution. The end, or ultimate, value at 300 cycles was selected, based on ASTM Designation C-291. The investigation, "Penetration of Chloride into Concrete" performed by Borje Ost and G. E. Monfore of the Portland Cement Association on the penetration of de-icing salt into concrete led to the selection of the concentration value of 4.0% for the brine solution.

The dynamic modulus of elasticity was measured periodically, with the value of 60% of initial modulus considered to be failure.

The reference or plain 5.0 cement factor samples reached failure at 55 cycles (D.F. = 11.0) for tap water and 78 cycles (D.F. = 15.5) for the brine solution. Companion samples representing 6.0 cement factor reached failure at 94 cycles (D.F. = 19.0) brine and 103 cycles (D.F. = 15.5) tap water.

Retarder B specimens for 5.0 cement factor failed at 141 cycles (D.F. = 28.2) brine and 141 cycles (D.F. = 31.9) tap water, and for 6.0 cement factor at 122 cycles (D.F. = 24.2) brine and 155 cycles (D.F. = 30.9) tap water.

For the 5.0 sack mix, Retarder A or Retarder B, when added to the concrete with a double dosage of air, without compensation, had a durability factor of 80 with the brine solution of 300 cycles.

The remainder of the specimens representing various test conditions, all of which contained entrained air, had durability factors in excess of 90 at the completion of 300 cycles.

The brine solution was periodically checked for the proper concentration and a uniform pH value. The results of these control tests are attached to this report as Table B-2.

TABLE B-1

DEFINITIONS OF SYMBOLS OR ABBREVIATIONS USED ON FIGURES B-1 THROUGH B-10

1. R: Reference
2. D: NVR "D", Neutralized Vinsol Resin type air-entraining admixture
3. RA: Retarder A: Lignosulfonate type set-retarding, water reducing admixture
4. RA + D(N): Retarder A + NVR "D": in normal manner
5. RA + D (PM): Retarder A + NVR "D", prior mixed before adding to batch
6. RB: Retarder B: Hydroxylated Carboxylic type set-retarding, water-reducing admixture
7. RB + D (N): Retarder B + NVR "D", normal method
8. RB + D (PM): Retarder B + NVR "D", prior mixed before adding to batch

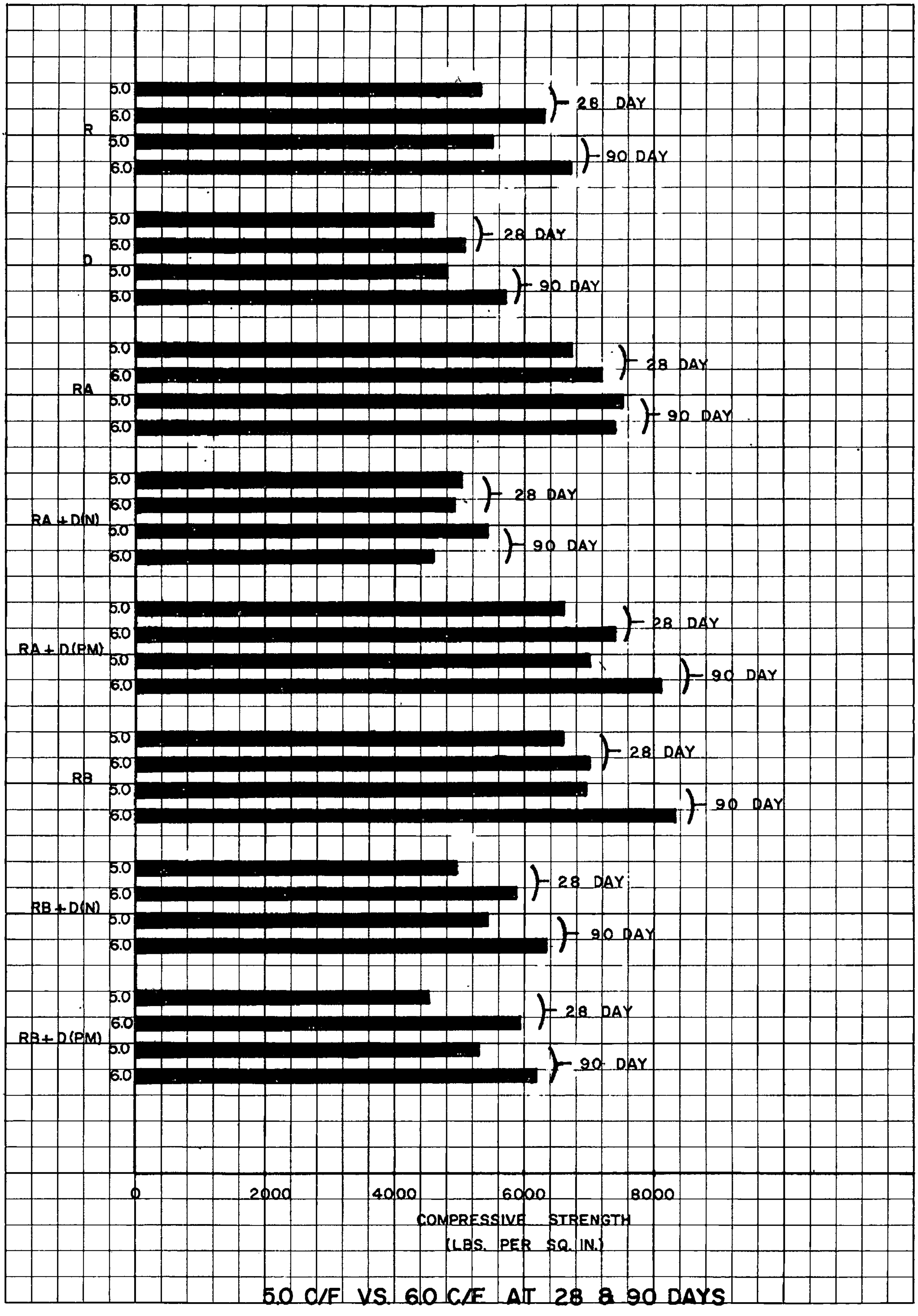

R
D
RA
RA + D(N)
RA + D(PM)
RB
RB + D(N)
RB + D(PM)
5.0
6.0
28 DAY
90 DAY
0
2000
4000
6000
8000
COMPRESSIVE STRENGTH
(LBS. PER SQ. IN.)
5.0 C/F VS. 6.0 C/F AT 28 & 90 DAYS

Figure B-1

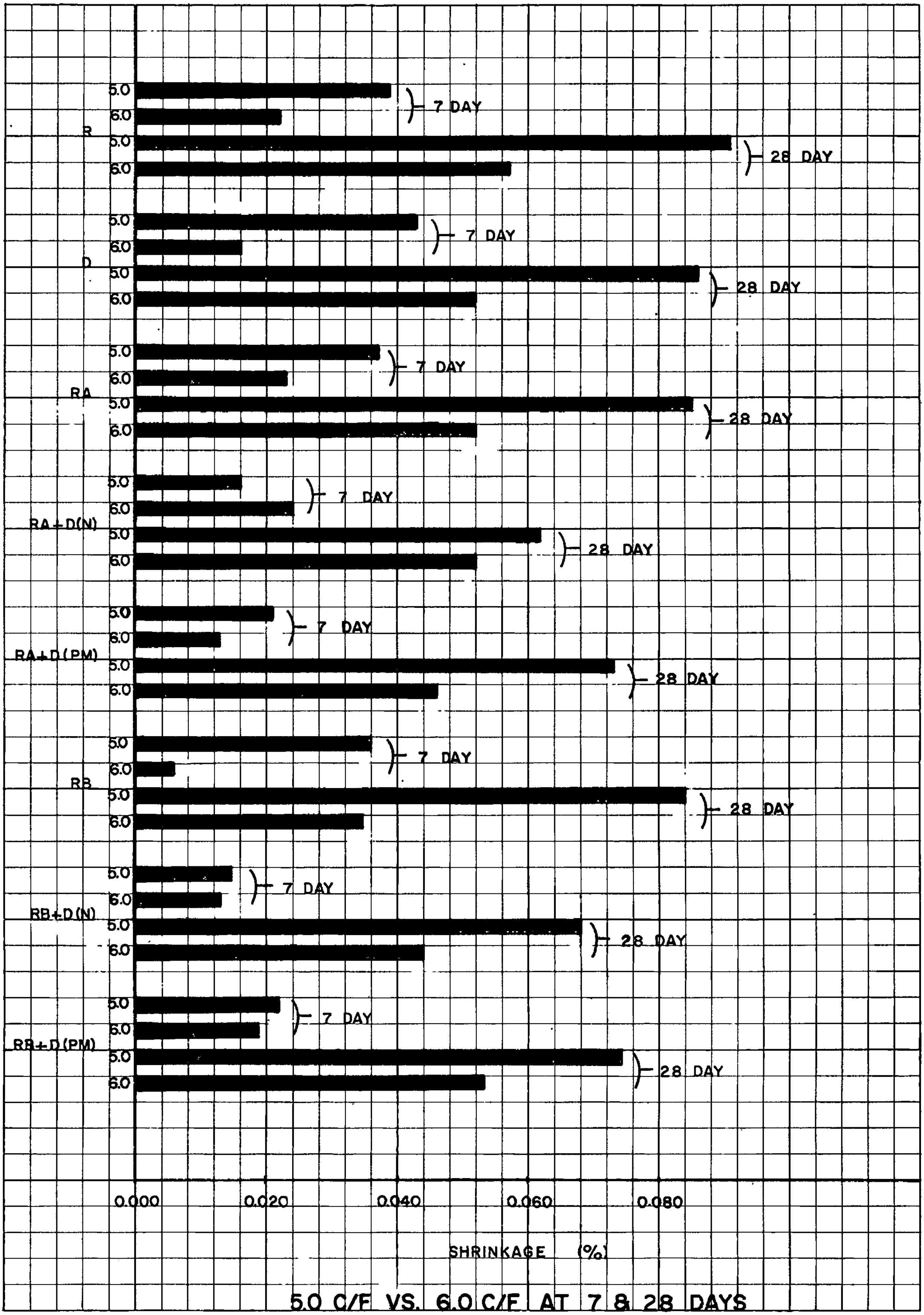

R
D
RA
RA+D(N)
RA+D(PM)
RB
RB+D(N)
RB+D(PM)
5.0
6.0
7 DAY
28 DAY
0.000
0.020
0.040
0.060
0.080
SHRINKAGE (%)
5.0 C/F VS. 6.0 C/F AT 7 & 28 DAYS

Figure B-2

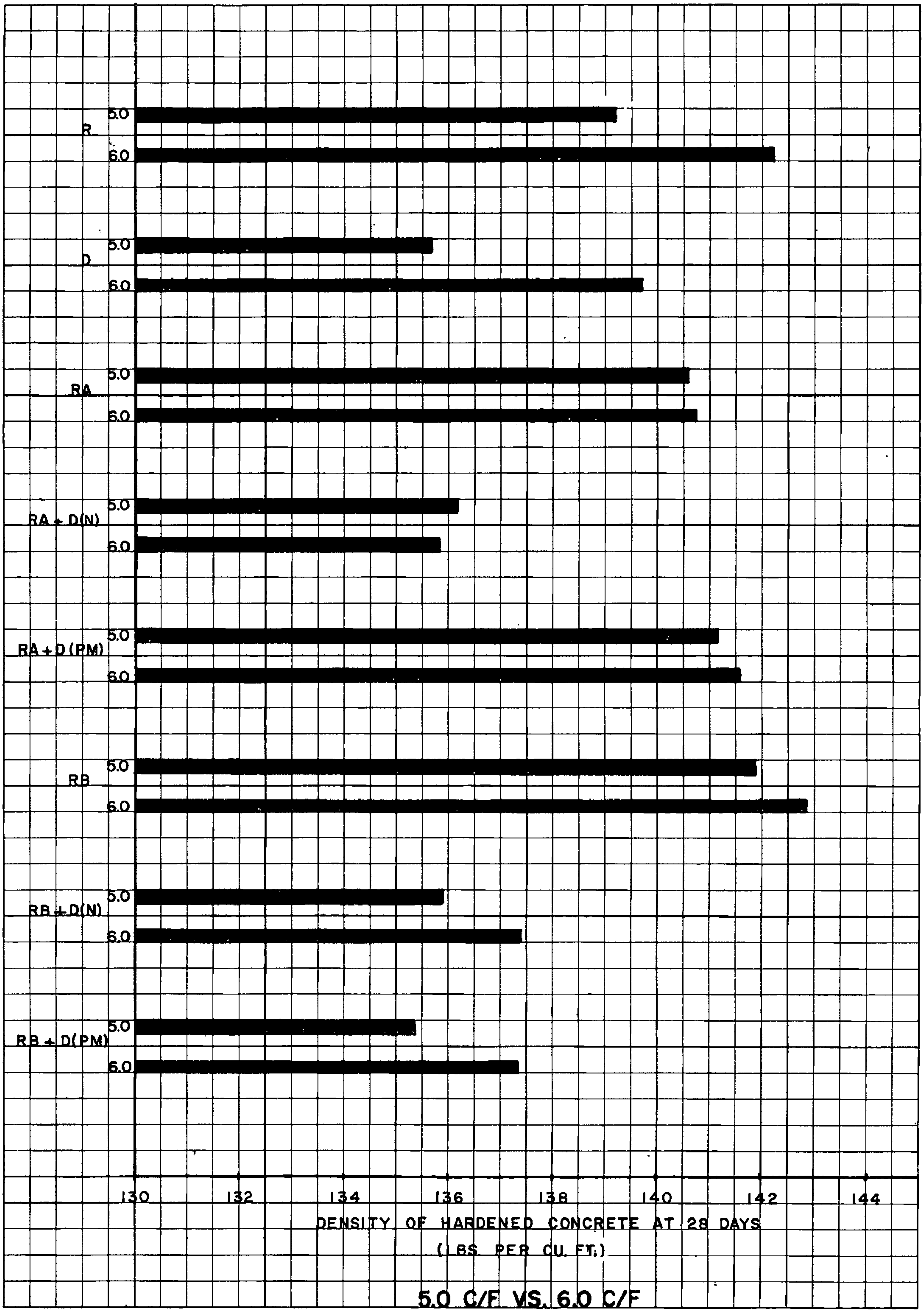
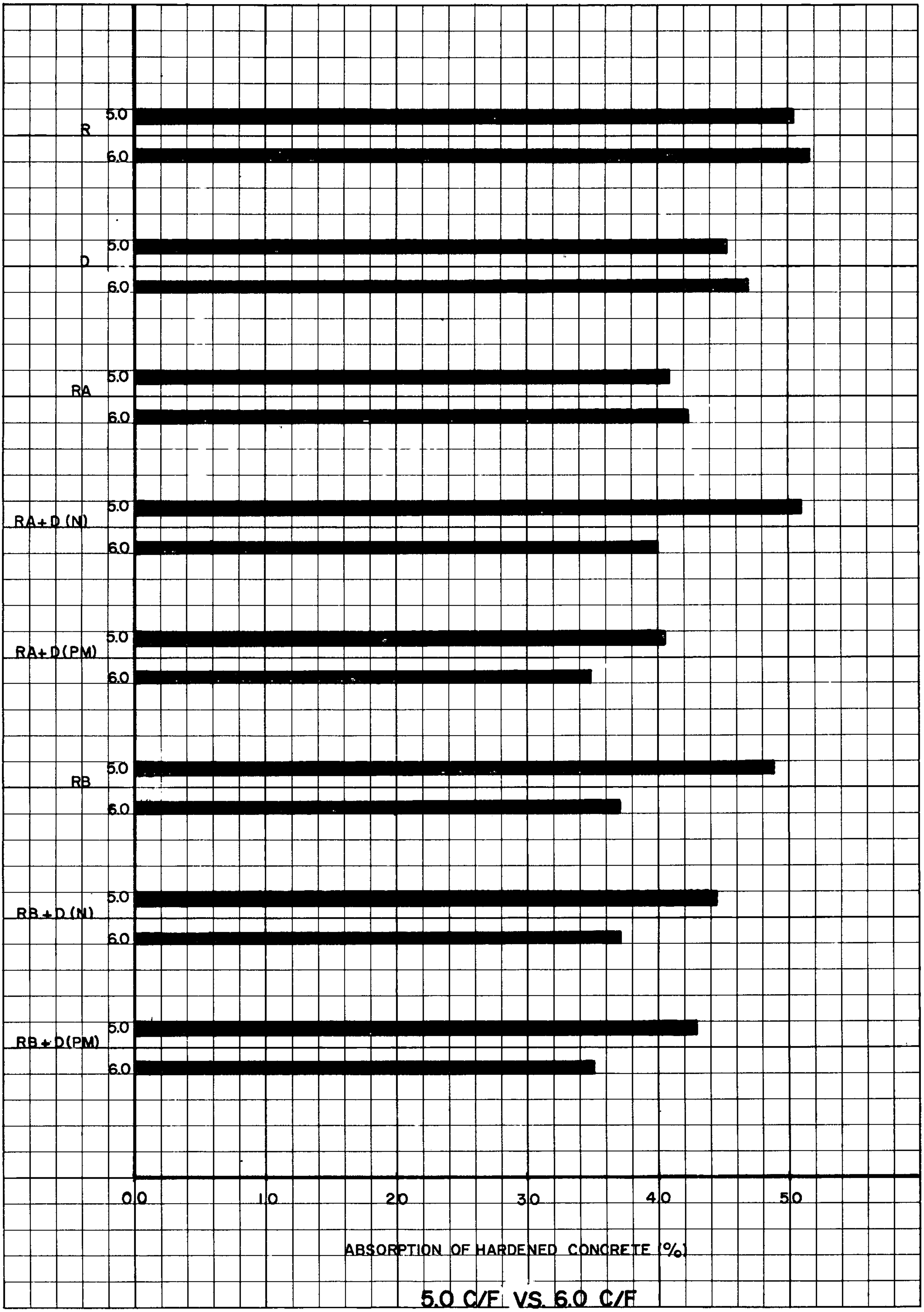
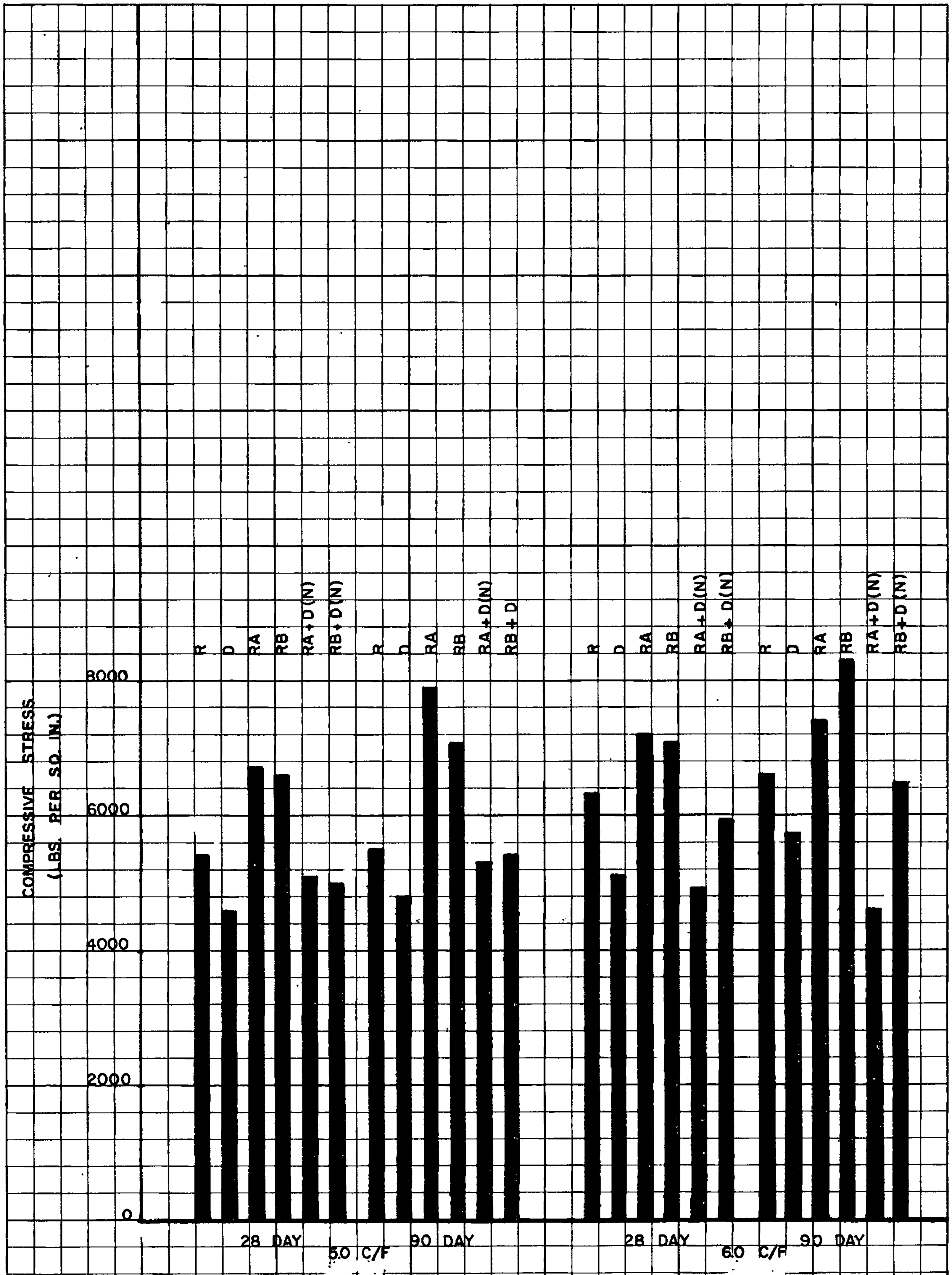

R
5.0
6.0
D
5.0
6.0
RA
5.0
6.0
RA + D(N)
5.0
6.0
RA + D(PM)
5.0
6.0
RB
5.0
6.0
RB + D(N)
5.0
6.0
RB + D(PM)
5.0
6.0
130
132
134
136
138
140
142
144
DENSITY OF HARDENED CONCRETE AT 28 DAYS
(LBS. PER CU. FT.)
5.0 C/F VS. 6.0 C/F

Figure B-3



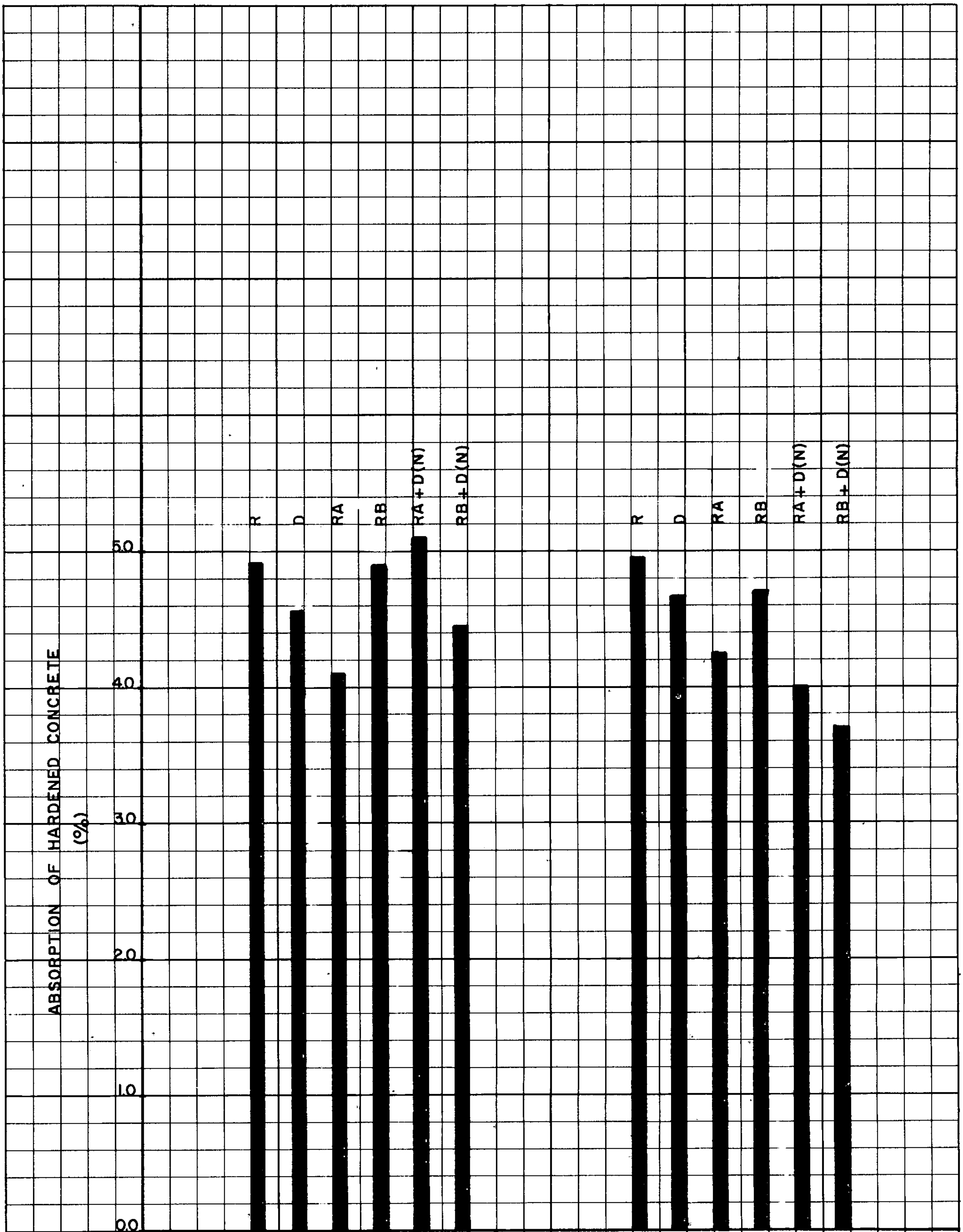
5.0 C/F VS. 6.0 C/F

Figure B-4



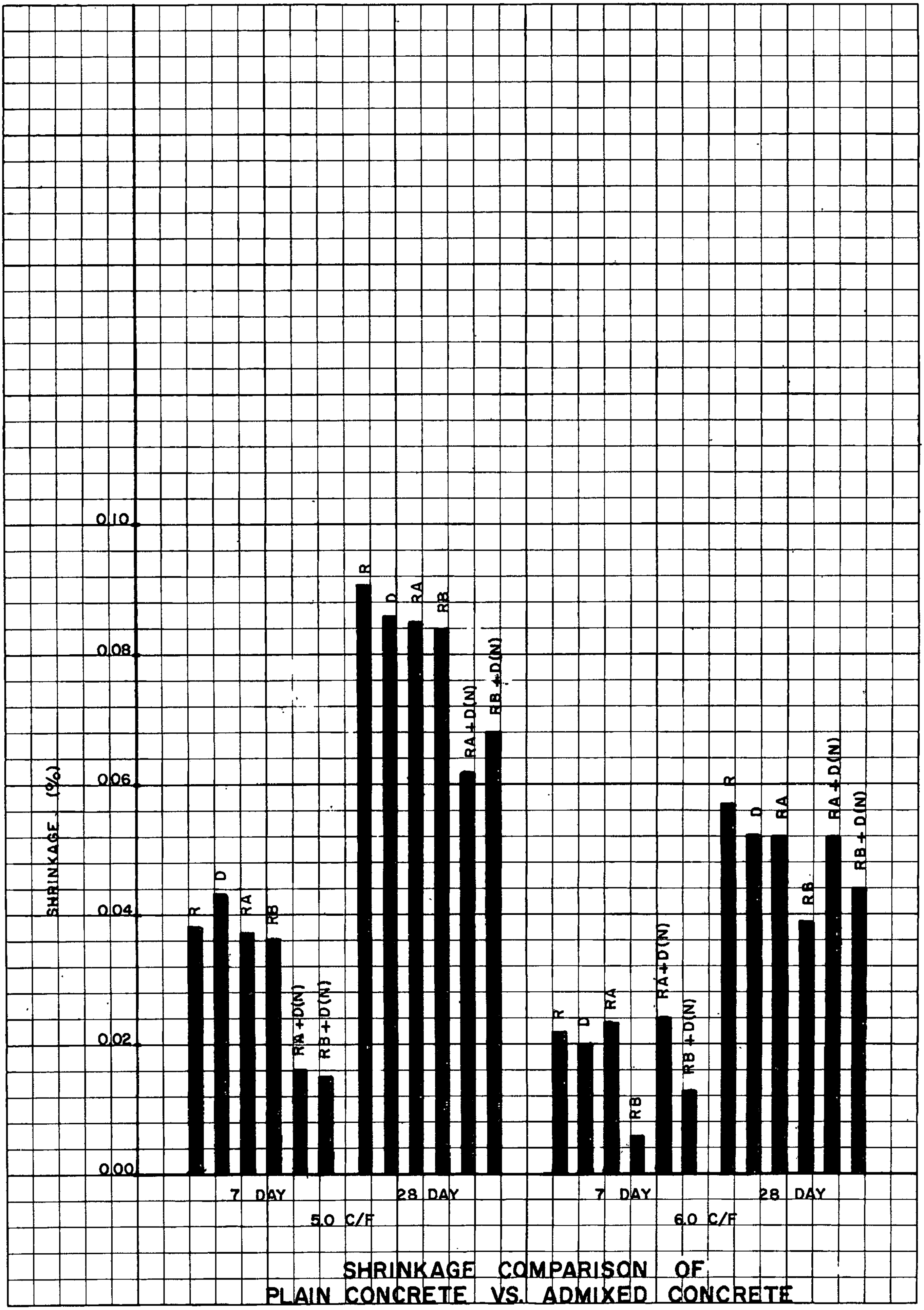
COMPRESSIVE STRENGTH COMPARISON
OF
PLAIN CONCRETE VS. ADMIXED CONCRETE

Figure B-5



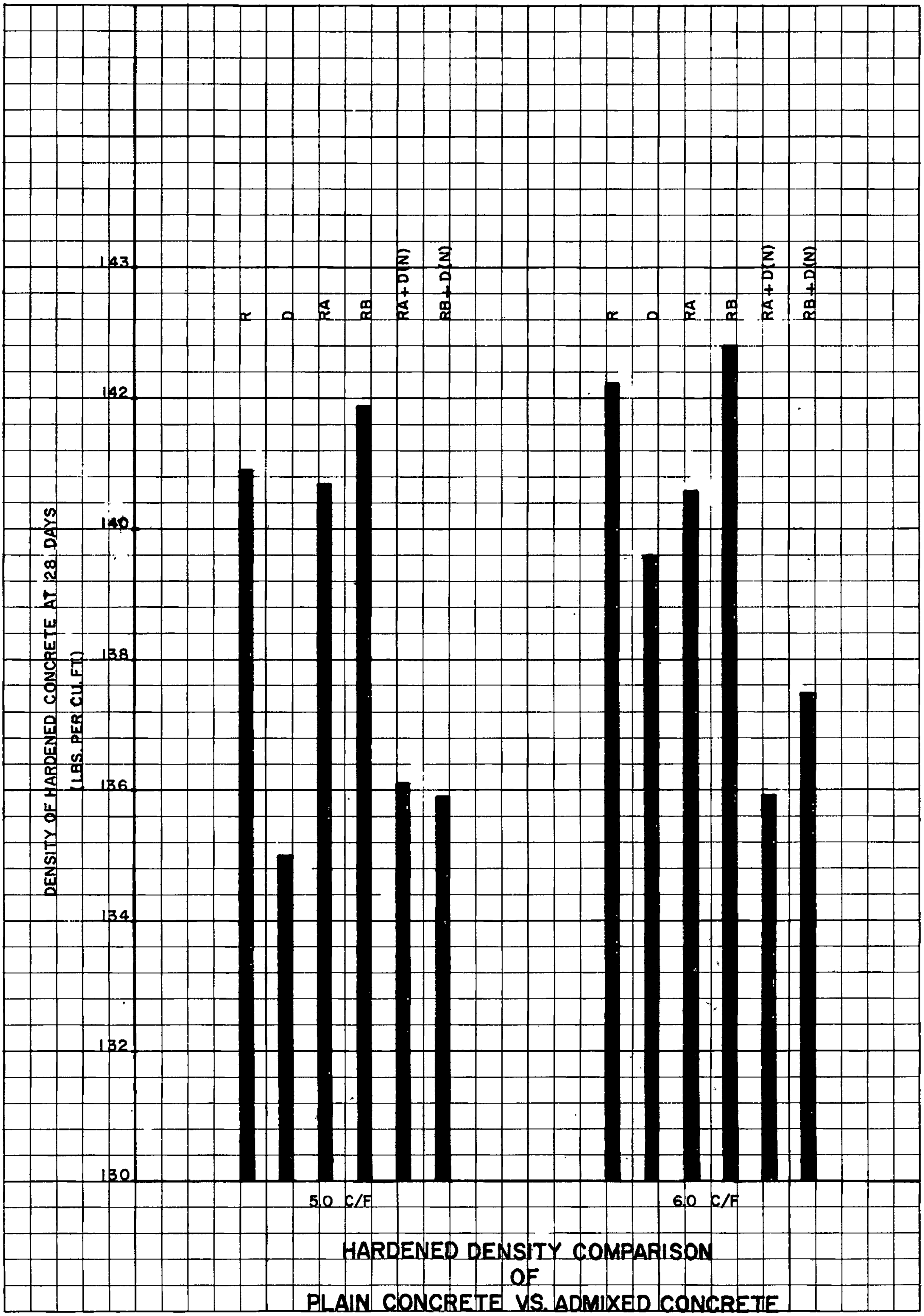
ABSORPTION COMPARISON
OF
PLAIN CONCRETE VS. ADMIXED CONCRETE

Figure B-6



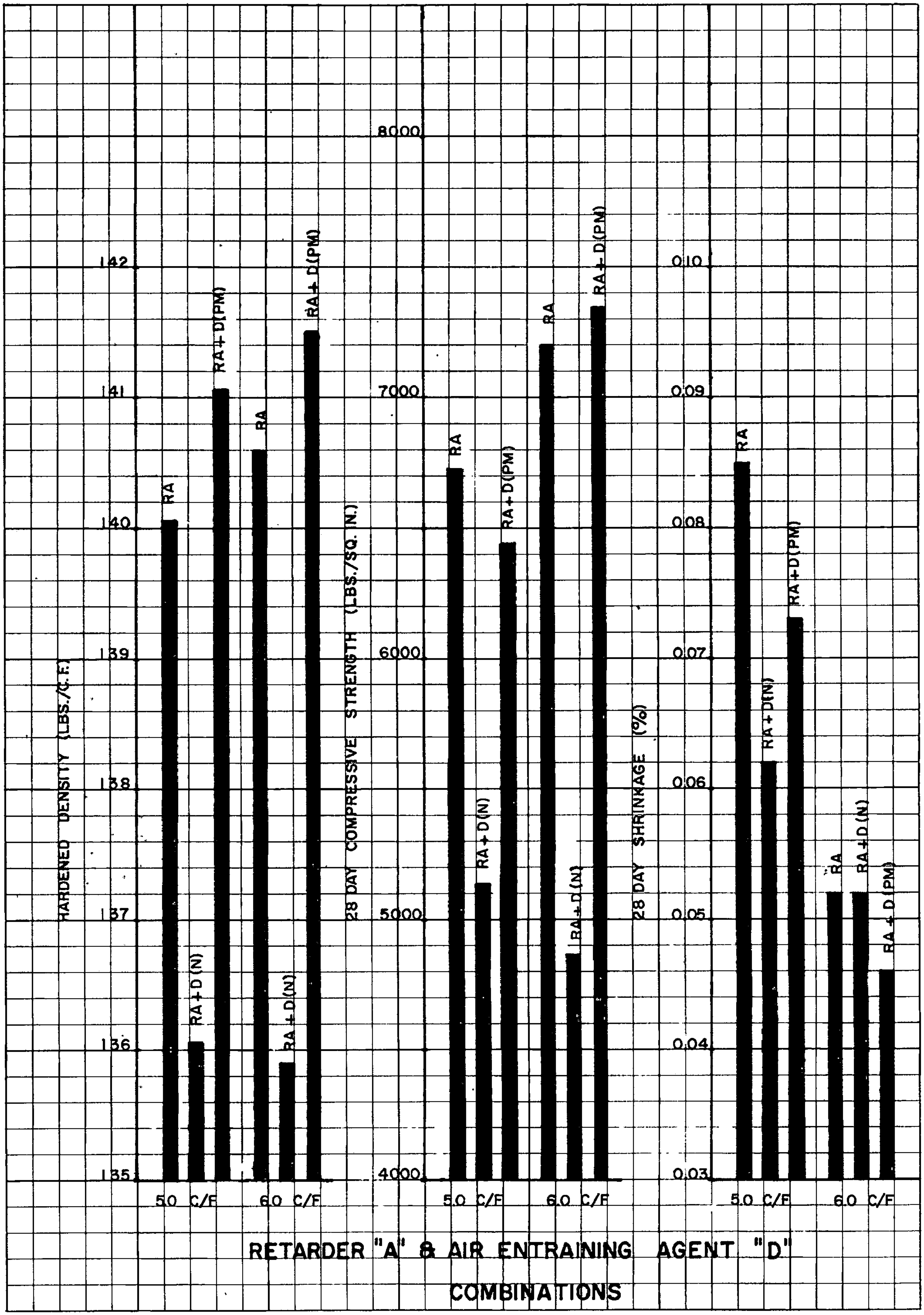
SHRINKAGE COMPARISON OF PLAIN CONCRETE VS. ADMIXED CONCRETE

Figure B-7



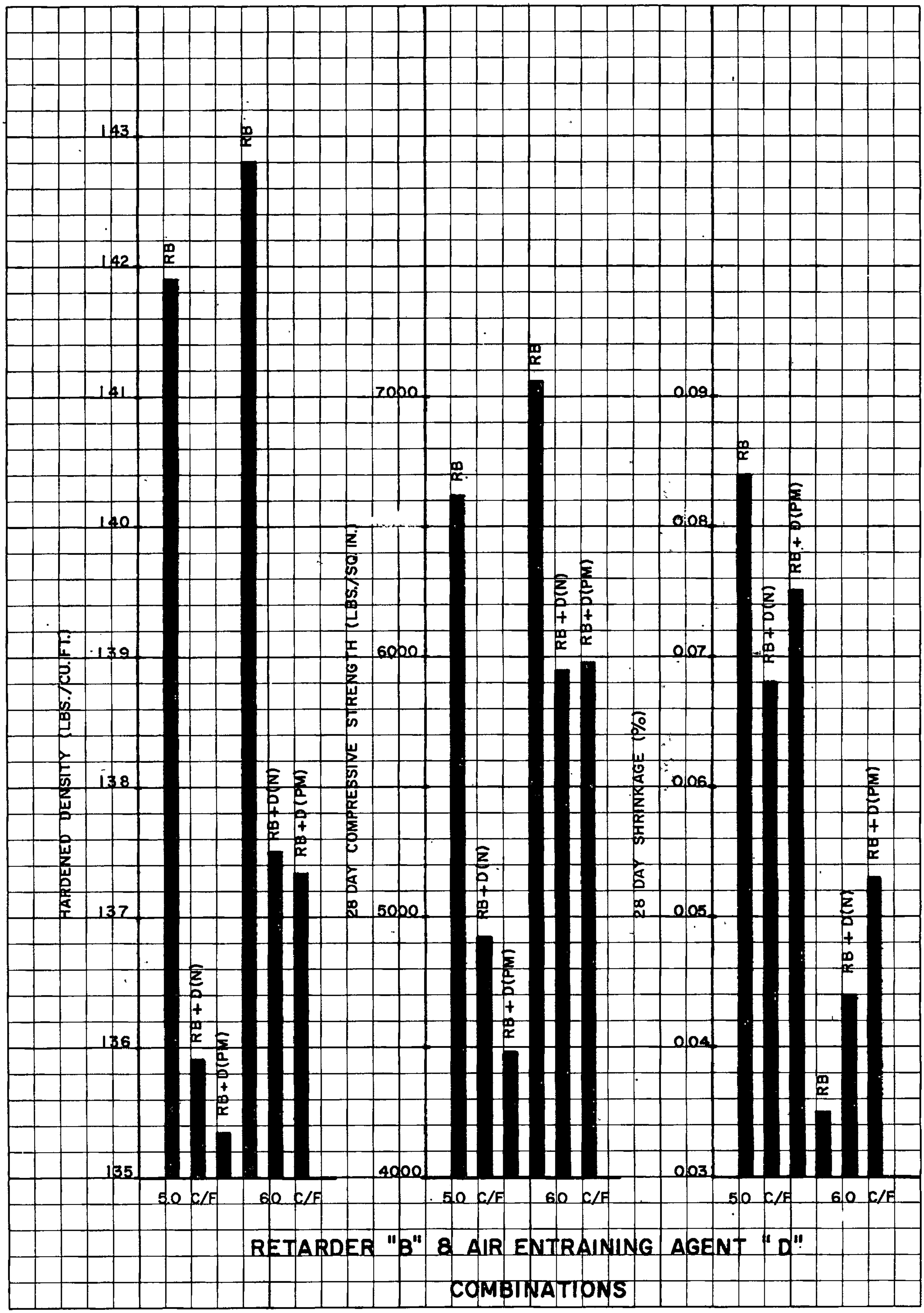
HARDENED DENSITY COMPARISON
OF
PLAIN CONCRETE VS. ADMIXED CONCRETE

Figure B-8



142
141
140
139
138
137
136
135
HARDENED DENSITY (LBS./C.F.)
RA
RA+D(N)
RA+D(PM)
RA
RA+D(N)
RA+D(PM)
5.0 C/F
6.0 C/F
8000
7000
6000
5000
4000
28 DAY COMPRESSIVE STRENGTH (LBS./SQ. IN.)
RA
RA+D(N)
RA+D(PM)
RA
RA+D(N)
RA+D(PM)
5.0 C/F
6.0 C/F
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
28 DAY SHRINKAGE (%)
RA
RA+D(N)
RA+D(PM)
RA
RA+D(N)
RA+D(PM)
5.0 C/F
6.0 C/F
RETARDER "A" & AIR ENTRAINING AGENT "D"
COMBINATIONS

Figure B-9



RETARDER "B" & AIR ENTRAINING AGENT "D"
COMBINATIONS

Figure B-10

TABLE B-2

TESTING OF FREEZE-THAW TEST SOLUTIONS
10-6-66 THROUGH 5-1-67

Attached is the data on the testing of tap water and salt brine being used in connection with the freeze-thaw tests on concrete (IP-4-66-A).

For purposes of standardization, we analyzed the brine solution for Chloride Ion content and calculated this chloride as % by weight sodium chloride. We attempted to keep this brine solution at a chloride ion concentration equivalent to that of a 4% solution of pure sodium chloride in water.

It was noted that the dissolved solids content did tend to build up in these solutions. The solutions were analyzed for this property and the results shown. We will continue testing these solutions while the tests continue. Additional data on future tests will be reported by memo at a later date.

TABLE B-2

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
10-6-66				
Brine	4.4	4.3		
Tap H_2O				
10-7-66				
Brine	3.9	4.1		
Tap H_2O				
10-10-66				
Brine	4.6	4.0		
Tap H_2O				
10-11-66				
Brine	4.5	4.0		
Tap H_2O				
10-13-66				
Brine	4.3	4.0		
Tap H_2O				
10-14-66				
Brine	4.1	4.1		
Tap H_2O	0.1	0.1		
10-17-66				
Brine	4.2	4.1		
Tap H_2O				
10-18-66				
Brine	3.9	3.8		
Tap H_2O				
10-19-66				
Brine	3.8	3.7		
Tap H_2O				
10-20-66				
Brine	3.8	3.7		
Tap H_2O				
10-21-66				
Brine	3.9	3.7		
Tap H_2O				

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

[Test Date]	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
10-24-66				
Brine	4.6	3.8	-	-
Tap H_2O	-	-	-	-
10-25-66				
Brine	4.5	4.0	-	-
Tap H_2O	-	-	-	-
10-26-66				
Brine	4.3	4.0	-	-
Tap H_2O	-	-	-	-
10-27-66				
Brine	4.1	4.0	-	-
Tap H_2O	-	-	-	-
10-28-66				
Brine	4.1	4.0	-	-
Tap H_2O	-	-	-	-
10-31-66				
Brine	4.4	4.1	-	-
Tap H_2O	-	-	-	-
11-1-66				
Brine	4.3	4.1	-	-
Tap H_2O	-	-	-	-
11-2-66				
Brine	4.3	4.1	-	-
Tap H_2O	-	-	-	-
11-4-66				
Brine	4.5	4.2	10.6	0.3
Tap H_2O	0.03	0.03	10.0	0.3
11-7-66				
Brine	4.0	3.8	10.6	0.3
Tap H_2O	0.03	0.02	10.0	0.15
11-9-66				
Brine	4.0	3.9	10.7	0.45
Tap H_2O	0.05	0.08	10.0	0.12

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
11-10-66				
Brine	4.5	3.9	10.65	0.45
Tap H_2O	0.06	0.06	9.35	0.07
11-14-66				
Brine	4.0	3.9	10.85	0.9
Tap H_2O	0.06	0.08	9.9	0.16
11-15-66				
Brine	4.6	3.9	10.45	0.8
Tap H_2O	0.03	0.06	9.75	0.1
11-16-66				
Brine	3.9	3.9	10.4	0.85
Tap H_2O	0.04	0.06	9.7	0.1
11-17-66				
Brine	4.4	4.0	10.45	0.9
Tap H_2O	0.04	0.06	9.6	0.1
11-18-66				
Brine	4.1	4.0	10.6	0.95
Tap H_2O	0.05	0.03	9.7	0.15
11-21-66				
Brine	4.2	4.1	10.75	1.15
Tap H_2O	0.07	0.07	9.65	0.15
11-22-66				
Brine	4.2	4.1	10.55	1.05
Tap H_2O	0.07	0.09	9.5	0.12
11-23-66				
Brine	5.0	4.1	10.55	1.10
Tap H_2O	0.07	0.06	9.55	0.11
11-25-66				
Brine	4.6	4.1	10.5	1.0
Tap H_2O	0.08	0.08	9.45	0.1
11-28-66				
Brine	4.3	4.3	10.6	1.1
Tap H_2O	0.09	0.1	9.35	0.1

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
11-30-66				
Brine	4.4	4.3	10.5	1.1
Tap H_2O	0.09	0.06	9.1	0.05
12-2-66				
Brine		4.3		
Tap H_2O		0.08		
12-5-66				
Brine	4.7	4.3	10.6	1.2
Tap H_2O	0.05	0.08	9.35	0.07
12-6-66				
Brine	5.9	4.3	10.6	1.2
Tap H_2O	0.05	0.17	9.4	0.08
12-7-66				
Brine	4.5	4.3	10.8	1.2
Tap H_2O	0.06	0.07	9.45	0.1
12-8-66				
Brine	4.3	3.8	9.4	0.05
Tap H_2O	0.06	0.08	9.4	0.1
12-9-66				
Brine	4.1	3.8	10.15	0.3
Tap H_2O	0.07	0.1	9.4	0.1
12-12-66				
Brine	4.1	3.9	10.9	0.6
Tap H_2O	0.08	0.06	9.45	0.1
12-13-66				
Brine	4.0	4.0	10.85	0.55
Tap H_2O	0.08	0.1	9.4	0.1
12-14-66				
Brine	4.4	4.0	10.75	0.55
Tap H_2O	0.08	0.07	9.4	0.1
12-15-66				
Brine	4.2	4.0	10.8	0.5
Tap H_2O	0.09	0.1	9.5	0.1

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
12-16-66				
Brine	4.2		10.5	0.3
Tap H_2O	0.09		9.0	0.1
12-19-66				
Brine	4.3		10.45	0.5
Tap H_2O	0.1		9.2	0.1
12-20-66				
Brine	4.7		10.65	0.55
Tap H_2O	0.11		9.4	0.1
12-21-66				
Brine	4.2		10.2	0.55
Tap H_2O	0.12		9.0	0.1
12-27-66				
Brine	4.3		9.95	0.5
Tap H_2O				
12-28-66				
Brine	4.5	4.2	10.35	0.6
Tap H_2O	0.04	0.07	10.3	0.15
12-29-66				
Brine	4.4	4.1	10.4	0.6
Tap H_2O	0.1	0.06	10.3	0.1
12-30-66				
Brine	4.4	4.3	10.15	0.6
Tap H_2O	0.05	0.06	10.0	0.15
1-2-67				
Brine	4.4	4.3	10.4	0.75
Tap H_2O	0.06	0.08	10.1	0.15
1-3-67				
Brine	4.6	4.3	10.35	0.7
Tap H_2O	0.07	0.1	10.0	0.15
1-4-67				
Brine	4.5	4.3	10.3	0.85
Tap H_2O	0.07	0.08	9.25	0.15

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
1-5-67				
Brine			10.4	0.8
Tap H_2O			9.85	0.15
1-6-67				
Brine	4.1	4.0	10.55	0.8
Tap H_2O	0.06	0.08	9.95	0.15
1-9-67				
Brine	4.1	4.0	10.65	1.05
Tap H_2O	0.04	0.06	10.1	0.15
1-10-67				
Brine	4.2	4.0	10.5	1.05
Tap H_2O	0.05	0.07	9.85	0.15
1-11-67				
Brine	4.2	4.0	10.45	1.0
Tap H_2O	0.05	0.08	10.15	0.15
1-12-67				
Brine	5.7	4.1	10.25	0.95
Tap H_2O	0.06	0.06	10.15	0.15
1-13-67				
Brine	6.1	4.1	10.15	1.0
Tap H_2O	0.06	0.08	9.8	0.15
1-16-67				
Brine	3.7	3.6	9.95	0.35
Tap H_2O	0.06	0.08	9.9	0.15
1-17-67				
Brine	3.6	3.6	10.0	0.35
Tap H_2O	0.07	0.08	10.0	0.15
1-18-67				
Brine	3.8	3.6	10.1	0.4
Tap H_2O	0.07	0.08	10.0	0.15
1-20-67				
Brine	3.8	3.6	10.1	0.4
Tap H_2O	0.08	0.08	9.85	0.12

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
1-23-67				
Brine	3.8	3.6	9.9	0.4
Tap H_2O	0.07	0.08	9.7	0.15
1-24-67				
Brine	3.8	3.6	10.0	0.4
Tap H_2O	0.06	0.08	9.8	0.2
1-25-67				
Brine	3.8	3.6	10.1	0.1
Tap H_2O	0.03	0.04	9.9	0.1
1-26-67				
Brine	3.8	3.8	10.0	0.4
Tap H_2O	0.04	0.06	9.8	0.15
1-27-67				
Brine	3.9	4.1	10.15	0.4
Tap H_2O	0.05	0.06	10.0	0.15
1-30-67				
Brine	4.0	3.8	9.95	0.45
Tap H_2O	0.05	0.08	9.85	0.15
1-31-67				
Brine	4.1	4.0	10.0	0.5
Tap H_2O	0.06	0.08	9.9	0.15
2-1-67				
Brine	4.0	4.0	10.1	0.5
Tap H_2O	0.06	0.08	9.95	0.15
2-2-67				
Brine	4.5	4.0	9.8	0.4
Tap H_2O	0.06	0.08	9.8	0.15
2-3-67				
Brine	4.1	4.0		
Tap H_2O	0.02	0.06		
2-6-67				
Brine	4.1			
Tap H_2O	0.04			

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Values***
2-9-67				
Brine	4.2	4.1	9.35	0.5
Tap H_2O	0.08	0.08	9.85	0.15
2-10-67				
Brine	4.3	4.1		
Tap H_2O				
2-13-67				
Brine	4.3	4.1		
Tap H_2O	0.04	0.08		
2-14-67				
Brine	4.3	4.1	9.7	0.65
Tap H2O	0.05	0.08	10.1	0.1
2-15-67				
Brine	4.4	4.1		
Tap H_2O	0.05	0.08		
2-16-67				
Brine	4.2	4.0		
Tap H_2O	0.05	0.08		
2-20-67				
Brine	4.3	4.1		
Tap H_2O	0.07	1.0		
2-21-67				
Brine	4.3	4.1		
Tap H_2O	0.07	0.05		
2-23-67				
Brine	4.2	4.0		
Tap H_2O	0.03	0.08		
2-24-67				
Brine	4.2	4.0		
Tap H_2O	0.04	0.06		
2-27-67				
Brine	5.4	4.1		
Tap H_2O	0.05	0.08		

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
2-28-67				
Brine	4.0	4.0		
Tap H_2O	0.06	0.08		
3-1-67				
Brine	4.0	4.0		
Tap H_2O	0.07	0.06		
3-3-67				
Brine	4.1			
Tap H_2O	0.07			
3-6-67				
Brine	4.6	4.0	10.45	1.0
Tap H_2O	0.04	0.06	10.45	0.15
3-7-67				
Brine	4.9	4.1		
Tap H_2O	0.04	0.03		
3-8-67				
Brine	5.0	4.1	10.45	0.95
Tap H_2O	0.04	0.03	10.3	0.15
3-9-67				
Brine	4.5	3.8	10.35	1.0
Tap H_2O	0.05	0.05	10.1	0.15
3-10-67				
Brine	4.4	4.0		
Tap H_2O				
3-13-67				
Brine	4.0	4.0	10.45	1.15
Tap H_2O	0.04	0.05	10.2	0.15
3-14-67				
Brine	4.2	4.0		
Tap H_2O	0.04	0.05		
3-15-67				
Brine	4.1	4.0		
Tap H_2O	0.05	0.08		

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
3-16-67				
Brine	4.0	4.0		
Tap H_2O	0.04	0.06		
3-17-67				
Brine	4.0	4.0	10.15	0.3
Tap H_2O	0.05	0.06	10.25	0.15
3-20-67				
Brine	4.1	4.0		
Tap H_2O	0.06	0.08		
3-21-67				
Brine	4.1	4.0		
Tap H_2O	0.06	0.08		
3-22-67				
Brine	4.1	4.0		
Tap H_2O	0.07	0.08		
3-23-67				
Brine	4.2	4.0		
Tap H_2O	0.07	0.08		
3-27-67				
Brine	5.0	4.1	10.0	0.35
Tap H_2O	0.04	0.06	10.35	0.1
3-28-67				
Brine	4.5	4.1		
Tap H_2O	0.04	0.06		
3-29-67				
Brine	4.5	4.1		
Tap H20	0.04	0.06		
3-30-67				
Brine	4.3	4.1		
Tap H_2O	0.05	0.06		
3-31-67				
Brine	4.4	4.1	9.9	0.45
Tap H_2O	0.05	0.08	10.05	0.10

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
4-3-67				
Brine	4.5	4.3		
Tap H_2O	0.04	0.06		
4-4-67				
Brine	4.8	4.3		
Tap H_2O	0.04	0.06		
4-5-67				
Brine	4.4	4.3		
Tap H_2O	0.05	0.06		
4-6-67				
Brine	5.9	4.3		
Tap H_2O	0.06	0.08		
4-7-67				
Brine	4.2	4.1		
Tap H_2O	0.05	0.08		
4-10-67				
Brine	4.5	4.0	10.15	0.5
Tap H_2O				
4-11-67				
Brine	4.4	4.0		
Tap H_2O	0.03	0.05		
4-12-67				
Brine	4.3	4.1		
Tap H_2O	0.04	0.06		
4-13-67				
Brine	4.2	4.1		
Tap H_2O	0.04	0.06		
4-14-67				
Brine	4.4	4.1		
Tap H_2O	0.04	0.06		
4-17-67				
Brine	4.0	3.8		
Tap H_2O	0.06	0.08		

TABLE B-2, CONT'D.

ANALYSIS OF FREEZE-THAW TEST SOLUTIONS

	Total Suspended & Dissolved Solids*	% NaCl**	pH	Neutralization Value***
4-18-67				
Brine	4.1	3.8		
Tap H_2O	0.03	0.06		
4-19-67				
Brine	5.1	4.0		
Tap H_2O	0.03	0.06		
4-20-67				
Brine	4.4	4.0		
Tap H_2O	0.04	0.06		
4-24-67				
Brine	4.2	4.0		
Tap H_2O	0.05	0.06		
4-25-67				
Brine	4.3	4.0		
Tap H_2O	0.03	0.06		
4-27-67				
Brine	4.1	4.0		
Tap H_2O	0.04	0.06		
4-28-67				
Brine	4.2	4.0		
Tap H_2O	0.04	0.06		
5-1-67				
Brine	4.9	4.3		
Tap H_2O	0.05	0.10		

*: Calculated as % by wt. residue upon oven drying test solution at 212°F. to constant wt.

**: Calculated as % by wt. sodium chloride in test solution.

***: Calculated as number of milliliters of 1.000 N. Hydrochloric Acid required to titrated a 200 ml sample of test solution to an end point of pH 8.2.

Test Method Tex-414-A

Rev: September 1965

Texas Highway Department

Materials and Tests Division

DESIGN OF PORTLAND CEMENT CONCRETE

Scope

This procedure sets forth the method for determining the proper proportions by weight of approved aggregates, portland cement and water to combine to produce concrete which will satisfy the requirements of the specifications. Design constants are provided and examples of application for strength design, specified cement content and air-entrained concrete are shown.

Definitions

The following definitions are given to clarify the meaning and use of certain terms in this procedure.

1. Concrete consists of a mixture of mineral aggregates, cement and water which when first made is plastic but soon hardens to a firm, solid substance used for structures and pavement.

2. Coarse aggregate consists of durable particles of gravel, crushed stone or other acceptable materials of uniform quality, free of objectionable materials and comprise that portion of the mineral aggregate retained on the 1/4-inch sieve.

3. Fine aggregate is that portion of the mineral aggregate which passes the 1/4-inch sieve and consists of sand, or a combination of sand and other acceptable materials which includes mineral filler.

4. Mineral filler consists of clean stone dust, crushed sand, crushed shell or other approved manufactured inert material.

5. Air entraining agent is an approved admixture combined with the concrete to improve the plasticity and cohesiveness of the mixture and increase the durability of the hardened concrete.

6. Paste is the term used for the mixture of cement and water. The consistency of the paste is determined by the proportion of water and cement and influences the workability and strength of the concrete.

7. Mortar is defined as cement paste combined with fine aggregate. The mortar hardens and holds the coarse aggregate into a solid, firm mass of concrete.

8. Fine Aggregate Factor (FAF) is the loose volume of fine aggregate in a unit volume of mortar and may be expressed as a percentage of that volume of mortar which is occupied by the fine aggregate in a loose state.

9. Excess paste is the absolute volume of paste in excess of the amount required to fill the voids in the fine aggregate. The excess paste is always equal to the complement of the fine aggregate factor when both are expressed as percentages or equal to 100-(FAF).

10. Coarse Aggregate Factor (CAF) is the loose volume of coarse aggregate in a unit volume of concrete. The coarse aggregate may also be expressed as a percentage of the volume of concrete which is occupied by the loose gravel.

11. Excess mortar is the absolute volume of mortar in excess of the amount required to fill the voids in the coarse aggregate and is equal to 100 - (CAF) when both the excess mortar and the coarse aggregate factor are expressed as percentages.

12. Saturated, Surface Dry Condition: Aggregate is considered to be in a saturated, surface dry condition when its interior voids or permeable pores are completely filled with water and the surfaces of the particles are dry.

13. Free moisture is surface moisture or moisture in excess of the S. S. D. condition contained in the aggregate. The free moisture is calculated as a percentage based upon the weight of the wet aggregate (stockpile condition).

14. Saturated Surface Dry Specific Gravity: The ratio of the weight of saturated, surface-dry aggregate to the bulk volume of the aggregate. The bulk volume of the aggregate is equal to the volume of water displaced by the aggregate in a saturated, surface dry condition.

15. Unit weight of aggregate measured in pounds per cubic foot of the material in a saturated surface-dry, loose condition is intended for use in portland cement concrete mix design.

16. Percent Solids: The values are calculated on the basis of absolute volume as shown in Test Method Tex-405-A. The percent solids is equal to the unit weight of the material divided by (62.5 x specific gravity) and multiplied by 100.

17. Percent Voids: The percent voids in material is equal to 100 minus the percent solids.

18. Absolute or Solid Volume: The absolute volume of a given amount of material is the total volume of the solid portion of that material. Concrete is designed on the basis of absolute or solid volume of the materials.

19. Cement Factor (CF) is the number of sacks of cement used to produce one cubic yard of concrete.

20. Water-Cement Ratio (W/C) is the number of gallons of water used to mix with each sack of cement in the concrete.

21. Yield of concrete is the total volume of concrete produced per sack of cement. See Test Method Tex-417-A for calculations.

22. Workability: The concrete is workable when it contains enough water in addition to the amount required to hydrate the cement to improve the consistency of the mixture so that the concrete can be easily placed and finished without forming honeycomb.

Preliminary Tests

1. Submit representative samples of cement, water, mineral filler and the aggregates to the Materials and Tests Division Laboratory for quality tests prior to beginning of construction.

2. Make all of the necessary determinations on the various aggregates proposed for use in concrete according to the following test methods:

	Determination	Test Method Number
(a)	Screen and Sieve Analysis	Tex-401-A
(b)	Decantation on Coarse Aggregate	Tex-406-A
(c)	Decantation on Fine Aggregate	Tex-406-A
(d)	Organic Impurities of Fine Aggregate	Tex-408-A
(e)	Saturated, Surface Dry Specific Gravity and Absorption of Aggregate	Tex-403-A
(f)	Specific Gravity of Mineral Filler	Tex-202-F
(g)	Unit Weight of Aggregates	Tex-404-A
(h)	Calculate the Percent Solids and Voids in the Aggregates	Tex-405-A

Design Constants

The values used for the design constants are so nearly correct that the small variations have practically no influence on the concrete mixture. The design constants are given below:

(a) Weight of one sack of cement = 94.0 pounds
(b) Volume of one sack of cement = 1 cubic foot
(c) Weight of one cubic foot of water = 62.5 pounds
(d) Weight of one gallon of water = 8.33 pounds
(d) Gallons of water per cubic foot = 7.5 gallons
(f) Specific gravity of water = 1.00
(g) Specific gravity of cement = 3.10

Typical Test Data and Application of Procedure

A. Strength Design Concrete

Conditions

The available materials tested are as follows:

Material	Test Determination	Test Value
Fine Aggregate	S.S.D. Specific Gravity	2.63
" "	Unit Weight S.S.D. loose Lbs./Cu.Ft.	104.7
" "	Percent solids	63.7
" "	Percent voids	36.3
Coarse Aggregate	S.S.D. Specific Gravity	2.60
" "	Unit Wt., S.S.D. loose lbs./Cu.Ft.	99.7
" "	Percent solids	61.4
" "	Percent voids	38.6
Fine Aggr. Factor (FAF) (assumed)		0.85
Coarse Aggr. Factor (CAF) (assumed)		0.80
Water-Cement Ratio, gals./sack of cement (Assumed)		6.5

The absolute volume design for a 1-sack batch is as follows:

1. Volume of Cement $= \frac{94}{62.5 \times 3.10} = 0.485$ cu. ft.

2. Volume of Water $= \frac{6.5}{7.5} = 0.867$ cu. ft.

3. Volume of Paste = 1.352 cu. ft.

4. The absolute volume of the mortar is calculated in two steps:

(a) Design one cubic foot of mortar as follows: The fine aggregate factor is 0.85 or each cu. ft. of mortar contains 0.85 cu. ft. (S.S.D. loose) sand. The volume of cement paste to fill the voids in the sand = 0.85 x 0.363 = 0.3086 cu. ft.
The remainder of the cu. ft. is excess cement paste = 1.00 - 0.85 = 0.1500 cu. ft.
The total cement paste per cu. ft. of mortar = 0.4586 cu. ft.

(b) Calculate the total volume of mortar for the 1-sack batch design:

Volume of mortar = $\frac{1.352}{0.4586}$ = 2.948 cu. ft.

5. Volume of fine aggregate = mortar less paste or 2.948 - 1.352 = 1.596 cu. ft.

6. Calculate the absolute volume of concrete in two parts:

(a) Design one cubic foot of concrete as follows: The coarse aggregate factor is 0.80, or each cu. ft. concrete contains 0.80 cu. ft. (S.S.D. loose) of coarse aggregate. The volume of mortar to fill the voids in the coarse aggregate is equal to 0.80 x 0.386 = 0.3088 cu. ft.

The remainder of the cu. ft. of concrete is excess mortar = 1.00 - 0.80 = 0.200 cu. ft.
The total mortar per cu. ft. of concrete = 0.5088 cu. ft.

(b) Calculate the total volume of concrete for the 1-sack batch design:

Volume of concrete = $\frac{2.948}{0.5088}$ = 5.794 cu. ft.

7. Volume of coarse aggregate equal to the volume of concrete in one sack batch less volume of mortar = 5.794 - 2.948 = 2.846 cu. ft.

8. The yield is equal to the total concrete produced per sack cement = 5.794 cu. ft.

9. Cement Factor = $\frac{27}{5.794}$ = 4.66 sacks per cu. yd. of concrete

10. Convert absolute volume of materials to weight for the one-sack batch design, as follows:

Weight of cement = 0.485 x (62.5 x 3.10) = 94 lbs.
Weight of water = 0.867 x (62.5 x 1.00) = 54.2 #
or $\frac{54.2}{8.33}$ = 6.5 gals.
Weight of fine aggregate = 1.596 x 62.5 x 2.63 = 262.3 lbs.
Weight of coarse aggregate = 2.846 x 62.5 x 2.60 = 462.5 lbs.

11. To determine the weights of materials to use for a large batch, use the yield of concrete for the 1-sack batch and the capacity of the mixer as shown below:

Specification Items 360 and 362-A permit 20 percent overload for a 27-E or larger paver. The capacity of the 27-E paver or size of batch then becomes 32.4 cu. ft. The number of sacks of (bulk) cement to produce 32.4 cu. ft. of concrete = 32.4/5.794 = 5.592

Weight of cement = 94.0 x 5.592 = 526
Weight of water = 54.2 x 5.592 = 303
Weight of fine aggr. = 262.3 x 5.592 = 1467
Weight of crs. aggr. = 462.5 x 5.592 = 2586

The weights of the mineral aggregates are calculated on the basis of saturated-surface dry condition of materials.

B. Specific Cement Factor Design Concrete

Conditions

For this design, the minimum number of sacks of cement per cu. yd. of concrete (CF) and the maximum number of gallons of water per sack of cement are fixed by the specifications.

The available materials tested are as follows:

Material	Test Determination	Test Value
Fine Aggregate	S.S.D. Specific Gravity	2.63
" "	Unit Weight S.S.D. loose #/cu. ft.	104.7
" "	Percent solids	63.7
Coarse "	S.S.D. Specific Gravity	2.60
" "	Unit weight S.S.D. loose #/cu. ft.	99.7
" "	Percent solids	61.4
Water-Cement Ratio gals. / sack cement (given)		6.0
Cement Factor, sacks/cu. yd. concrete (given)		5.0
Coarse Aggregate Factor (assumed)		0.80

Determine the fine aggregate factor.

The method of design for a 1-sack batch is as follows:

1. Absolute volume of concrete = $\frac{27\ (\text{cu. ft.})}{5.0\ (\text{sacks})}$ = 5.400 cu. ft.
2. Loose Volume of coarse aggregate = (yield) x (CAF) = 5.400 x 0.80 = 4.320 cu. ft.
3. Absolute volume of coarse aggregate = loose vol. x % solids, = 4.320 x 0.614 = 2.652 cu. ft.
4. Absolute volume of mortar = (yield) - (vol.CA) = 5.400 - 2.652 = 2.748 cu. ft.
5. Absolute volume of water = $\frac{6.0}{7.5}$ = 0.800 cu. ft.
6. Absolute volume of cement = $\frac{94}{(3.10 \times 62.5)}$ = 0.485 cu. ft.
7. Absolute volume of paste = 1.285
8. Absolute volume of fine aggr. = 2.748 (mortar) - 1.285 (paste) = 1.463 cu. ft.

Yield 5.400 cu. ft.

9. Fine Aggregate Factor =

$$\frac{\text{absolute volume of fine aggregate}}{(\%\text{ solids fine aggr.})\times(\text{abs. vol. mortar})}$$

$$= \frac{1.463}{0.637 \times 2.748} = \frac{1.463}{1.750} = 0.84$$

To convert absolute volume to weight, see the example for strength design.

C. Design for Air-Entrained Concrete

The design for air-entrained concrete can be easily adapted to both the strength design and the specified cement factor design since the absolute volume of the concrete is used as a basis of design. In designing concrete which is to contain entrained air, first make a basic design for normal cement concrete and then alter this design to allow for the air by reducing the volume of the water and sand. The water is reduced because of the increased workability produced by the entrained air. The volume of sand is reduced for the following reasons.

1. The air bubbles have a tendency to form on the sand and sometimes cause the air content to be very high if the amount of sand is not reduced.

2. With the full amount of sand together with the added air, the batch appears to become over sanded.

3. A portion of the sand is removed to compensate for part of the volume of air so that the yield of concrete will remain the same.

Conditions

Assume that the basic design for a 5-sack per cubic yard of concrete batch is the same as illustrated in Section B for Specified Cement Factor Concrete. The details of the normal batch design will not be repeated but the absolute volumes for a 1-sack batch design are given below.

Materials	Absolute Volumes
Cement	0.485 cu. ft.
Water	0.800 cu. ft.
Fine Aggregate	1.463 cu. ft.
Coarse Aggregate	2.652 cu. ft.
Yield of Concrete =	5.400 cu. ft.

1. In order to adjust this batch design for the volume of entrained air, an air content must be assumed. The specifications allow for an air content of 3 to 6 percent of the volume of concrete. Estimate and design for 4% air. The absolute volume of air = 5.400 (yield) x .04 = 0.216 cu. ft.

2. The results obtained and experience gained from research done with concrete containing various types of entraining agents indicate that the amount to reduce the water for average conditions is approximately 40% of the air content. Absolute volume of water = 0.800 - (0.216 x 0.4) = 0.7136 cu. ft.

3. The volume of the coarse aggregate remains the same and the volume of the fine aggregate is reduced to maintain the same yield as the normal batch.

		1-Sack Batch
Absolute volume of cement =	0.4850	0.4850
" " " water =	0.7136	0.7136
" " " air =	0.2160	0.2160
" " " crs. aggr. =	2.6520	2.6520
	4.0666	
Abs. Vol. of fine aggregate = 5.400 - 4.0666 =		1.3334
Yield =		5.4000

These volumes multiplied by solid weights per cubic foot will give the batch weights to produce 5.4 cubic feet of concrete per sack of cement if the air content is exactly 4%, but the air content usually varies from the assumed value. In this illustration, suppose the air content measured as described in Test Method Tex-416-A was equal to 4.5%. The actual yield with 4.5% air $= \frac{5.400 - 0.216}{95.5} \times 100 = 5.428$ cu. ft.

Cement factor $= \frac{27}{5.428} = 4.97$ sacks per cu. yd. of concrete.

Water-cement ratio = 0.7136 x 7.5 = 5.35 gallons per sack.

Trial Batches

Prepare trial mixtures of concrete to observe the workability and to determine the various control factors required in the specifications as outlined below:

Determination	Test Method No.
1. Slump of Concrete	Tex-415-A
2. Air Content of Concrete	Tex-416-A
3. Unit Weight of Concrete	Tex-417-A
4. Compressive Strength	Tex-418-A
5. Flexural Strength	Tex-420-A

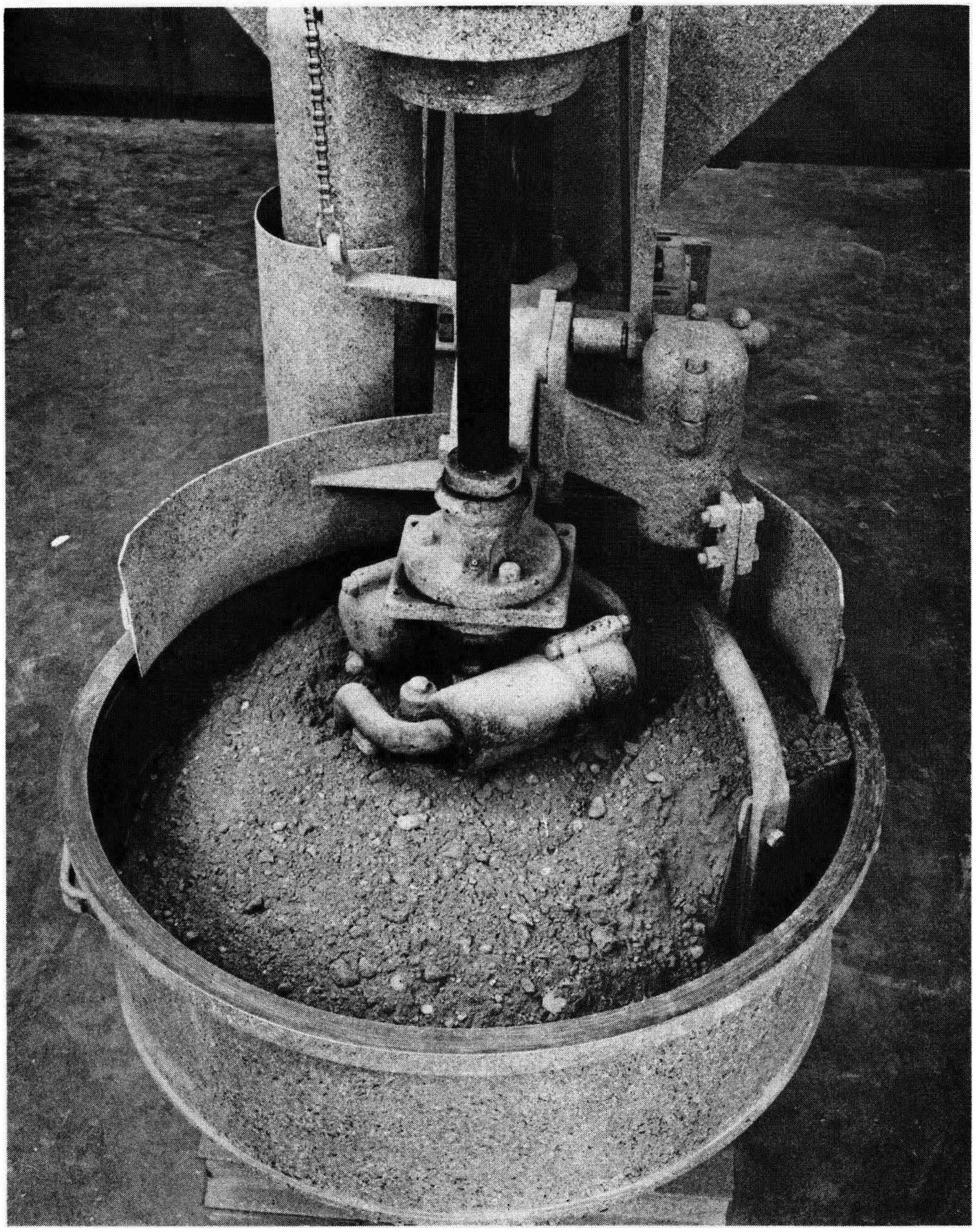
Notes

1. The cementing properties of the cement paste are greatly affected by the amount of mixing water used. The strength of the concrete decreases as the water-cement ratio increases, other factors

which influence the strength remaining the same. For a given consistency of concrete a lean mixture requires a higher water-cement ratio than a rich mixture of concrete.

2. Excess paste and excess mortar tend to separate and lubricate the particles of aggregate to improve the plasticity and cohesiveness of the concrete.

3. Air-entraining admixtures are used to improve the workability and durability of the concrete. The air content of the concrete may be altered by the type of mixer used, the speed at which it is operated and the volume of concrete batch mixed in addition to the amount of air-entraining material recommended by the manufacturer.



Test Method Tex-415-A
Rev: September 1966

Texas Highway Department

Materials and Tests Division

SLUMP OF PORTLAND CEMENT CONCRETE

Scope

This test method, which is a slight modification of A.S.T.M. Designation: C 143, describes a procedure for determining the slump of freshly mixed concrete by means of a slump cone both in the laboratory and in the field.

Apparatus

1. Mold: A slump cone made of metal not readily attacked by the cement paste and in the form of a truncated cone with the base 8 inches in diameter, the top 4 inches in diameter and 12 inches in height. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The cone is provided with foot pieces and handles as shown in Figure 1.

2. Tamping rod: A straight steel rod 5/8 inch in diameter and approximately 24 inches in length, having one end rounded to a hemispherical tip, the diameter of which is 5/8 inch.

Figure 1

3. Small hand-scoop

4. A rule graduated in 1/8-inch increments

Sample

The sample of concrete from which the test specimens are made shall be representative of the entire batch and secured immediately after mixing operations have been completed. The sample may be obtained at the mixer or after the concrete has been placed on the roadway.

Procedure

1. Dampen the slump cone and place it on a level, rigid surface. Hold the slump cone down firmly while placing, rodding and finishing the concrete.

2. Use the small hand-scoop to place the concrete into the mold. Immediately after mixing, carefully fill the slump cone in three layers, each layer occupying approximately one-third the volume of the mold, in such a manner as to secure a uniform distribution of the concrete. (Figure 2)

3. Rod each layer with 25 strokes of the tamping rod distributing the strokes uniformly over the cross-section of each layer. For the bottom layer rod the material throughout the full depth. Rod the second layer and top layer each throughout its depth so that the rod just penetrates into the underlying layer.

4. After the top layer has been rodded, use the tamping rod as a straight edge and strike off the surface of the concrete level with the top of the mold. Remove the slump cone immediately from the concrete by raising it carefully in a vertical direction. Do not jerk the mold or vibrate the test specimen. (Figure 3)

5. Measure the slump of the concrete by determining the difference between the height of the mold and the height over the original center of the base of the specimen. Place the mold on a level with the base of the specimen and lay the rod horizontally across the top of the mold so that it extends over the center of the specimen. Measure the distance from the bottom of the rod to the top of the specimen to the nearest 1/4-inch. Record this measurement as the slump of the concrete. (Figure 4)

Notes

When there is a considerable amount of coarse aggregate over 2 in. in size in concrete, remove the oversize particles before making the test for slump.

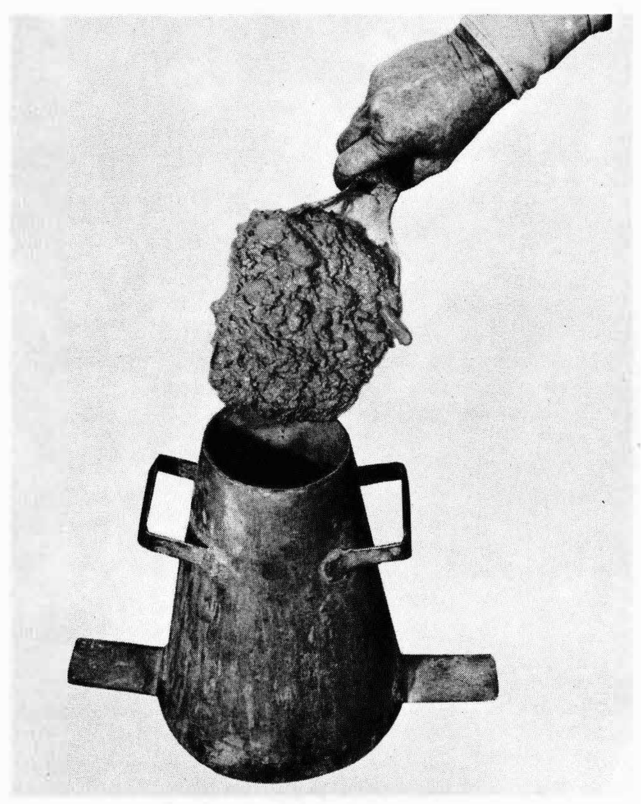


Figure 2

Figure 3

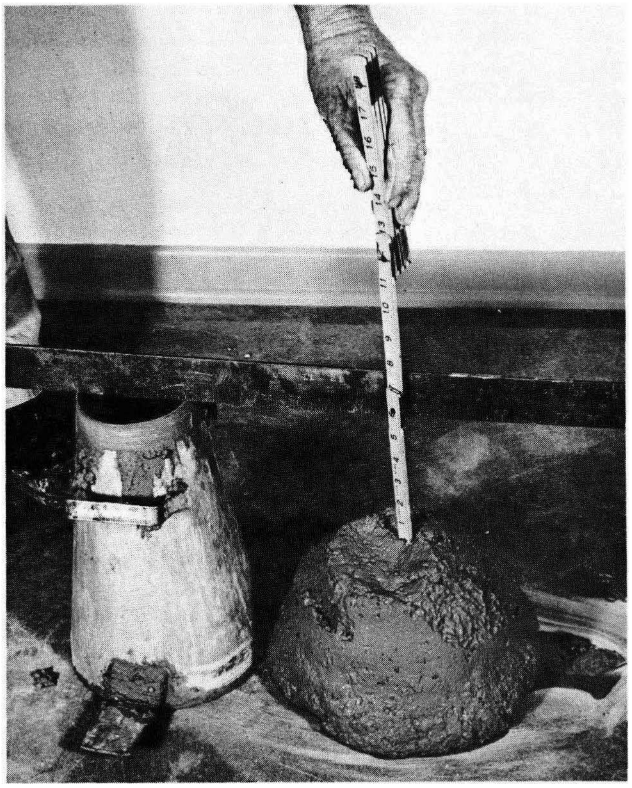


Figure 4

Test Method Tex-416-A
Rev: September 1966

Texas Highway Department

Materials and Tests Division

AIR CONTENT OF FRESHLY MIXED CONCRETE

Scope

This test method covers procedures for determining the air content of freshly mixed concrete by both the gravimetric and pressure methods. Although detached instructions for operating each type of pressure meter are usually enclosed in the case in which the instrument is stored, a detailed procedure employing a pressure type meter is described.

Apparatus

The apparatus consists of the following items:

A. Gravimetric Method

1. A heavy duty balance of 80 pounds capacity sensitive to 0.1 pound with weights.
2. Tamping rod, a straight steel rod 5/8-inch in diameter and about 24 inches long with one end rounded to a hemispherical tip.
3. A calibrated measure: A cylindrical metal measure having a capacity of 1/2 cubic foot. The container shall be watertight with top and bottom parallel to each other and smooth. The measure preferably should be machined on the inside to accurate dimensions of 10.0 inch diameter and 11.0 inch height, and made of metal sufficient in thickness to resist deformation under rough usage.
4. Small hand scoop.
5. A metal straight-edge 18 inches in length and about 2 inches wide.

B. Volumetric Method

1. An Air Meter consisting of a bowl and a top section conforming to the requirements of ASTM Designation: C-173. The bowl shall be of machined metal and shall be sufficiently rigid to withstand normal field use. It shall have a diameter equal to one to 1.25 times the height. The top section shall have a capacity approximately equal to the bowl and shall be equipped with a flexible gasket and with hooks or lugs to attach to the flange on the bowl to make a watertight connection. It shall be equipped with a transparent neck graduated in increments not greater than 0.5 percent from 0 at the top to 9 percent, or more, of the volume of the bowl. The upper end of the neck shall be threaded and equipped with a screw cap and gasket to make a watertight fit.
2. A metal funnel with a spout of a size permitting it to be inserted through the neck of the top section and long enough to extend to a point just above the bottom of the top section.
3. Tamping Rod, a straight steel rod 5/8-inch in diameter and about 24 inches long with one end rounded to a hemispherical tip.
4. A metal straight-edge 18 inches in length and about 2 inches wide.
5. A metal cup having a capacity equal to 1.0 percent of the volume of the bowl of the air meter.
6. Rubber syringe bulb.
7. A metal or glass pouring vessel of approximately 1-quart capacity.
8. A blunt-nosed brick mason's trowel.
9. Small hand scoop.

C. Pressure Method

1. Pressure Meter: A calibrated pressure type meter meeting the requirements of ASTM Designation: C-231. Figure 1.
2. A blunt-nosed brick mason's trowel.
3. Tamping Rod, a straight steel rod 5/8-inch in diameter and about 24 inches long with one end rounded to a hemispherical tip.

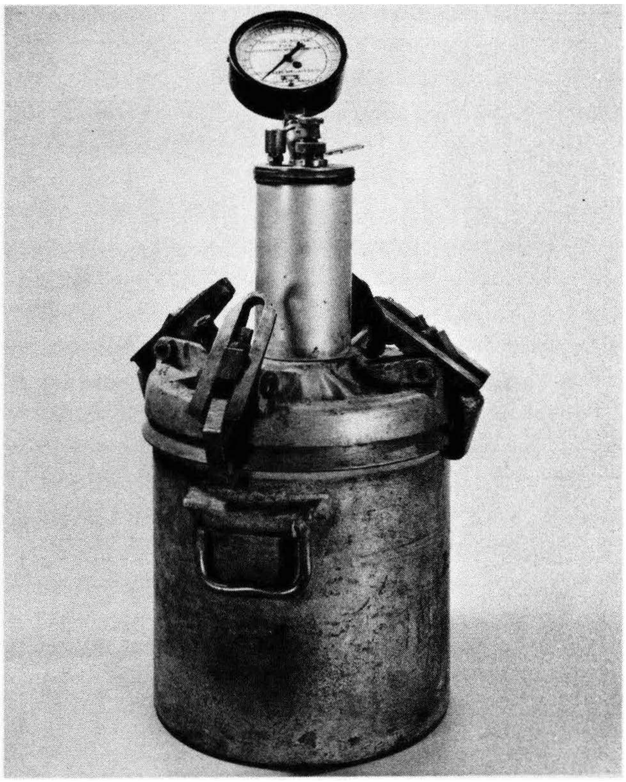


Figure 1

4. A metal straight-edge 18 inches in length and about 2 inches wide.

5. A rubber or rawhide mallet.

6. A pouring vessel of approximately 1/2 gallon capacity.

7. A specially formed circular collar to fit into and extend over the side of the measuring bowl of the meter for catching any mortar which might overflow from the bowl. (optional)

8. Small hand scoop.

Preparation of Sample

Design and mix the concrete in accordance with Test Method Tex-414-A.

Test Procedure

A. Gravimetric Method

1. Use the calibrated measure or the bowl of the pressure meter and determine the unit weight (U_c) of the freshly mixed concrete as specified in Test Method Tex-417-A.

Calculations

1. Calculate the total absolute volume of the concrete in the batch in cubic feet from the following expression:

$$V_A = \frac{W_c}{G_c \times 62.5} + \frac{W_f}{G_f \times 62.5} + \frac{W_w}{62.5} + \frac{94N}{3.10 \times 62.5}$$

Where:

V_A = Total absolute volume of the component ingredients in the batch of concrete

G_c = S.S.D. specific gravity of the coarse aggregate

G_f = S.S.D. specific gravity of the fine aggregate

G_w = Specific gravity of water is assumed to be 1.00

3.10 = an average value for specific gravity of cement

Where:

W_c = total weight (pounds) of S.S.D. coarse aggregate

W_f = total weight (pounds) of S.S.D. fine aggregate

W_w = total weight (pounds) of mixing water added to batch

N = number of sacks of cement in batch

94 pounds = net weight of a sack of cement

2. The theoretical unit weight of the concrete in pounds per cubic foot is, customarily, a laboratory determination and the value is assumed to remain constant for all batches made using identical materials and proportions.

The value is calculated from the formula:

$$U_T = \frac{W}{V_A}$$

U_T = the theoretical unit weight of concrete, in pounds per cubic foot, calculated on an air-free basis

V_A = total absolute volume of concrete

$W = W_c + W_f + W_w + (N \times 94)$ = total weight of the component ingredients in the batch of concrete in pounds.

3. Calculate the air content of the concrete as follows:

$$A = \frac{U_T - U_c}{U_T} \times 100$$

A = Air content in the concrete

U_c = The actual unit weight of concrete in pounds per cu. ft.

B. Volumetric Method

Calibration of Volume Type Meter

1. The volume of the bowl of the air meter, in cubic feet, shall be determined by accurately weighing the amount of water required to fill it, and dividing this weight by the unit weight of water at the temperature of calibration. (See Tex-404-A, Table I) A glass cover plate shall be used to cover the bowl to remove excess water and to insure that the container is full.

2. The accuracy of the graduations on the neck of the air meter shall be determined by filling the assembled measuring bowl and top section with water to the level of the mark for any convenient air content. A quantity of water equal to 1.0 percent of the volume of the bowl shall be added to the water already in the neck. The height of the water column shall be increased by an amount equivalent to 1.0 percent of air.

3. The volume of the measuring cup shall be checked by adding one cupful of water to the assembled apparatus in the manner described above. Such addition shall increase the height of the water column by an amount equivalent to 1.0 percent of indicated air.

Test Procedure

1. Using the scoop, aided by the trowel if necessary, fill the bowl with freshly mixed concrete in three layers of equal depth. Rod each layer 25 times with the tamping rod, and tap the sides of the bowl 10 to 15 times after each rodding.

2. After placement of the third layer of concrete, strike off the excess concrete with the straight edge until the surface is flush with the top of the bowl. Wipe the flange of the bowl clean.

3. Clamp the top section into position on the bowl, insert the funnel, and add water until it appears in the neck. Remove the funnel and adjust the water level, using the rubber syringe, until the bottom of the meniscus is level with the zero mark. Attach and tighten the screw cap.

4. Invert and agitate the unit until the concrete settles free from the base; and then, with the neck elevated, roll and rock the unit until the air appears to have been removed from the concrete. Set the apparatus upright, jar it lightly, and allow it to stand until the air rises to the top. Repeat the operation until no further drop in the water column is observed.

5. When all the air has been removed from the concrete and allowed to rise to the top of the apparatus, remove the screw cap. Add, in small increments, one measuring cupful of isopropyl alcohol, using the syringe to dispel the foamy mass on the surface of the water.

6. Make a direct reading of the liquid in the neck, reading to the bottom of the meniscus, and estimating to the nearest 0.1 percent.

7. Calculate the air content of the concrete in percent by adding to the reading the amount of alcohol used.

C. Pressure Method

Calibration of Pressure Type Meter

The volume of the base and the initial pressure line are predetermined by the manufacturer. The calibration of the meter may be checked as follows:

1. Remove the detachable cover and pressure-tight chamber assembly from the measuring bowl or base and screw the short piece of straight tubing into the threaded petcock hole on the underside of the cover.

2. Fill the bowl full of water and clamp the cover on the bowl with the tube extending down into the water.

3. With both petcocks open, add water with the rubber syringe through the petcock having the tube extension below until all of the air is forced out the opposite petcock. Leave both petcocks open.

4. Pump up air pressure to a little above the predetermined initial pressure line. Wait a few seconds for the compressed air to cool to normal temperature and then adjust the pressure gauge reading at the proper initial pressure line by means of the built-in pump or by bleeding off air as needed.

5. Close both petcocks and immediately press down on the center thumb lever to exhaust air into the measuring bowl. Wait a few seconds until the needle on the pressure gauge is stabilized. If all of the air was eliminated and the initial pressure line was correctly selected, the gauge should read zero percent. If two or more check tests show a consistent variation from 0% in the result, then change the initial pressure line to compensate for the variation. Use the newly established pressure reading for subsequent tests.

6. Screw the curved tube into the outer end of petcock and by pressing on thumb lever and controlling flow of water with petcock lever, fill the 5% calibrating vessel (345 ml.) level full of water from the measuring bowl.

7. Release the air by opening the free petcock. Open the other petcock and allow the water in the curved pipe to flow back into the bowl. The bowl now contains 5% air in addition to the water.

8. With petcocks open, apply pressure and set the proper initial pressure reading in exactly the same manner as outlined in step 4. Close the petcocks and immediately exhaust the air into the bowl by means of the thumb lever. After a few seconds wait, the dial gauge should now indicate 5% air.

9. Repeat the operations given above in paragraphs 6 through 8 to check the instrument for results at 10%, 15% and 20% air. Remove the tubes from the petcocks.

Test Procedure

1. Set the circular collar into the top of the measuring bowl. The collar aids in keeping the exterior of the bowl clean by catching or deflecting the material which overflows the side.

2. Place a representative sample of the concrete in the measuring bowl in three equal layers. Consolidate each layer with 25 strokes of the tamping rod and by lightly tapping the exterior of the bowl 10 to 15 times. Rod each layer throughout the full depth using only enough force to cause the rod to penetrate the surface of the underlying layer. Remove the collar and strike off the excess concrete, by means of the metal straight edge, level with the top of the bowl.

3. Fasten the cover and pump assembly securely on the measuring bowl with petcocks open.

4. Use the rubber syringe to inject water through one petcock until all of the air in the meter above the concrete is expelled through the opposite petcock. Leave petcocks open.

5. Apply pressure by means of the built-in pump to set the gauge needle on the predetermined initial pressure line. Wait a few seconds for the temperature of the compressed air to equalize and then adjust the needle to proper position.

6. Close both petcocks and press down the thumb lever to release the air into the bowl. Hold the thumb lever down for a few seconds while lightly tapping the gauge with finger.

7. Read the percent of air entrained in the concrete on the dial. Open the petcocks to release the pressure and then remove cover. Clean the bowl, cover and petcock openings.

Determination of Correction Factor for Lightweight Aggregate and Slag

1. Design and mix a batch of concrete containing lightweight aggregate without adding the air entraining agent. Determine the air content of a sample of this mixture by one of the methods outlined above.

2. Subtract this value from the air content determined for the concrete mixture containing air entraining material and the same aggregates and cement used before.

Test Method Tex-417-A

Rev: September 1966

Texas Highway Department

Materials and Tests Division

WEIGHT PER CUBIC FOOT AND YIELD OF CONCRETE

Scope

Part I of this test method, which is a modification of A.S.T.M. Designation: C 138, covers the procedure for determining the weight per cubic foot of freshly mixed concrete and provides formulas for calculating the volume of concrete produced from a mixture of known quantities of the component materials and the yield in terms of the volume of concrete per unit volume of cement.

Part II describes the procedure for determining the weight per cubic foot of air dried concrete.

PART I

WEIGHT PER CUBIC FOOT AND YIELD OF CONCRETE

Apparatus

The apparatus shall consist of the following:

1. A heavy duty balance of 80 pounds capacity sensitive to 0.01 pound and mounted on a platform as shown in Figure 1 of Test Method Tex-404-A. A set of weights which includes an additional 5-pound weight (ratio of balance is equal to 5 to 1).

2. A 1/2 cubic foot measure: A cylindrical metal measure with inside diameter 10.0" and inside height of 11.0", provided with a handle. The container shall be watertight with top and bottom true and even preferably machined to accurate dimensions on the inside and of sufficient rigidity to retain its form under rough usage. Calibrate the measure by accurately determining the weight of water at a convenient temperature (°F) that is required to fill the measure as specified in Test Method Tex-404-A and calculate the factor (F) for the measure.

3. Tamping rod: A straight steel rod 5/8 inch in diameter and approximately 24 inches in length with one end rounded to a 5/8-inch diameter hemispherical tip.

4. A steel straight-edge 18 inches in length and about 2 inches wide.

5. Small hand-scoop.

Sample

The sample of freshly-mixed concrete for the unit weight determination shall be representative of the entire batch and obtained immediately after mixing operations have been completed.

Procedure

1. Immediately after mixing, carefully fill the calibrated measure to one-third of its capacity by distributing the concrete uniformly over the bottom of the container. Rod the concrete throughout the full depth of the material with 25 strokes of the tamping rod, distributing the strokes evenly over the surface of the layer. Tap the exterior surface of the measure lightly 10 to 15 times or until no large air bubbles appear on the surface of the rodded concrete.

2. The measure shall then be filled to two-thirds of its capacity and the concrete again rodded and tapped as described before. When rodding the second and third layers, do not allow the rod to penetrate far into the underlying concrete.

3. Finally, fill the measure to overflowing with concrete and repeat the above rodding and tapping operations.

4. After consolidation of the concrete, use the straight edge to strike off the surface of the concrete level with the top of the measure. Clean the exterior of the measure and weigh to obtain the net weight of concrete to the nearest 0.01 pound.

Calculations

1. Calculate the actual unit weight of concrete in pounds per cubic foot as follows:

$$U_c = WF$$

Where:

U_c = Unit weight of concrete in pounds per cubic foot

W = Net weight of concrete in measure (pounds)

F = Factor for the measure (reciprocal of volume)

2. Calculate the actual volume of concrete produced per batch from the following formula:

$$V_c = \frac{W_c + W_f + W_w + (N \times 94)}{U_c}$$

Where:

V_c = Volume of concrete produced per batch in cubic feet

W_c = Total weight (pounds) of S. S. D. coarse aggregate
W_f = Total weight (pounds) of S.S.D. fine aggregate
W_w = Total weight (pounds) of mixing water added to batch
N = Number of sacks of cement in batch

94 pounds = net weight of a sack of cement.

3. Calculate the yield of concrete as follows: '

$$\text{Yield} = \frac{V_c}{N}$$

Yield is the total concrete produced per sack of cement

V_c = Actual volume of coarse aggregate, fine aggregate, cement and water used in the batch of concrete
N = Number of sacks of cement per batch

PART II

WEIGHT PER CUBIC FOOT OF AIR DRIED CONCRETE

This procedure describes the determination of the weight per cubic foot of air dried concrete. The value is used for compliance with the specifications and in dead load determinations.

Procedure

1. At the time pilot designs are being made and compressive specimens are being prepared, one to three extra specimens should be made for this unit weight determination. Cure these specimens in the normal manner (three to seven days depending upon the type of cement used). At the end of the curing period remove the specimens from the curing tank or room and allow them to air-dry at room temperature until twenty-eight days of age.

2. Weigh the specimens to the nearest 0.01 pound.

3. Measure the specimens as accurately as possible, using an average of at least three measurements for all values.

4. The weight per cubic foot is the weight of the specimen divided by the volume as determined from the measurements.

Note

It is preferred that the air drying be performed in a field laboratory building or office. The specimens should be kept where they will not be subjected to moisture change or direct sunshine.

Test Method Tex-418-A
Rev: September 1966

Texas Highway Department

Materials and Tests Division

COMPRESSIVE STRENGTH OF MOLDED CONCRETE CYLINDERS

Scope

This method covers a procedure for molding, curing and testing cylindrical test specimens of concrete for compressive strength. This compressive strength test also applies to cores taken from hardened concrete in structures or concrete pavement.

Apparatus

1. Molds: Cylindrical steel molds with 6 inches inside diameter and 12 inches in height made from seamless steel tubing split along one element and fitted with two bolts for closing, the ends preferably machined true and even so that the axis of the mold is at right angles to the base plate. The molds are fastened to a metal base plate by means of clamps or bolts. The assembled mold and base plate shall be watertight and lightly greased or oiled before use.

2. Tamping rod: A straight steel rod 5/8-inch in diameter and approximately 24 inches in length having one end rounded to a 5/8-inch diameter hemispherical tip.

3. Small hand-scoop

4. Steel straightedge, 18 inches in length and about 2 inches wide.

5. Trowel

6. A micrometer caliper for measuring the diameter of test cylinder, or a Grant Area-Meter for determining the cross-sectional area of specimens directly in square inches.

7. Testing Machine: The Materials and Tests Division uses both Baldwin-Tate-Emery and Southwark-Emery testing machines which meet the requirements of A.S.T.M. Designation: E4 and have been approved by the Bureau of Public Roads Reference Laboratory.

8. Curing tank containing water maintained at a temperature of 70°F to 90°F.

9. Supply of burlap or cotton mats

Test Record Forms

Record cylinder identification and test data on concrete cylinder work sheet, Form No. 383, and report the test results in pounds per square inch on Form No. 197. Record all information for cores taken from hardened concrete on Form No. 400 and report the corrected compressive stress on Form No. 106.

Procedure

1. Set the assembled watertight mold, which has been lightly greased, on a firm level surface.

2. Form the test cylinder by placing the concrete in the mold in three layers of approximately equal volume. In placing each scoopful of concrete move the scoop around the top edge of the mold as the concrete slides from it in order to prevent the segregation of the particles and to secure a uniform distribution of concrete in each layer. All particles of aggregate larger than 2 inches in size should be removed. Rod each layer 25 times with the rounded end of the tamping rod, distributing the strokes uniformly over the cross-section of the mold. Rod each layer using only enough force to cause the rod to penetrate slightly into the underlying layer. When voids are left by the tamping rod, tap the sides of the mold lightly to close the voids.

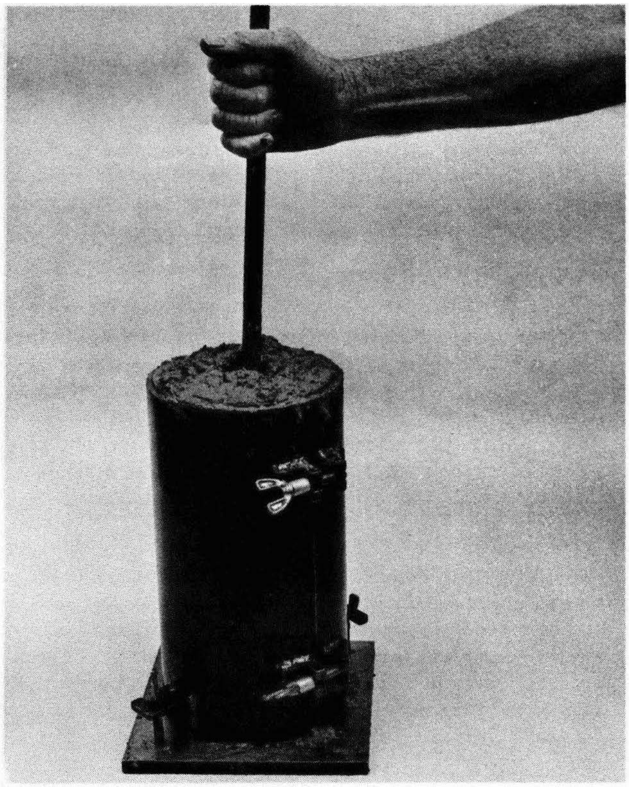


Figure 1

3. Use the steel tamping rod or finishing trowel to strike off the excess concrete level with the top of the mold and smooth the top surface of the cylinder with a trowel.

Curing Specimens

4. In the Field

(a) Storage conditions during the first 24 hours have an important influence on the strength developed in concrete. During the first 24 hours all test cylinders shall be stored under conditions that prevent loss of moisture from the specimens and the temperature adjacent to the cylinder maintained at 70°F to 90°F. Immediately after forming the cylinders, cover them with several thicknesses of wet burlap or wet cotton mats and keep the covering thoroughly saturated until the cylinders are removed from the molds. Approximately 24 hours after the cylinder is made, transport the cylinder in the mold to the field laboratory. Remove the base and mold being careful not to damage the test cylinder. Place the cylinder in the curing tank and keep immersed in water maintained at a temperature of 70°F to 90°F. The cylinders shall not be exposed to a stream of flowing water.

(b) Test cylinders for determining when a structure may be put into service or if the governing specifications require that the cylinders be cured in the same manner as certain members of the structure, such as prefabricated concrete piles and beams, shall receive the same protection from the elements as is given to the concrete they represent.

(c) The test specimens should be cured in the field for at least three-fourths of the test period. The cylinders should then be carefully wrapped in wet paper, then sewed in wet burlap or sealed in a plastic bag for shipment to the Austin Division Laboratory.

5. In Laboratory

(a) From two to four hours after forming the test cylinder cover the mold with a piece of glass 8" x 8" in size, and allow to set undisturbed for at least 24 hours. Then remove the mold and place the cylinder in the damp room to cure under conditions of controlled temperature of 70° F to 76° F and 100% humidity for the specified period of time.

(b) Place concrete cores taken from hardened concrete in water and keep immersed at least 48 hours before capping. If the test specimens cored from concrete are uneven on the bottom, use a masonry saw or hammer and chisel to smooth the surface to approximately right angles to the axis of the core.

6. The concrete test cylinders and cores are measured to determine the height and cross-section area.

7. The ends of all compression test specimens are capped with suitable capping material to obtain smooth plane bearing surfaces. The capping material is mixed to a stiff paste and applied to the cylinders allowing ample time for hardening before testing the cylinder. The adhesion of the paste to the glass capping plate and steel base plate may be avoided by coating the plates with a thin covering of oil or grease. A small portion of the prepared paste is placed on the base plate. The cylinder is held in a vertical position over the paste and pressed down against the base plate causing the paste to spread out underneath the cylinder. About an equal amount of paste is then placed on top of the cylinder and smoothed into a thin layer by pressing the glass plate down on top of the cylinder and paste. The caps shall be made as thin as practicable and shall not break or flow when the specimen is tested.

8. Place the plain bearing block, with its hardened face up, on the platen of the testing machine directly under the spherically seated upper bearing block. Place the test specimen on the lower bearing block and carefully align the axis of the test cylinder with the center of the upper bearing block. As the spherically seated block is brought to bear on the cylinder, rotate its movable part by hand to obtain uniform seating.

9. Apply the load continuously and without shock. Test the specimen at a constant rate of loading within the range of 20 to 50 p.s.i. per second. Increase the load until the specimen fails, and record the maximum load applied to the test cylinder.

Calculations

1. Calculate the compressive strength of concrete as follows:

$$S = \frac{P}{A}$$

Where:

S = Unit compressive stress in pounds per square inch
P = Total load applied, in pounds
A = Cross-sectional area of specimen in square inches

2. Correct the unit compressive strength of concrete cores by use of the following expression:

$$S = \frac{P}{A} F$$

Where:

F = Correction Factor for H/D ratio.

If the ratio of the height to diameter of a core taken from hardened concrete is appreciably less than two, allowance for the ratio H/D shall be made by multiplying the compressive strength by the applicable correction factor given in Table I.

Notes

The load in the compressive test should be made in the same direction in which the concrete was compacted in the test cylinder.

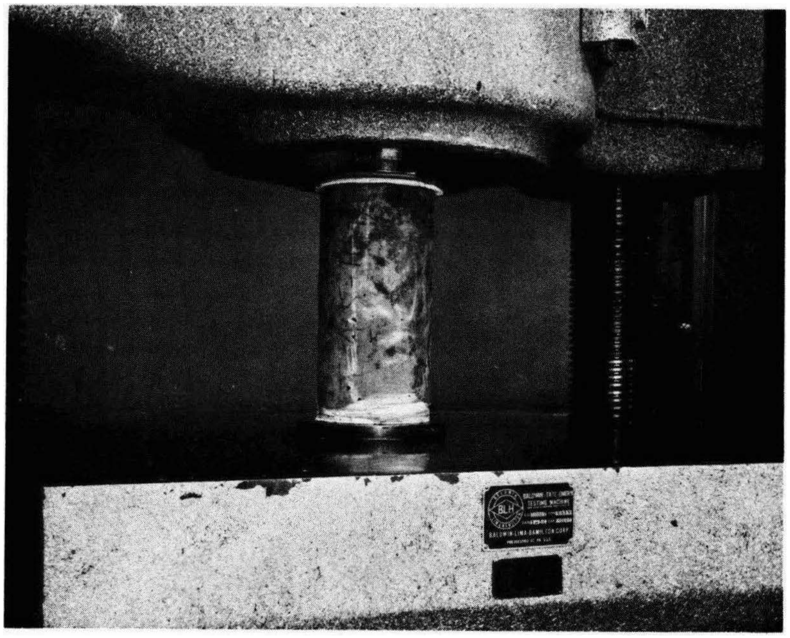


Figure 2

TABLE I

H/D FACTORS

H/D	FACT.	H/D	FACT.	H/D	FACT.	H/D	FACT.	H/D	FACT.
0.80	.735	1.09	.895	1.38	.957	1.67	.976	1.96	.997
0.81	.740	1.10	.900	1.39	.958	1.68	.977	1.97	.998
0.82	.745	1.11	.902	1.40	.959	1.69	.977	1.98	.998
0.83	.750	1.12	.907	1.41	.960	1.70	.978	1.99	.999
0.84	.760	1.13	.910	1.42	.960	1.71	.978	2.00	1.000
0.85	.765	1.14	.914	1.43	.961	1.72	.978	2.01	1.001
0.86	.770	1.15	.916	1.44	.962	1.73	.979	2.02	1.002
0.87	.780	1.16	.920	1.45	.963	1.74	.979	2.03	1.003
0.88	.785	1.17	.922	1.46	.964	1.75	.980	2.04	1.003
0.89	.790	1.18	.925	1.47	.964	1.76	.981	2.05	1.004
0.90	.795	1.19	.928	1.48	.965	1.77	.982	2.06	1.005
0.91	.800	1.20	.930	1.49	.966	1.78	.982	2.07	1.006
0.92	.805	1.21	.932	1.50	.966	1.79	.983	2.08	1.006
0.93	.815	1.22	.934	1.51	.967	1.80	.984	2.09	1.007
0.94	.820	1.23	.936	1.52	.968	1.81	.985	2.10	1.008
0.95	.825	1.24	.938	1.53	.968	1.82	.985	2.11	1.009
0.96	.830	1.25	.940	1.54	.969	1.83	.986	2.12	1.010
0.97	.835	1.26	.941	1.55	.970	1.84	.987	2.13	1.010
0.98	.840	1.25	.943	1.56	.970	1.85	.988	2.14	1.011
0.99	.845	1.28	.944	1.57	.971	1.86	.989	2.15	1.012
1.00	.850	1.29	.946	1.58	.972	1.87	.990	2.16	1.013
1.01	.855	1.30	.947	1.59	.972	1.88	.990	2.17	1.014
1.02	.860	1.31	.948	1.60	.972	1.89	.991	2.18	1.014
1.03	.865	1.32	.950	1.61	.973	1.90	.992	2.19	1.015
1.04	.870	1.33	.951	1.62	.974	1.91	.993	2.20	1.016
1.05	.875	1.34	.952	1.63	.974	1.92	.993	2.21	1.017
1.06	.880	1.35	.953	1.64	.975	1.93	.994	2.22	1.018
1.07	.885	1.36	.954	1.65	.975	1.94	.995	2.23	1.019
1.08	.890	1.37	.956	1.66	.976	1.95	.996	2.24	1.020

Test Method Tex-421-A

Rev: October 1963

Texas Highway Department

Materials and Tests Division

DETERMINATION OF MODULUS OF ELASTICITY OF CONCRETE

Scope

This test method describes the procedure for determining the modulus of elasticity of concrete by means of a compressometer.

Definition

The modulus of elasticity is defined as the ratio of normal stress to corresponding strain for compressive stresses below the proportional limit of the concrete.

Apparatus

1. Compressometer: The compressometer (Figure 1) consists of two circular metal bands each provided with three set screws for fastening the instrument onto the test specimen. The three spacer rods hold the bands in position so that each pair of set screws will press against the same element of the specimen and be located 10 inches apart, making the effective height for the measurement of deflection of the test cylinder exactly 10 inches. The device is equipped with two micrometer dial gauge assemblies for measuring deflection of the cylinder.

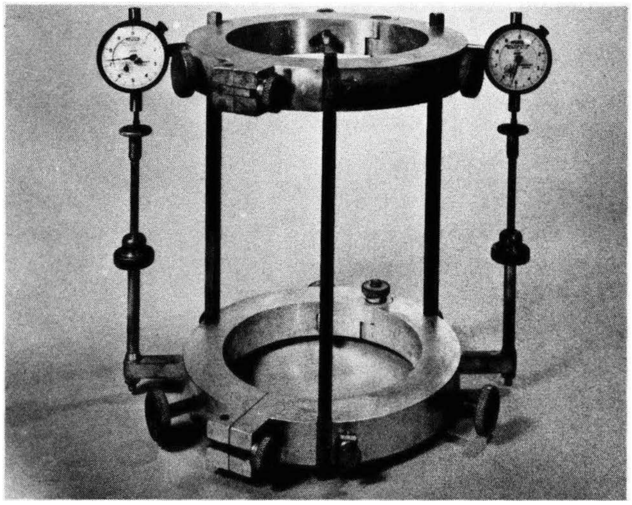


Figure 1

2. Testing Machines: The Materials and Tests Division uses both the Baldwin-Tate-Emery and Southwark-Emery testing machines. The machines are regulated to apply the load at a rate within the range of 20 to 50 p. s. i. per second.

Test Record Forms

Record the test data and results on Form D9-A-4 "Concrete Cylinder Work Sheet Modulus of Elasticity".

Preparation of Test Specimens

Prepare, cure and cap the ends of the required number (usually 4) of concrete test cylinders 6 inches in diameter and 12 inches in height for each design mixture as described in Test Method Tex-418-A.

Procedure

1. Very carefully measure the test cylinder and determine the cross-sectional area (A).

2. Test one specimen in compression as described in Test Method Tex-418-A to obtain the ultimate compressive strength of the concrete. Use this value to estimate the maximum safe load to apply to cylinders used in determining the modulus of elasticity in order not to damage the compressometer due to broken cylinder.

3. Attach the compressometer firmly to the concrete test cylinder and center the cylinder in the testing machine, Figure 2. Remove the three spacer rods and adjust the two micrometer dial gauges to indicate a zero reading.

4. With the testing machine adjusted to maintain a constant speed (applied loading of 35 p. s. i. per second), apply a load of approximately 10,000 pounds and then carefully and slowly release the load. Repeat this operation several times to have the dial gauges set exactly on zero and to remove any slack or irregularity that might exist in the assembly.

5. Operate the testing machine at the rate specified above and read the dial gauges at increments of load of 5,000 pounds for the first 50,000 pounds; then at intervals of 10,000 pounds, until the maximum safe loading has been reached. Record the deflection to the nearest 1/10,000 inch as h. Release the load and remove test cylinder.

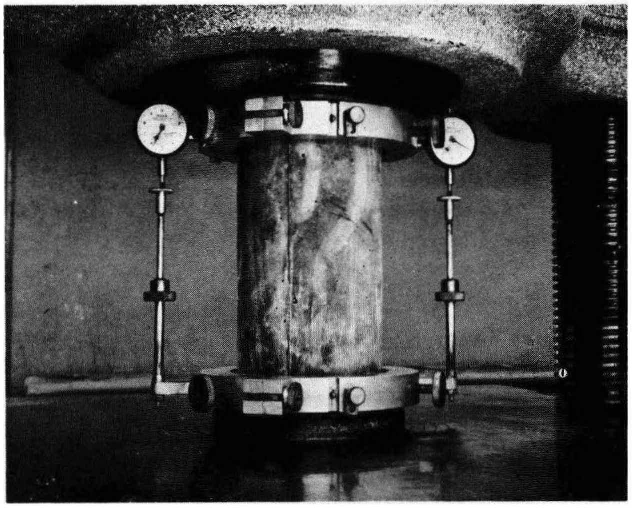


Figure 2

Calculations

1. Calculate the unit stress for the various loads as follows:

$$s = \frac{P}{A}$$

Where:

P = Applied load in pounds

A = Area of test cylinder in square inches

2. Calculate the modulus of elasticity, E, as a ratio of the unit stress to the unit deformation. Since the effective height of specimen is exactly 10 inches, the unit deformation, for the respective loadings, is equal to one-tenth of the dial gauge reading. Use the following expression:

$$E = \frac{s}{d}$$

Where:

E = Modulus of elasticity in pounds per square inch

s = The unit stress in pounds per square inch

$d = \frac{h}{10}$ = corresponding deformation per unit length in inches.

h = dial gauge reading to the nearest 1/10,000 inch

Notes:

The average values of stress and strain for loading between 20,000# and 140,000# are used to determine the modulus of elasticity of normal concrete and loading between 20,000# and 100,000# are used to obtain E for concrete containing lightweight aggregate. If the results obtained appear to diverge from the required normal value, the stress-strain curve should be plotted and E obtained between limits of a tangent drawn to this curve.

Test Method Tex-422-A
Rev: October 1963

Texas Highway Department

Materials and Tests Division

LINEAL SHRINKAGE OF PORTLAND CEMENT CONCRETE

Scope

This test method covers a procedure for determining the lineal shrinkage of concrete due to any cause other than applied stress.

Apparatus

1. Molds: Metal molds (Figure 1) for casting prismatic concrete specimens 3 inches by 2 inches by 24 inches in length. The molds are designed so that the test specimens are formed with the longitudinal axis horizontal and made of metal of sufficient thickness to prevent distortion during the placing of concrete. The inside of the molds machined so that the surface of specimens will be perfectly smooth.

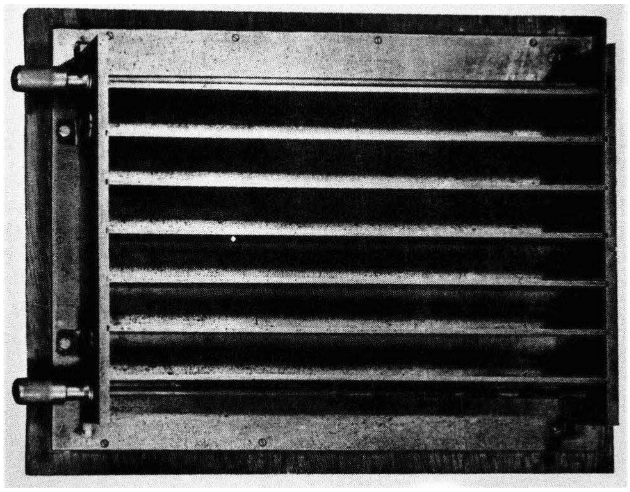


Figure 1

2. Tamping Rod: A straight steel rod 5/8-inch in diameter and about 24 inches in length, having one end rounded to a hemispherical tip.

3. Measuring Device: A micrometer dial gauge mounted on a rigid frame and base.

4. Small Hand-Scoop

5. Steel Straightedge, 18 inches long and about 2 inches wide.

6. Mason's Trowel

Procedure

1. Design, proportion and mix the concrete as described in Test Method Tex-414-A.

2. Place the freshly mixed concrete in the mold in two approximately equal layers. Remove aggregate particles larger than 1 inch in diameter. Consolidate each layer with 25 strokes of the tamping rod uniformly distributed over the full length of the mold. In addition, as the top layer is being placed, work the concrete thoroughly along the edges of the mold by spading the concrete with several strokes of a mason's trowel. The top layer should slightly overfill the mold.

3. After compaction is complete, remove the excess material with a straightedge and use the trowel to smooth the surface of test specimen. At least three test specimens should be prepared for each concrete design or test condition.

4. Allow the specimens to remain in the molds undisturbed for 24 hours. Then remove the specimens from the mold, carefully handling them to avoid damage, mark the exact center of one end of each test specimen, use the measuring device to measure the length of each specimen to the nearest 1/10,000 inch and record this measurement as the original length of specimen as L.

5. Properly identify the specimens and place in damp room to cure for 7 days. After the curing period (7 days) remove specimens from damp room and carefully measure their lengths.

6. After measurement at the end of moist curing, store all specimens at room temperature of 75°F in a convenient place where the specimens will not be disturbed. Observe the condition of the concrete and measure the length of each test specimen at the end of total periods of dry storage of 1, 2, 3, 6 and 12 months and 6 month intervals thereafter if desired. Obtain the measurements after the periods of dry storage in the storage room to prevent the effects of changes due to temperature and humidity.

Calculation

Calculate the linear contraction during dry storage for any length of storage as follows:

$$L_s = \frac{L - l}{L}$$

L_s = linear shrinkage or linear contraction (change in length in inches per inch)

L = original length in inches measured after the 24-hour curing period

l = length of specimen in inches at end of period of dry storage

Notes

This test is used for research purposes to be considered in design procedure.

Test Method Tex-423-A

June 1962

Texas Highway Department

Materials and Tests Division

RESISTANCE OF CONCRETE SPECIMENS TO FREEZING AND THAWING

Scope

This test method describes a procedure for determining the resistance of concrete specimens to laboratory freezing in air and thawing while immersed in water. It is intended for use in determining the effects of variation in the properties of the aggregates used in the concrete, and it indicates the relative ability of the concrete to resist disintegration due to changes in the natural elements.

Apparatus

1. The apparatus specified in Test Method Tex-420-A
2. Tank of clean water maintained at room temperature
3. Deep freezer controlled at 0°F
4. Heating oven maintained at a temperature of 140°F to 230°F.

Test Specimens

1. The specimens for use in this test are sections of beams molded and cured (for 7 days) as specified in Test Method Tex-420-A. Specimens submitted from the field laboratories may have been cured for longer periods of time.

Procedure

1. Immediately after the specified curing period, the freezing and thawing test is started by placing the specimens in water. The beam sections are kept immersed in water at room temperature for 24 hours.

2. Remove the specimens from the water and dry the durface with a towel or cotton cloth. Then place the specimens in the deep freezer for a period of 24 hours.

3. After the freezing period, return the test beam sections to the water tank and allow them to thaw in water for 24 hours.

4. Next, surface dry the specimens and place them in the oven to dry for a 24 hour period. These four steps are considered as one cycle. Observe the condition of the test specimen after each cycle, take pictures of the specimen or record a description of its visual appearance and make special note of any defects which develop.

5. Repeat these operations for as many cycles as desired, usually 5 to 10 cycles are sufficient to disclose any defect in concrete or unsound aggregate.

Reporting Test Results

Report a description of the visual appearance giving special comment on any defects in the test specimens after the required number of cycles.

APPENDIX C

THE EFFECT OF CEMENT COMPOSITION ON THE PHYSICAL PROPERTIES OF MORTARS CONTAINING VARIOUS ADMIXTURES

I. SCOPE:

The investigation into the causes of extensive concrete bridge deck deterioration required additional information on the proper use of concrete making materials. The purpose of this investigation is to determine the variation in the physical properties of laboratory mixed cement mortar containing the predominant types of admixtures, and made with five different Type I cements. These cements represent both a geographical spread and a fairly wide range of compound analysis.

II. LIMITATIONS:

This investigation was limited to five cement sources and two each air-entraining and set-retarding, water-reducing admixtures in order to accelerate the investigation as much as possible with available space and personnel.

III. OBJECTIVES:

To determine and compare the effect of differences in the compound analysis of various Type I cements on the physical properties of laboratory prepared mortar mixtures as measured by tensile and compressive strengths, entrained air, water reduction and initial setting time for the following mix conditions:

1. Reference, or Plain
2. With Lignosulfonate type set-retarding, water reducing admixture (Retarder A).
3. With Hydroxylated carboxylic type set-retarding, water-reducing

admixture (Retarder B).

4. With two Neutralized Vinsol Resin (NVR) air-entraining admixtures (NVR "S" and NVR "D").
5. With each set-retarding admixture in combination with each air-entraining admixture.

IV. SUMMARY:

1. The set-retarding properties of the admixtures tested varied between cements as much as 3:15 hours for Retarder A and 4:10 hours for Retarder B.
2. Entrained air varied up to 3.4% between cements for NVR concretes and up to 4.6% for Retarder A + NVR.
3. Water-reduction capabilities of water-reducing admixtures varied between cements from 6 to 15% for Retarder A and from 0 to 2% for Retarder B.
4. Water-reduction capabilities of air-entraining admixtures with various cements were from 3 to 12% for NVR "S" and 2 to 9% for NVR "D".
5. Water-reduction capabilities at each test condition were approximately the same with all cements with two exceptions. Cement A yielded 3% to 6% less water reduction for all conditions except with Retarder B, which gave no more than 2% reduction with all cements.
6. Cements A and T were the two cements high in C_3A, 13.16 and 13.47%, respectively, yet Cement T consistently yielded the shortest retarding of initial set while Cement A yielded the longest retardation in six of the eight test conditions.

7. All admixtures and their combinations yielded 28 day compressive and tensile strengths lower than control specimens on all cements except Retarder B which increased or closely maintained strengths.
8. 7-day tensile strengths for different cements varied by approximately 30% for Retarder "B", NVR "D", and Retarder "B" plus NVR "S". This variation reduced to approximately 15% at 28 days.
9. 7-day and 28-day tensile strengths varied between cements by approximately 10-15% for all mixtures containing Retarder A, NVR "S" and Retarder B plus NVR "D".
10. Test conditions yielded a wide range in compressive strengths with variations of approximately 43% between cements.

V. CONCLUSIONS:

1. Comparison of test results with the different cements indicates significant differences in amount or magnitude of compressive and tensile strengths, entrained air, set-retardation and water-reduction for all types and combinations of admixtures.

   Based on concrete mortar mixes where the only allowable variables are the cement and the admixture, significant and in some cases extreme differences result when a change is made in either material. These differences apparently cannot be explained by the differences in chemical analysis of the cement alone.
2. These differences are of sufficient magnitude to indicate that without complete pilot testing of the initial design with actual materials to be used on the project, or without re-testing any time brand, type or quantity of cement or admixture is changed,

the quality and characteristics of the concrete will be subject to question. A cement or admixture is not necessarily acceptable for substitution into a design merely because it meets current specifications governing that material.

3. The excessive bleeding characteristic of a hydroxylated carboxylic set-retarding admixture requires that it be used only with an air entraining admixture to relieve this undesirable characteristic.

VI. MATERIALS:

1. Graded Ottawa sand.
2. 5 Type I cements representing a cross-section of the State.
3. 2 Neutralized Vinsol Resin Air-entraining agents.
4. 2 Set-retarding, water-reducing admixtures, one a lignosulfonate type, and one a hydroxylated carboxylic type.
5. Tap water.

VII. DISCUSSION:

A history of difficulties encountered over the State in placing concrete plus a need to further evaluate the use of materials to establish any effect which they might have on the current bridge deck deterioration problem led to this laboratory conducted investigation.

Materials: Five Type I cements representing a geographical cross section of cement producers in the State were selected. The tri-calcium aluminate (C_3A) content of two of the cements ("A" and "T") were high, two ("G" and "L") low and one ("E" was in the medium range). The chemical analysis is shown in Table C-1.

A mortar mixture made with standard and graded Ottawa sand was selected for investigation in order to avoid the numerous variables of grading, composition and shape inherent with coarse and fine aggregates.

Two widely used set-retarding, water-reducing admixtures, a lignosulfonate type (Retarder A) and a hydroxylated carboxylic type (Retarder B), were selected from the current list of approved admixtures for use on Texas Highway projects.

In a like manner, two Neutralized Vinsol Resin air-entraining admixtures, (NVR "S" and NVR "D") made by two different manufacturers, were selected.

Method of Determination: Standard test procedures for determining the tensile and compressive strengths, entrained air and time of initial set were used. Methods of preparation of test specimens were modified to allow all specimens and all determinations made on the plastic mortar to be accomplished with a single batch. A uniform consistency was maintained throughout by adding sufficient water to control the flow to 100 ± 5. This provided the basis for the per cent water reduction referred to in this report. In order to perform entrained air determinations, the resulting mixture was necessarily slightly wetter than normal for molding compression and tensile test specimens.

Mixing Procedure:

The mixture design and sequence of mixing was as follows:

1300 gms. graded Ottawa sand

1300 gms. standard sand

650 gms. cement

Sufficient water to yield 100 ± 5 flow on flow table.

The mixing sequence consisted of mixing the sand and cement in a mechanical mixer for 30 seconds, adding the water over a 15 second period followed by 15 seconds of additional mixing at a slow speed; stopping the mixer and scraping the sides for 15 seconds followed by final mixing for 1 minute at medium speed. Admixtures, when used, were introduced in the mixing water. When two admixtures were used, the mixing water was divided and each admixture was introduced into the batch with a portion of the water, at the same time, and from opposite sides of the mixer.

Results of Testing: Test results are given in tabular form, Tables C-2 through C-6.

1. Table C-2 outlines the 7 day and 28 day tensile strengths of each cement. The magnitude of the differences is greater at 7 days than at 28 days for certain of the test conditions. Apparently Retarder B, NVR "D" and the combination of Retarder B and NVR "S" slow the gain in strength of some cements, while Retarder A and NVR "S" has little effect. This difference is reduced at 28 days and results in an erratic pattern varying as much as 27 to 60 psi., or approximately 10 to 20% difference in tensile strengths between cements.
2. Table C-3 outlines the 7 and 28 day compressive strengths. The significant differences in strength between cements are erratic and do not follow any particular pattern for one cement. Cement "L" is low in strength for most conditions, while Cement "A" varies from the highest strengths to the lowest strengths for different test conditions. Values varied by 535 to 2000

psi., approximately 25 to 50%, at 7 days, and contrary to tensile test results, the variation was not reduced at 28 days.

3. Table C-4 outlines the amount of air entrained for each cement per test condition. The difference varies from 1.9 to 4.6% between cements.
4. Table C-5 outlines the amount of water reduction from the control mortar possible to maintain consistency. This value does not vary appreciably for most cements with the exception of Cement "A" which is consistently lower. Retarder "B" was found to be ineffective as a water reducing agent.
5. Table C-6 shows the amount of time initial set was retarded over that of the control mortar for each cement and test condition. Cement "A" gave high values of retardation, while Cement "T", also high in C_3A, gave values significantly lower with all combinations of both retarding agents. Values obtained on the remaining cements varied without pattern between the extremes of Cement "A" and "T".
6. Test specimens of all mortars made with Retarder "B" suffered extensive surface damage from bleeding.

TABLE C-1

CEMENT A

	TENSILE STRENGTH		COMP. STRENGTH		AIR	H_2O	FLOW	SETTING TIME
Mix Data	7 Day	28 Day	7 Day	28 Day	%	%	%	Hrs.Min.
Control	273	353	3000	4163	8.8	65.0	96	3:30
Plus Ret. "A"	217	267	2160	2663	23.0	59.0	103	8:25
Plus Ret. "B"	333	377	3498	4497	9.3	64.0	95	10:10
Plus NVR "S"	257	277	2375	2930	19.9	62.0	96	5:50
Plus NVR "D"	297	317	2195	3027	19.2	63.0	103	5:05
Plus "A" & "S"	187	187	1472	1408	33.0	54.0	95	9:30
Plus "A" & "D"	173	190	1207	1153	33.0	54.0	96	9:30
Plus "B" & "S"	267	307	2433	2980	22.1	57.0	97	10:30
Plus "B" & "D"	250	273	2107	2615	22.6	57.0	97	10:15
CEMENT E								
Control	290	360	2055	3325	7.8	68.0	100	4:30
Plus Ret. "A"	253	307	2188	3297	21.0	56.5	100	7:35
Plus Ret. "B"	293	393	1817	3188	7.4	68.0	105	9:00
Plus NVR "S"	213	310	1710	2512	17.9	59.0	96	5:25
Plus NVR "D"	230	303	1710	2630	16.8	60.0	100	5:15
Plus "A" & "S"	180	233	1442	2012	29.5	54.0	101	9:25
Plus "A" & "D"	173	243	1502	1763	29.0	54.0	104	8:45
Plus "B" & "S"	223	307	1500	2463	21.7	57.0	101	10:00
Plus "B" & "D"	213	280	1298	2263	21.7	57.0	103	10:15
CEMENT G								
Control	213	357	1868	2971	7.4	68.0	104	3:50
Plus Ret. "A"	213	293	1653	2388	21.7	56.5	99	7:20
Plus Ret. "B"	267	347	1767	2863	8.5	67.0	101	8:45
Plus NVR "S"	250	300	1703	2405	18.7	59.0	96	5:00
Plus NVR "D"	247	300	1685	2413	19.0	60.0	101	5:20
Plus "A" & "S"	173	207	1182	1557	30.0	54.0	100	9:15
Plus "A" & "D"	153	207	1260	1467	29.0	54.0	103	9:00
Plus "B" & "S"	180	253	1127	1695	23.4	57.0	105	10:40
Plus "B" & "D"	197	257	1327	2145	21.1	56.0	99	9:30
CEMENT L								
Control	237	330	1690	3117	9.3	67.0	104	4:00
Plus Ret. "A"	243	263	1980	2763	24.0	52.0	98	7:00
Plus Ret. "B"	233	357	1498	2565	9.1	66.0	105	9:50
Plus NVR "S"	200	250	1488	2272	18.7	55.0	98	4:45
Plus NVR "D"	197	277	1278	2105	20.2	58.0	97	4:30
Plus "A" & "S"	153	217	1058	1600	30.0	54.0	101	8:15
Plus "A" & "D"	160	217	1068	1408	29.3	54.0	102	8:45
Plus "B" & "S"	160	253	1137	1965	24.0	56.0	102	11:35
Plus "B" & "D"	190	253	1167	2333	20.6	56.0	104	10:05
CEMENT T								
Control	243	350	2377	3421	7.0	68.0	97	3:40
Plus Ret. "A"	237	277	2092	2750	21.7	56.5	98	5:20
Plus Ret. "B"	300	373	2652	3692	8.2	66.0	96	7:10
Plus NVR "S"	227	260	1780	2475	19.4	60.0	98	4:30
Plus NVR "D"	253	283	1458	2587	18.3	61.0	99	4:45
Plus "A" & "S"	203	217	1667	2237	28.4	54.0	95	6:30
Plus "A" & "D"	193	233	1772	1982	29.0	54.0	95	6:30
Plus "B" & "S"	220	297	2016	2878	21.7	57.0	104	8:15
Plus "B" & "D"	230	280	2098	2773	21.1	56.0	96	8:40

All Tensile and Compressive Strength Values are Average of 3 Specimens

Additive Dosage for 650 Gm. Cement

Retarder "A" - 6.6 cc
Retarder "B" - 1.4 cc
NVR "S" - 0.5 cc
NVR "D" - 0.4 cc

TABLE C-2

TENSILE STRENGTH

Condition	Age (Days)	"A"	"E"	"G"	"L"	"T"
Control	7	273	290	213	237	243
	28	353	360	357	330	350
Retarder A	7	217	253	213	243	237
	28	267	307	293	263	277
Retarder "B"	7	333	293	267	233	300
	28	377	393	347	357	373
NVR "S"	7	257	213	250	200	227
	28	277	310	300	250	260
NVR "D"	7	297	230	247	197	253
	28	317	303	300	277	283
Ret.A + NVR "S"	7	187	180	173	153	203
	28	187	233	207	217	217
Ret.A + NVR "D"	7	173	173	153	160	193
	28	190	243	207	217	233
Ret."B" + NVR "S"	7	267	223	180	160	220
	28	307	307	253	253	297
Ret."B" + NVR "D"	7	250	213	197	190	230
	28	273	280	257	253	280

TABLE C-3

COMPRESSIVE STRENGTH (psi.)

Condition	Age (Days)	"A"	"E"	"G"	"L"	"T"
Control	7	3000	2055	1868	1690	2377
	28	4163	3325	2971	3117	3421
Retarder A	7	2160	2188	1653	1980	2092
	28	2663	3297	2388	2763	2750
Retarder B	7	3498	1817	1767	1498	2652
	28	4497	3188	2863	2565	3692
NVR "S"	7	2375	1710	1703	1488	1780
	28	2930	2512	2405	2272	2475
NVR "D"	7	2195	1710	1685	1278	1458
	28	3027	2630	2413	2105	2587
Ret. A + NVR "S"	7	1472	1442	1182	1058	1667
	28	1408	2012	1557	1600	2237
Ret. A + NVR "D"	7	1207	1502	1260	1068	1772
	28	1153	1763	1467	1408	1982
Ret. B + NVR "S"	7	2433	1500	1127	1137	2016
	28	2980	2463	1695	1965	2878
Ret. B + NVR "D"	7	2107	1298	1327	1167	2098
	28	2615	2263	2145	2333	2773

TABLE C-4

ENTRAINED AIR (%)

	"A"	"E"	"G"	"L"	"T"
Control	8.8	7.8	7.4	9.3	7.0
Retarder A	23.0	21.0	21.7	24.0	21.7
Retarder B	9.3	7.4	8.5	9.1	8.2
NVR "S"	19.9	17.9	18.7	18.7	19.4
NVR "D"	19.2	16.8	19.0	20.2	18.3
Ret. A + NVR "S"	33.0	29.5	30.0	30.0	28.4
Ret. A + NVR "D"	33.0	29.0	29.0	29.3	29.0
Ret. B + NVR "S"	22.1	21.7	23.4	24.0	21.7
Ret. B + NVR "D"	22.6	21.7	21.1	20.6	21.1

TABLE C-5

WATER REDUCTION

	"A"	"E"	"G"	"L"	"T"
Control					
Retarder A	6%	11½%	11½%	15%	11½%
Retarder B	1%	0	1%	1%	2%
NVR "S"	3%	9%	9%	12%	8%
NVR "D"	2%	8%	8%	9%	7%
Ret. A + NVR "S"	11%	14%	14%	13%	14%
Ret. A + NVR "D"	11%	14%	14%	13%	14%
Ret. B + NVR "S"	8%	11%	11%	11%	11%
Ret. B + NVR "D"	8%	11%	12%	11%	12%

TABLE C-6

RETARDATION OF INITIAL SET

	"A"	"E"	"G"	"L"	"T"
Control					
Retarder A	4:55	3:05	3:30	3:00	1:40
Retarder B	7:40	4:30	4:55	4:50	3:30
NVR "S"	2:20	1:55	1:10	0:45	0:50
NVR "D"	1:35	1:45	1:30	0:30	1:05
Ret. A + NVR "S"	6:00	4:55	5:25	4:15	2:50
Ret. A + NVR "D"	6:00	4:15	5:10	4:45	2:50
Ret. B + NVR "S"	7:00	5:30	6:50	7:35	4:35
Ret. B + NVR "D"	6:45	5:45	5:40	6:05	5:00

APPENDIX D

THE STATE OF TEXAS

INVESTIGATION OF VARIOUS CHEMICAL CHARACTERISTICS OF DETERIORATED PORTLAND CEMENT CONCRETE

MATERIALS AND TESTS DIVISION
MCMXVII

TED W. BECKER
CHEMIST III

IP 5-67 J

TEXAS HIGHWAY DEPARTMENT

TEXAS HIGHWAY DEPARTMENT

Materials and Tests Division

INVESTIGATIONAL PROJECT NO. IP-5-67-J

March 1967

INVESTIGATION OF VARIOUS CHEMICAL CHARACTERISTICS
OF
DETERIORATED PORTLAND CEMENT CONCRETE

I. SUBJECT:

Various samples of hardened portland cement concrete having been cored from Texas Highway Department bridge decks were submitted to the Chemical Section of the Materials and Tests Division of the Texas Highway Department for partial chemical analysis in connection with IP-4-67-A. The pulverized core material was subjected to the following determinations:

1. Per cent by weight water soluble material.
    a. total dissolved solids
    b. soluble chlorides
    c. soluble sulfates
2. Per cent by weight moisture gain of oven dried material in moist air.
3. Ion exchange capacity in M.E./100 g. of pulverized sample.
4. Cement content.

II. PURPOSE:

To determine, if possible, one or more of the basic causes of the concrete deterioration being experienced in many of the structures from which the samples had been cored.

III. CONCLUSIONS:

1. The water soluble salt content of a badly deteriorated core was found to be quite similar to that of a sound core from the same structure. In the unsound core the salt content was found to be rather uniform from top to bottom of core. Water soluble chloride and sulfate content of a badly deteriorated core was also found to be uniform from the top to the bottom of the core. No unusually large amounts of soluble salts were found to be present in the set of cores tested.

2. All pulverized core materials tested exhibited moisture gain potentials but no relationship could be drawn between the magnitude of moisture gain under test conditions and the reported condition of the concrete deck being analyzed.

3. The ion exchange capacity of the pulverized cores varied from core to core. Exchange capacity being a function of sand, aggregate or materials other than cement we found no overall correlation between the magnitude of ion exchange capacity in a given core with the condition of the deck from which it was derived.

4. The cement content of the pulverized cores tested was found to be generally speaking within the prescribed anticipated limits. Within the limits of the test procedure employed, no shortage of cement was detected.

IV. MATERIALS:

All materials were samples of hardened portland cement concrete cored from Texas Highway Department bridge decks for the purpose of this investigation. For identification of cores and the location of bridges from which cores were taken, refer to Texas Highway Department Investigational Project IP-4-67-A. The majority of the cores discussed in this paper will be identified as to location, etc., in IP-4-67-A. However, some of the samples not specifically referred to therein will be identified as to source by special note in this report.

V. EQUIPMENT:

Cores were selected and taken from bridge decks utilizing conventional Texas Highway Department core drill equipment. Samples were reduced in size or pulverised utilizing a Braun pulverizer. All material was ground to pass a 60 mesh sieve with the exception of the cement content samples which were ground to pass 170 mesh. A magnet was used to remove magnetic particles from the samples (most of which can be attributed to abrasion on the hardened steel face plates of the Braun pulverizer).

VI. METHODS OF PERFORMING VARIOUS TESTS:

1. Per cent by weight water soluble material.
    - a. total dissolved solids --- conventional gravimetric determination.
    - b. soluble chlorides --- titrimetric analysis (Volhard Method).
    - c. soluble sulfates --- gravimetric determination.
2. Per cent by weight moisture gain of oven dried material in moist air --- conventional gravimetric determination.
3. Ion exchange capacity in M.E./100 g. of pulverized sample.
    - a. Standard Texas Method (see Appendix I)
    - b. Methylene Blue Method --- Field Procedure (see Appendix II)
    - c. Methylene Blue Method --- Research Procedure (see Appendix III)
    - d. Ammonium Acetate Method --- Centrifuge -- no digestion period (see Appendix IV)
4. Cement content --- Determined by ASTM Designation: C 85-54 (1961) "Standard Methods of Test for 'Cement Content of Hardened Portland Cement Concrete'" as modified (see Appendix V Procedure Change 1) to allow for utilization of core samples weighing less than the 10 pound minimum normally specified.

VII. TEST DATA, RESULTS AND CALCULATIONS:

1. Per cent by weight water soluble material.

On June 21, 1966, we received portions of three concrete cores. All samples were ground to pass a #60 (250 microns) U.S. Standard Series sieve. The cores were identified as Core A, Core 3 and Core 4.

Core 3 was divided into three sections; top, middle and bottom. A weighed portion of each section was blended together and was called combination of 3. A partial chemical analysis was run on the cores submitted June 21, 1966, with the following results.

Total Dissolved Solids

Core A* ---------- 2.7% by wt. total water soluble portion of original sample

Core 3** (Top) ------- 2.4% by wt. total water soluble portion of original sample

Core 3, Combination -- 2.0% by wt. total water soluble portion of original sample

Core 4 ---------- 2.5% by wt. total water soluble portion of original sample

Water Soluble Chloride (Calculated as chloride ion)

Core 3 (Top) ------- 1.6% by wt. of pulverized core

Core 4 ----------- 1.4% by wt. of pulverized core

Core A ----------- not determined

Core 3, Combination -- not determined

Water Soluble Chloride (Calculated as sodium chloride)

Core 3 ----------- 2.7% by wt. of pulverized core

Core 4 ----------- 2.3% by wt. of pulverized core

Core A ----------- not determined

Core 3, Combination -- not determined

Note: *Core A sampled from bridge in Dist. 1, Hunt County, SH 24, at Greenville, Project 136-1-29, constructed in Nov. 1962, 3rd span from East end in right side of west bound structure.

**Cores 3 & 4 sampled from Collin County, Dist. 18, SH 24, Project C 135-5-11, constructed in Nov. 1957, located 200 yds. West of Dist. Line. Core 3 from center slab west bound lane; Core 4 from east slab (west bound lane).

Water Soluble Sulfate (Calculated as sulfate ion)

Core 4 ------------ 0.4% by wt. of pulverized core

Core A ------------ 0.5% by wt. of pulverized core

Core 3 (Top) --------- 0.7% by wt. of pulverized core

Core 3 (Middle) ------- 0.5% by wt. of pulverized core

Core 3 (Bottom) ------- 0.5% by wt. of pulverized core

Core 3, Combination 0.5% by wt. of pulverized core

2. Per cent by weight moisture gain of oven dried material in moist air. The samples listed below were ground to pass a #60 (250 microns) U.S. Standard Series Sieve.

All tests were performed on samples previously oven dried for 24 hours @ 150°F.

Samples to be tested were placed in a 99.9% relative humidity environmental test cabinet for a period of 24 hours. Resulting gain in weight of samples is calculated as per cent moisture gain.

Material Pulverized from Core No.	Per Cent Moisture Gain
D*	2.4
Montmorillonite Clay	7.0
A**	1.9
Core 3, Combination	5.7
8-63-4-3	0.7
Victoria	1.8
8-37-2-6	0.4
8-43-7-4	0.7
8-63-1-2	0.3
8-79-10-2	0.6
8-43-2-6	0.6

Note: *Sample "D" submitted for analysis at the direction of Mr. J. C. Dingwall (see letter from D-5 to D-9 dated July 6, 1966). Material from Adobe Walls Creek Bridge on SH 118, Brewster Co., Control 358-5-3, Sta. 366+59.0 to Sta. 367+61.0. Project S 1155(4) Permanent Str. 23.

**Core A sampled from bridge in Dist. 1, Hunt Co., SH 24, at Greenville, Project 136-1-29, constructed in Nov. 1962, 3rd span from East end in right side of west bound structure.

3. Ion exchange capacity in M.E./100 g. of pulverized sample.

A. Standard Texas Method

The samples listed below were ground to pass a #60 (250 microns) U.S. Standard Series Sieve. Determination of samples was by a standard method of the Texas Highway Department (i.e. Ammonium Acetate Method with 16 hours digestion period). For details of test procedure employed, see Appendix I.

A. Standard Texas Method

Code	Material Pulverized from Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
A*	(Original sample)	0.2	10 to 20
A	(Rerun on Original sample)	0.3	10 to 20
3**	(Combination-Original sample)	1.5	54
3	(Combination-Resample)	0.5	54
4**	(Original sample)	0.4	20
4	(Rerun on Original sample)	0.4	20
Montmorillonite Clay	(Source A)	86.0	--
Montmorillonite Clay	(Source B)	28.8	--
"D"***	(Original sample)	12.6	--
"D"	(Rerun on Original sample)	13.3	--
Blank		0.0	--
Blank		0.0	--
12	8-63-5-5	3.2	33
36	Victoria	0.0	--
4-1	8-63-2-1	2.4	33
15	8-37-2-6	6.6	55
9	8-63-1-2	1.7	33
31	8-79-10-2	4.0	50
33	8-43-7-4	4.9	51
28	8-43-2-6	4.5	51

Note: *Core A sampled from bridge in Dist. 1, Hunt Co., SH 24, at Greenville, Project 136-1-29, constructed in Nov. 1962, 3rd span from East end in right side of west bound structure.

**Cores 3 & 4 sampled from Collin Co., Dist. 18, SH 24, Project C 135-5-11, constructed in Nov. 1957, located 200 yds West of Dist. Line. Core 3 from center slab west bound lane; Core 4 from east slab (west bound lane).

***Core "D" submitted for analysis at the direction of Mr. J.C. Dingwall (see letter from D-5 to D-9 dated July 6, 1966). Material from Adobe Walls Creek Bridge on SH 118, Brewster Co., Control 358-5-3, Sta. 366+59.0 to Sta. 367+61.0. Project S 1155(4) Permanent Str. 23.

A. Standard Texas Method -Contd.

	Material Pulverized from Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
10	8-63-6-4	5.0	33
37	24-9-3-1	1.7	20
41	24-12-7-6	2.6	20
42	24-12-1-2	2.3	40
	14-219-2-2	0.4	10
	15-119-6-2	0.5	20
1G	14-219-2-2 (Rerun)	0.0	10
1B	14-92-3-1	0.0	44
2G	14-2-2-5	0.2	10
2B	14-59-26-2	0.4	32
3G	15-96-2-2	1.2	20
3B	15-94-1-3	1.3	40
4G	8-283-1-1	0.4	10
4B	8-31-4-5	1.6	51
5G	8-54-1-4	0.5	20
5B	8-36-5-4	1.3	20
6G	8-176-1-3	0.8	10
6B	8-63-5-5	2.4	33
7G	10-2-6-5	1.1	10
7B	10-1-6-4X	0.5	31
8G	23-8-1-2	0.8	20
8B	23-1-2-4	0.2	20
9G	19-27-2-4	0.6	10
9B	19-1-1-3	0.5	30
10G	5-1-3-4	1.7	20
10B	5-1-2-2X	0.5	30
11G	5-2-2-2	2.1	20
11B	5-23-8-4	2.2	51

3. B. Methylene Blue Method -- Field Procedure

The samples listed below were ground to pass a #60 (250 microns) U.S. Standard Series Sieve. Samples were heated briefly and digested briefly. For details of test procedure employed, see Appendix II.

B. Methylene Blue Method (Field Procedure)

Material Pulverized From Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
4-15-3-5	2.6	40
4-7-20-3	0.3	30
14-219-2-2	1.9	10
14-219-2-2 (sample digested 16 hours)	0.7	10
5-2-2-2	2.2	20
8-43-7-4	0.9	51

B. Methylene Blue Method (Field Procedure) Contd.

Material Pulverized From Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
8-43-7-4 (sample wet - ground in Ball Mill)	1.3	51
2-Aggregate*	0.8	
2-Sand*	1.0	
Baroid Div. of National Lead Co's.: "National Standard Bentonite"	74.7	
18-X-1-2	2.1	30
20-147-3-4 (Source B)	31.9	33

3. C. Methylene Blue Method -- Research Procedure

The samples listed below were ground to pass a #60 (250 microns) U.S. Standard Series Sieve. Samples were placed in an Oster brand blender for 15 minutes at high speed setting after which sample was allowed to digest 16 hours. For details of test procedure employed, see Appendix III.

C. Methylene Blue Method (Research Procedure)

Material Pulverized From Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
"D"**	6.3	10
14-219-2-2	1.5	10
24-96-2-3	0.9	20
3-22-5-3	1.2	52
4-7-15-3	1.1	20
3-72-2-2	0.6	51
7-17-3-4	1.0	51
16-34-7-2	0.4	44
3-2-2-3	1.4	20
4-15-3-5	0.6	40
3-9-10-1X	1.0	20
4-7-20-3	0.6	30
20-1237-3-2	1.4	33
18-142-1-5	0.8	33
24-20-5-2	1.6	33

Note: *May 1956 sample of aggregate and sand from source employed initially for core 8-31-4-5, i.e., limestone and silica sand and gravel.

**Core "D" submitted for analysis at the direction of Mr. J. C. Dingwall (see letter from D-5 to D-9 dated July 6, 1966). Material from Adobe Walls Creek Bridge on SH 118, Brewster Co., Control 358-5-3, Sta. 366+59.0 to Sta. 367+61.0. Project S 1155(4) Permanent Str. 23.

A. Standard Texas Method -Contd.

Code	Material Pulverized from Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
10	8-63-6-4	5.0	33
37	24-9-3-1	1.7	20
41	24-12-7-6	2.6	20
42	24-12-1-2	2.3	40
	14-219-2-2	0.4	10
	15-119-6-2	0.5	20
1G	14-219-2-2 (Rerun)	0.0	10
1B	14-92-3-1	0.0	44
2G	14-2-2-5	0.2	10
2B	14-59-26-2	0.4	32
3G	15-96-2-2	1.2	20
3B	15-94-1-3	1.3	40
4G	8-283-1-1	0.4	10
4B	8-31-4-5	1.6	51
5G	8-54-1-4	0.5	20
5B	8-36-5-4	1.3	20
6G	8-176-1-3	0.8	10
6B	8-63-5-5	2.4	33
7G	10-2-6-5	1.1	10
7B	10-1-6-4X	0.5	31
8G	23-8-1-2	0.8	20
8B	23-1-2-4	0.2	20
9G	19-27-2-4	0.6	10
9B	19-1-1-3	0.5	30
10G	5-1-3-4	1.7	20
10B	5-1-2-2X	0.5	30
11G	5-2-2-2	2.1	20
11B	5-23-8-4	2.2	51

3. B. Methylene Blue Method -- Field Procedure

The samples listed below were ground to pass a #60 (250 microns) U.S. Standard Series Sieve. Samples were heated briefly and digested briefly. For details of test procedure employed, see Appendix II.

B. Methylene Blue Method (Field Procedure)

Material Pulverized From Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
4-15-3-5	2.6	40
4-7-20-3	0.3	30
14-219-2-2	1.9	10
14-219-2-2 (sample digested 16 hours)	0.7	10
5-2-2-2	2.2	20
8-43-7-4	0.9	51

B. Methylene Blue Method (Field Procedure) Contd.

Material Pulverized From Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
8-43-7-4 (sample wet - ground in Ball Mill)	1.3	51
2-Aggregate*	0.8	-
2-Sand*	1.0	-
Baroid Div. of National Lead Co's.:		
"National Standard Bentonite"	74.7	-
18-X-1-2	2.1	30
20-147-3-4 (Source B)	31.9	33

3. C. Methylene Blue Method -- Research Procedure

The samples listed below were ground to pass a #60 (250 microns) U.S. Standard Series Sieve. Samples were placed in an Oster brand blender for 15 minutes at high speed setting after which sample was allowed to digest 16 hours. For details of test procedure employed, see Appendix III.

C. Methylene Blue Method (Research Procedure)

Material Pulverized From Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
"D"**	6.3	10
14-219-2-2	1.5	10
24-96-2-3	0.9	20
3-22-5-3	1.2	52
4-7-15-3	1.1	20
3-72-2-2	0.6	51
7-17-3-4	1.0	51
16-34-7-2	0.4	44
3-2-2-3	1.4	20
4-15-3-5	0.6	40
3-9-10-1X	1.0	20
4-7-20-3	0.6	30
20-1237-3-2	1.4	33
18-142-1-5	0.8	33
24-20-5-2	1.6	33

Note: *May 1956 sample of aggregate and sand from source employed initially for core 8-31-4-5, i.e., limestone and silica sand and gravel.

**Core "D" submitted for analysis at the direction of Mr. J. C. Dingwall (see letter from D-5 to D-9 dated July 6, 1966). Material from Adobe Walls Creek Bridge on SH 118, Brewster Co., Control 358-5-3, Sta. 366+59.0 to Sta. 367+61.0. Project S 1155(4) Permanent Str. 23.

3. D. Ammonium Acetate Method -- Centrifuge -- No digestion period. The samples listed below were ground to pass a #60 (250 microns) U.S. Standard Series Sieve. For details of test procedures employed, see Appendix IV.

D. Ammonium Acetate Method (Centrifuge - No digestion period)

Material Pulverized From Core No.	Ion Exchange Capacity (M.E./100 g. sample)	Slab Rating
3-9-10-1X	10.6	20
3-107-17-1	10.7	44
3-2-2-3	10.6	20
3-22-5-3	10.6	52
3-72-2-2	10.7	51
4-7-20-3	11.5	30
4-7-15-5	13.0	20
4-15-3-5	9.0	40
7-17-1-1	9.5	30
7-17-3-4	6.8	51
7-24-5-1	14.0	44
7-25-2-4	11.9	21
16-31-2-2	11.0	20
16-34-7-2	6.8	44
16-7-2-2	7.7	20
18-X-17-4	7.4	44
18-X-1-2	11.9	30
18-0-3-5	9.4	33
18-96-3-4	9.4	44
18-142-1-5	9.8	30
20-147-3-4	6.8	33
20-17-19-3	9.0	20
20-1237-3-2	7.7	33
24-20-5-3	9.7	33
24-39-3-5	8.4	20
24-97-4-2	10.8	44
24-96-2-3	13.2	20

4. Cement Content:

A. Summary of Cement Content Calculations

Sample No.*	Cement called for in Design,		Amt. Present by CaO,		Amt. Present by SiO_2 Run #1		Amt. Present by SiO_2, Run #2	
	% by wt.	Sacks/ cu.yd.	% by wt.	Sacks/ cu.yd.	% by wt.	Sacks/ cu.yd.	% by wt.	Sacks/ cu.yd.
1y	11.89	5.0	10.86	4.6	9.99	4.2	11.16	4.7
2y	11.71	5.0	11.74	5.0	12.62	5.4	15.70	6.7
3y	12.54	5.0	12.12	4.8	14.39	5.7	13.98	5.6
4y	12.54	5.0	54.46	21.7	11.34	4.5	15.67	6.2
5y	12.27	5.0	10.62	4.3	17.45	7.1	16.48	6.7
6y	13.63	5.5	20.99	8.5	13.21	5.3	13.38	5.4

Note: *Samples designated as #1 through 6 may be identified more specifically as follows:

		Slab Rating
Sample #1y	8-79-7-4	50
#2y	8-31-4-5	51
#3y	15-89-4-5	20
#4y	15-142-4-2	30
#5y	4-15-2-6	50
#6y	5-1-5-1X	32

B. Calculation of Cement Content in Cores

Sample No. 1y.

Avg. Analysis:	% CaO	% SiO_2 (Run #1)	% SiO_2 (Run #2)
Concrete	26.84	2.56	2.78
Fine Aggregate	9.70	0.54	0.46
Coarse Aggregate	31.85	0.20	0.18
Cement	65.65	22.62	

From batch design, wt. ratio of materials that should be present in hardened concrete are as follows:

Cement	94.0
Water	18.8
Fine Aggregate	281.15
Coarse Aggregate -	396.84
Total:	790.79

For all calculations, it is assumed that the amount of chemically combined water in the sample analyzed = 20% of the weight of the cement.
Let x = pounds of cement actually used. 0.2x = water present.

Cement content based on CaO (Sample #1y)

$$(677.99 + 1.2x)\ (0.2684) = 281.15(0.097) + 396.84(0.3185) + 0.6565x$$
$$181.97 + .3221x = 27.27 + 126.39 + .6565x$$
$$.3344x = 181.97 - 153.66 = 28.31$$
$x = 84.66$ lbs. cement per 779.58 lbs. concrete = 10.86% cement

Cement content based on SiO_2 (Run #1) (Sample #1y)

$$(677.99 + 1.2x)\ (0.0256) = 281.15(0.0054) + 396.84(0.0020) + 0.2262x$$
$$17.360 + .0307x = 1.518 + .7937 + .2262x$$
$$.1955x = 17.360 - 2.312 = 15.048$$
$x = 76.97$ lbs. cement per 770.35 lbs. concrete = 9.99% cement

Cement content based on SiO_2 (Run #2) (Sample #1y)

$$(677.99 + 1.2x)\ (0.0278) = 281.15(0.0046) + 396.84(0.0018) + 0.2262x$$
$$18.848 + .0334x = 1.293 + .714 + .2262x$$
$$.1928x = 18.848 - 2.007 = 16.841$$
$x = 87.35$ lbs. cement per 782.81 lbs. concrete = 11.16% cement

Amount of cement that should have been present in Sample #1y, based on batch design $= \frac{94.0\ (100)}{790.79} = 11.89\%$ by wt.

Sample No. 2y.

Avg. Analysis:	% CaO	% SiO_2 (Run #1)	% SiO_2 (Run #2)
Concrete	39.85	3.10	3.95
Fine Aggregate	16.38	0.30	0.76
Coarse Aggregate	45.04	0.24	0.29
Cement	65.67	22.80	

Batch design wt. ratios:

Cement	- 94.0
Water	- 18.8
Fine Aggregate	- 245.88
Coarse Aggregate	- 443.76
Total:	802.44

Amount of cement that should be present $= \frac{94.0\ (100)}{802.44} = 11.71\%$ by weight

Cement content based on CaO (Sample #2y)

$$(689.64 + 1.2x)\ (.3985) = (245.88)\ (.1638) + (443.76)(.4504) + .6567x$$
$$274.82 + .4782x = 40.27 + 199.86 + .6567x$$
$$.1786x = 274.82 - 257.98 = 16.84$$
$x = 94.28$ lbs. cement per 802.78 lbs. concrete = 11.74% cement

Sample No. 2y, contd.

Cement content based on SiO_2 (Run #1) (Sample #2y)

$(689.64 + 1.2x)\ (.0310) = (245.88)(.003) + (443.76)(.0024) + .228x$

$21.379 + .0372 = .738 + 1.065 + .2280x$

$.1908x = 21.379 - 1.803 = 19.576$

$x = 102.60$ lbs. cement per 812.76 lbs. concrete = 12.62% cement

Cement content based on SiO_2 (Run #2) (Sample #2y)

$(689.64 + 1.2x\ (.0395) = 245.88\ (.0076) + (443.76)(.0029) + .2280x$

$27.24 + .0474x = 1.869 + 1.287 + .2280x$

$.1806x = 27.240 - 3.156 = 24.084$

$x = 133.36$ lbs. cement per 849.67 lbs. concrete = 15.70% cement

Sample #3y.

Avg. Analysis:	% CaO	% SiO_2 (Run #1)	% SiO_2 (Run #2)
Concrete		2.99	2.88
Fine Aggregate		0.22	0.18
Coarse Aggregate		0.04	0.015
Cement		20.15	

Wt. Ratios from batch design:

Cement - 94.0
Water - 18.8
Fine Aggregate - 239.19
Coarse Aggregate - 397.68
Total: 749.67

Amount of cement that should be present = $\frac{94.0\ (100)}{749.67} = 12.54\%$

Cement content based on CaO:

$(636.87 + 1.2x)\ (0.4327) = 239.19\ (0.3693) + 397.68\ (0.5046) + 0.6678x$

$275.57 + 0.5192x = 88.33 + 200.67 + 0.6678x$

$0.1486x = 13.43$

$x = 90.38$ lbs. cement per 745.33 lbs. concrete = 12.12% cement

Cement content based on SiO_2 (Run #1) (Sample #3y)

$(636.87 + 1.2x)\ (0.0299) = 239.19\ (0.0022) + 397.68\ (0.0004) + 0.2015x$

$19.04 + 0.0359 = 0.53 + 0.16 + 0.2015x$

$0.1656x = 18.35$

$x = 110.81$ lbs. cement per 769.84 lbs. concrete = 14.39% cement

Cement content based on SiO_2 (Run #2) (Sample #3y)

(636.87 + 1.2x) (0.0288) = 239.19 (0.0018) + 397.68 (0.00015) + 0.2015x
18.34 + 0.0346 = 0.43 + 0.06 + 0.2015x
0.1669x = 17.85
x = 106.95 lbs. cement per 765.21 lbs. concrete = 13.98% cement

Sample #4y.

Avg. Analysis:	% CaO	% SiO_2 (Run #1)	% SiO_2 (Run #2)
Concrete	51.18	2.46	3.44
Fine Aggregate	43.64	0.15	0.30
Coarse Aggregate	42.80	0.09	0.14
Cement	66.55	20.83	

Wt. ratios from batch design:

Cement	-	94.0
Water	-	18.8
Fine Aggregate	-	239.19
Coarse Aggregate	-	397.68
Total:		749.67

Amount of cement that should be present = $\frac{94.0\ (100)}{749.67} = 12.54\%$

Cement content based on CaO: (Sample #4y)

(636.87 + 1.2x) (0.5118) = 239.19 (0.4364) + 397.68 (0.4280) + 0.6655x
325.95 + 0.6142x = 104.38 + 170.21 + 0.6655x
0.0513x = 51.36
x = 1001.16 lbs. cement per 1838.26 lbs. concrete = 54.46% cement

Cement content based on SiO_2 (Run #1) (Sample #4y)

(636.87 + 1.2x) (0.0246) = 239.19(0.0015) + 397.68(0.0009) + 0.2083x
15.67 + 0.0295x = 0.36 + 0.36 + 0.2083x
0.1788x = 14.95
x = 83.61 lbs. cement per 737.20 lbs. concrete = 11.34% cement

Cement content based on SiO_2 (Run #2) (Sample #4y)

(636.87 + 1.2x) (0.0344) = 239.19(0.0030) + 397.68(0.0014) + 0.2083x
21.91 + 0.0413x = 0.72 + 0.56 + 0.2083x
0.1670x = 20.53
x = 122.93 lbs. cement per 784.39 lbs. concrete = 15.67% cement

Sample #5y.

Avg. Analysis:	% CaO	%SiO_2 (Run #1)	%SiO_2 (Run #2)
Concrete	9.8	4.28	4.10
Fine Aggregate	2.32	0.72	0.70
Coarse Aggregate	4.22	0.56	0.61
Cement	63.0	21.75	

From batch design, wt. ratios as follows:

Cement	-	94.0
Water	-	18.8
Fine Aggregate	-	225.54
Coarse Aggregate	-	427.63
Total:		765.97

Amount of cement that should be present $= \frac{94.0}{765.97}(100) = 12.27\%$

Cement content based on CaO: (Sample #5y)

$(653.17 + 1.2x)\ (0.098) = 225.54(0.0232) + 427.63\ (0.0422) + 0.63x$
$64.01 + 0.1176x = 5.23 + 18.05 + 0.63x$
$0.5124x = 40.73$
$x = 79.49$ lbs. cement per 748.56 lbs. concrete = 10.62% cement

Cement content based on SiO_2 (Run #1) (Sample #5y)

$(653.17 + 1.2x)\ (0.0428) = 225.54(0.0072) + 427.63(0.0056) + 0.2175x$
$27.96 + 0.0514x = 1.62 + 2.39 + 0.2175x$
$0.1661x = 23.95$
$x = 144.19$ lbs. cement per 826.20 lbs. concrete = 17.45% cement

Cement content based on SiO_2 (Run #2) (Sample #5y)

$(653.17 + 1.2x)\ (0.0410) = 225.54(0.0070) + 427.63(0.0061) + 0.2175x$
$26.78 + 0.0492x = 1.58 + 2.61 + 0.2175x$
$0.1683x = 22.59$
$x = 134.22$ lbs. cement per 814.23 lbs. concrete = 16.48% cement

Sample #6y.

Avg. Analysis:	% CaO	%SiO_2 (Run #1)	%SiO_2 (Run #2)
Concrete	26.75	3.00	3.20
Fine Aggregate	11.4	0.12	0.32
Coarse Aggregate	22.1	0.17	0.36
Cement	63.0	21.75	

Wt. ratios based on batch design:

Cement - 94.0
Water - 18.8
Fine Aggregate - 216.67
Coarse Aggregate - 360.11
Total: 689.58

Amount of cement that should have been present = $\frac{94.0}{689.58}(100) = 13.63\%$

Cement content based on CaO: (Sample #6y)

(576.78 + 1.2x) (.2675) = (216.67)(.114) + (360.11)(.221) + .630x
154.289 + .321x = 24.700 + 79.584 + .630x
.309x = 154.289 - 104.284 = 50.005
x = 161.828 lbs. cement per 770.98 lbs. concrete = 20.99% cement

Cement content based on SiO_2 (Run #1) (Sample #6y)

(576.78 + 1.2x) (.03) = (216.67)(.0012) + (360.11)(.0017) + .2175x
17.30 + .0360x = .260 + .612 + .2175x
.1815x = 17.30 - .872 = 16.428
x = 90.51 lbs. cement per 685.39 lbs. concrete = 13.21% cement

Cement content based on SiO_2 (Run #2) (Sample #6y)

(576.78 + 1.2x) (.032) = (216.67)(.0032) + (360.11)(.0036) + .2175x
18.460 + .0384x = .693 + 1.296 + .2175x
.1791x = 18.460 - 1.989 = 16.471
x = 91.97 lbs. cement per 687.14 lbs. concrete = 13.38% cement

VIII.. DISCUSSION:

a. Comparison of results with other data.

1. Per cent by weight water soluble material.

The under surface of the deck from which the cores were taken is reported to have had a considerable incrustation of material which appeared to have been deposited by evaporation. Much of the deck under study being badly deteriorated and knowing the effect of chlorides in causing expansive corrosion surrounding reinforcing steel, it was decided to determine, if possible, the salt concentration in the cores taken from the structure. It was also felt to be of interest to determine if the level of salt concentration varied from top to bottom in the deck, or from sound to unsound cores taken from this same deck.

The test results indicate salt content of a low magnitude and very little significant difference in salt content between samples taken from the top, the middle or the bottom of the deck in question. So-called "sound" cores showed almost identical salt content as compared to cores taken from deteriorated portions of the same deck. From the test results obtained it was concluded that although the level of salt observed might possibly be a potential cause of trouble, it certainly was not present in extremely large amounts to indicate other than anticipated normal conditions. To accurately determine "normal" salt concentration in concrete might well prove to be a project in itself. The salt concentration observed in these samples may be attributed to: 1) admixtures in the concrete mix, 2) the possible use of ice-removal salts on the decks, 3) penetration of the concrete by naturally occurring salt-bearing surface water or road film deposited by traffic or by nature, 4) the natural salt content of the aggregate, sand, water and cement employed in the original mix. According to Lea & Desch[1] (see X., Bibliography) water soluble salts from the cement itself would be of minor proportion. They state: "The hydration products of cement are all compounds of relatively low solubility; were it not so, mortars and concretes would not remain stable in contact with water, but would rapidly suffer attack."

Although much has been written concerning the effects of various salts on concrete, a survey of literature available indicates that little work has been done regarding determining the range of soluble salt concentration in various concretes -- normal or otherwise. Since the salt concentration observed in these cores tested was not unduly large, further investigation was not considered warranted.

2. Per cent by weight moisture gain of oven dried pulverized core material in moist air.

3. Ion exchange capacity of pulverized core material.

The literature survey on this subject failed to reveal any work which had been done on concrete itself. There was found a wealth of material on the evaluation or detection of deleterious materials in aggregates for concrete but not on their detection in concrete itself. The standard test procedures employed to detect such substances in aggregates were applied to the testing of concrete itself. For example, expansive clay a known deleterious substance in concrete aggregate exhibits the following characteristics:

a. High moisture absorption
b. High ion exchange capacity
c. High plasticity index values

On the other hand, the P.I. of pulverized core is practically nil as might well be expected. How about water absorption or ion exchange? Reason would lead one to expect normal concrete to be water resistant. Should this badly deteriorated concrete evidence a high moisture absorption characteristic as compared to sound concrete, it might indicate the presence of faulty aggregates such as montmorillonite clay or of some other deleterious substance.

According to Crumpton & Badgley[2] (see X., Bibliography) one gram of montmorillonite clay absorbs approximately five grams of water and swells to twenty times its original thickness. Buth, Ivey and Hirsch[3 & 4] (see X., Bibliography) in their work on concrete aggregates relate ion-exchange capacity to the strength of concretes in which they are incorporated. According to Spangler[5] (see X., Bibliography) clay minerals are definitely crystalline in character -- composed chiefly of alumina, silica, and water---. Spangler also discusses the base exchange characteristics of clays and how this phenomenon changes the clays with respect to their plasticity, shrinkage and swell. Crumpton & Badgley[6] (see X., Bibliography) also discuss the action of hydrated montmorillonite clay which act as lubricants between the silt and sand grains in loess and allow the grains to collapse into the void spaces during compaction or loading. According to Schubler[7] (see X., Bibliography) a heavy clay of 90% clay 10% sand has a water holding capacity of 61% by weight, 62.9% by volume and requires 10 hours 19 minutes to lose 90% of this moisture at 18.8°C. He showed water vapor absorption of 40 grams per 1000 in 48 hours on the same heavy clay. This data leads one to believe that the test conditions chosen for the investigation of moisture gain in pulverized concrete was probably valid. The test data concerning moisture gain failed to correlate between sound and unsound cores nor did it correlate with ion exchange values obtained. It had been hoped that cores showing a relatively high moisture absorption characteristic would also evidence a high ion exchange capacity and thereby give two good indications of the presence of expansive clay aggregates. The subject of clays seems to be rather involved as was learned from Mr. Weintritt of the Baroid Corp. in Houston. Clays may be work has been done regarding determining the range of soluble salt concentration in various concretes -- normal or otherwise. Since the salt concentration observed in these cores tested was not unduly large, further investigation was not considered warranted.

2. Per cent by weight moisture gain of oven dried pulverized core material in moist air.

3. Ion exchange capacity of pulverized core material.

The literature survey on this subject failed to reveal any work which had been done on concrete itself. There was found a wealth of material on the evaluation or detection of deleterious materials in aggregates for concrete but not on their detection in concrete itself. The standard test procedures employed to detect such substances in aggregates were applied to the testing of concrete itself. For example, expansive clay a known deleterious substance in concrete aggregate exhibits the following characteristics:

a. High moisture absorption
b. High ion exchange capacity
c. High plasticity index values

On the other hand, the P.I. of pulverized core is practically nil as might well be expected. How about water absorption or ion exchange? Reason would lead one to expect normal concrete to be water resistant. Should this badly deteriorated concrete evidence a high moisture absorption characteristic as compared to sound concrete, it might indicate the presence of faulty aggregates such as montmorillonite clay or of some other deleterious substance.

According to Crumpton & Badgley[2] (see X., Bibliography) one gram of montmorillonite clay absorbs approximately five grams of water and expansive in nature but not necessarily show correlation with high water absorption. For example, Kaolinite expands considerably but does not evidence an extremely high water absorption characteristic as compared to montmorillonite clay which does absorb water to a great degree. A method to differentiate between the types of clays was needed if water absorption were to serve as a valid indication. Ion exchange was found to be a characteristic shared in common by all expansive clays so detection of expansive clay in these cores was attempted by ion-exchange capacity determinations in the pulverized core material.

The three year study of clays in concrete aggregates by Buth, Ivey and Hirsch[4] (see X., Bibliography) definitely correlates high ion exchange capacity in aggregates with lessened concrete strengths. The ion exchange capacity determinations in their work, however, were made on the aggregates before incorporation into concrete batch design and not on hardened, pulverized concrete as such.

The early ion exchange capacity data seemed to indicate some degree of correlation between high ion exchange capacity values and severely deteriorated decks. True there were data scatterings which indicated lack of correlation. It was decided that the limited number of tests indicated a trend sufficient to justify further exploration to discover if such a relationship actually existed. Numerically speaking, there were not enough tests or data to validly form any definite conclusions. Having decided to further investigate ion exchange on a large number of cores and noting considerable time and expense was involved in each determination, an attempt was made to find a short cut method which would reduce testing costs while allowing a larger statistical sampling of the many cores available for study.

Mr. W. V. Ward of the Houston Urban Project called attention to a paper on this subject as applied to clays which he felt might be of interest to the Department. This work by Nevins & Weintritt[8] (see X., Bibliography) ably presented a method for ion exchange capacity determination which, if it could be successfully applied to this bridge deck study, could save considerable expense since testing time per sample would be reduced from hours to minutes. The work was well substantiated and documented for use with clays. However, after extensive evaluation it was found that there was no correlation between the method under consideration and other more time consuming methods which had been employed for this purpose. It should be kept in mind that all of these methods were intended for use with clays and that the lack of correlation experienced between these various methods came about when these clay methods were applied to the testing of pulverized concrete. Acknowledgment is extended to Mr. Nevins and Mr. Weintritt of the Baroid Division of the National Lead Co. in Houston who personally consulted with Materials and Tests Division personnel as concerns this potential application of their procedure. They assisted in this work to the extent of having cooperative tests run at their Houston facility to substantiate the results being obtained by the Materials and Tests Division in utilizing Baroid's test procedure. The respective test results on some 6 samples determined by both conventional and short-cut procedures were in agreement. A joint conclusion was reached that for reasons unknown the short-cut procedure (Methylene Blue Method) did not correlate with standard procedures (Ammonium Acetate Method) as applied to pulverized concrete. Further attempts to pursue this approach were abandoned and conventional methods were employed to conclude the investigation. One of several conventional methods was chosen as probably the more valid of the methods employed and the investigation was completed using that method -- namely the Ammonium Acetate Centrifuge Method. (see Appendix IX).

After evaluating a sufficient sampling of ion exchange test data on these cores, it is concluded that this is negative research. No valid conclusion is to be drawn from the findings. As many high ion exchange capacity core samples came from badly deteriorated decks as were reported to come from sound decks employing the same aggregates. Perhaps the potential for future deterioration exists in these "sound" decks but as of this writing it is felt that there is no proof or disproof of the presence of faulty aggregates of the expansive clay type through the evaluation of the ion exchange values found as related to observed deck condition.

4. Cement content determination.

The test data was compared with probable mix design for purposes of evaluation. This comparison is to be found in the "calculation of cement content in the cores"---4 B. At best this procedure for the determination of cement content in hardened concrete is an "estimation". The inherent accuracy attainable with the method leaves much to be desired. Several assumptions were made in this determination which can contribute to sizeable errors.

Assumptions:

a. The values for calcium and for soluble silica for the cement were average values for Portland cement rather than actual analysis values for the cement employed in the original mixes.

b. The sand and aggregates chosen to represent the sand and aggregate in the original mix were samples taken from the same pit source some 10 to 20 years after the original samples were taken. The assumption here is that the analyzed values for calcium and soluble silica, etc. in these later samples will serve to represent those of the original sand and aggregates. Obviously, this is not necessarily true.

c. The batch design, ratio of sand to aggregate, etc. was as originally specified for the jobs in question.

As Lea & Desch[9] (see X., Bibliography) state: "Though so apparently simple in principle the difficulties in practice of obtaining even approximately accurate values are often considerable. If the aggregate is free from any appreciable quantity of calcareous compounds the lime content of the concrete can be used as the basis of estimation, but when this is not so the soluble silica content has to be used." They state further: "In favorable cases when the composition of the cement is known and the content of soluble material in the aggregate is negligible, the error in the calculated cement content by weight of a mortar or concrete may not exceed 5 per cent. If the composition of the cement has to be assumed the possible errors rise and may reach 10 per cent by the silica method."

ASTM C 85-54 (1961) the "Standard Methods of Test for Cement Content of Hardened Portland Cement Concrete" states under Scope: "1. This method of test for determining the cement content of concrete is applicable to hardened portland cement concretes except those containing certain aggregates or admixtures which liberate soluble silica under the conditions of this test, such as slag, diatomites, and sodium silicate."

These qualifications as concerns the procedure employed should be considered and any results shown should be weighed against the validity of the test method employed. Polivka, Kelly and Best[10] (see X., Bibliography) in their evaluation of the procedure which has been employed here show on six samples selected for their study an average relative error of 35.2% where materials were not available as in this case for the silica method and 8.1% for the calcium method utilizing ASTM C 85-54 as discussed. They further state: "In any case, accuracy within 10 per cent is not meaningful since concrete cannot be controlled in the field within 10 per cent."

These determinations are of interest although not necessarily conclusive due to the inherent errors in the standard procedures employed.

b. Comments of persons performing work.

The data presented here has been compiled and edited by T. W. Becker, Chemist III. Acknowledgment is given to those performing the work herein assembled. Those directly involved were:

Mr. Don L. O'Connor, Engineer III
Mr. Charlie A. Dumas, Chemist II
Mr. Joe E. Chamberlain, Materials Analyst II
Mr. Leonard A. Iselt, Engr. Tech. II
Mr. Charles E. Screws, Materials Analyst II
Mr. Pat D. Kimbrough, Engr. Tech. II
and others not specifically mentioned.

All of the above personnel assisted to varying degrees in this work of the Asphalt and Chemical Section of the Materials and Tests Division. As to comments of these individuals concerning this work:

Mr. O'Connor: 1. "I believe that for our purposes, determination of calcium by the EDTA method would be more desirable than the methods set forth in ASTM C 85-54. Less time is required for the EDTA method and it is more fool proof. Slightly better accuracy can be obtained using the ASTM method, provided the analyst exercises extreme care and very good technique.

2. "In the soluble silica determination the results obtained varied with the baking temperature and length of the baking period. It is suggested that it would be well, if possible, to work with a material containing a known amount of soluble silica to determine the optimum time and temperature of baking."

Mr. Dumas: 1. "The blanks for the various soluble silica determinations varied somewhat from one series of determinations to another. I believe this was due in part, at least, to the small amount of spattering which occurred in evaporating the sample to dryness on the steam bath and upon baking. Extreme care should be exercised in this portion of the test if accuracy is to be attained."

Mr. Iselt: "In crushing and grinding the concrete cores, the ventilation fans over the grinding machine should be left turned off so that you do not carry away some of the cement fines. Also, in setting the steel grinding plates on the Braun Pulverizer if the faces are not set too close and you repeat the grinding over and over, you will get less steel from the plates in the sample than if the plates were set closely together. We used an automotive pickup rod with a large magnet ½-inch in diameter and 3½ inches long attached to a handle. This special magnet was passed through the pulverized sample in a plastic sack and after removing the magnet plus steel and other magnetic particles from the sample the magnet was cleaned with a rag and the whole procedure was repeated until all the steel, etc. was removed from the sample. Careful grinding can save a lot of time."

Mr. Kimbrough: "Acid baking and steam table samples should be kept under a hood since the fumes can be pretty irritating. When taking the silica determination samples to dryness avoid 'bumping' and particularly spattering by heating on a hot plate to only within 15 to 20 ml. of dryness and then moving the sample to a steam table or to a pan of heated sand."

Mr. Becker: "It is to be noted that the amount of sample required by ASTM (approximately 30 pounds) for determination of cement content was not used. Only a single 4-inch diameter core and in some cases even less material was used to represent each sample determined. The limitation here being that a minimum of cores were taken from these structures which are for the most part still in use by the travelling public. The average sample used in the various determinations was approximately four pounds prior to crushing, etc. Had 3 or 4 cores of material from each portion of the deck been available, these cores combined into a single sample from each portion of the deck would have given a more representative sampling."

IX. APPENDIX

Appendix I

Standard Texas Highway Department Method for the Determination of Ion Exchange Capacity of Pulverized Hardened Portland Cement Concrete--Ammonium Acetate Method with 16 Hours Digestion Period.

A 15 gram sample of pulverized material was weighed into a 250 ml. Erlenmeyer flask and 100 mls. of normal neutral (pH-7) ammonium acetate was added. The flasks were stoppered with rubber stoppers and shaken vigorously at 15 minute intervals for one hour (4 times) and then allowed to digest for 16 hours. The samples were agitated and then poured into 7 cm. buchner funnels fitted with No. 42 Whatman filter paper which had been previously wetted with distilled water. Side neck filtering flasks of 600 ml. capacity were used so that the rate of filtration could be controlled by applying a partial vacuum. The samples were kept covered with watch glasses to minimize contact with air. After the first 100 ml. of Leachate had passed through the sample and before visible drying or cracking developed, 50 ml. of fresh leachate was added and filtering continued as before until four such 50 ml. batches had been used. The rate of leaching was regulated so that the leaching process required at least two hours. Following the leaching the samples were washed three times with 50 ml. batches of 80 per cent methyl alcohol. The samples were drained well between each addition of alcohol but care was exercised to avoid drying out the sample. The samples were then transferred to 800 ml. Kjeldahl flasks.

The sample plus filter paper was washed into the distillation flask with 375 mls. of distilled water. Ten grams of sodium chloride, several small pieces of boiling stones, and 25 ml. of 20% sodium hydroxide added to the contents of the flask. The mixture was stoppered and agitated by swirling motion. Any ammonia that was displaced during agitation was neutralized by 50 ml. of 0.1 N. sulfuric acid and 100 mls. distilled water in a 250 ml. gradulate placed beneath the condenser of the distillation set-up. The burner was lit and the flame adjusted so that the mixture began to boil in about 15 minutes. Distillation was continued until a total of 100 mls. of distillate had been carried over into the gradulate.

The distillate-neutralization solution mixture was then transferred to a 400 ml. beaker and titrated using 0.1 N sodium hydroxide with four drops of methyl red as an indicator.

Appendix II

Methylene Blue Method (Field Procedure) for the Rapid Determination of the Ion Exchange Capacity of Pulverized Hardened Portland Cement Concrete.

A 5 gram sample of the pulverized material was weighed out into a 250 ml Erlenmeyer flask. Ten mls of distilled water, 15 mls of 3% hydrogen peroxide, and 0.5 mls of 0.5N sulfuric acid was added to the sample.

The sample mixture was boiled gently for 10 minutes after which it was then diluted with 50 mls of distilled water. The sample and flask were then placed on a magnetic stirrer and the sample was stirred during the addition of the methylene blue test solution which was added 1 ml at a time. After each addition of 1 ml, the sample was allowed to stir for 30 seconds. While the solids were still suspended, one drop of liquid was removed from the flask by a stirring rod and placed on a Whatman #30 filter paper. The end point of the titration is reached when dye appears as a greenish-blue ring surrounding the dyed solids.

When the blue tint spreading from the spot is detected, the sample was stirred an additional 2 minutes and another drop placed on the filter paper. If the blue ring was again evident, the end point has been reached. If the ring does not appear, the process continues as before until a drop taken after stirring 2 minutes shows the blue tint.

Appendix III

Methylene Blue Method (Research Procedure) for the Determination of the Ion Exchange Capacity of Pulverized Hardened Portland Cement Concrete.

A 5 gram sample of pulverized material was weighed out and placed into an Oster brand blender along with 180 mls. of distilled water. The blender was run at high speed for 15 minutes. The sample was washed out of the blender with distilled water into a 400 ml. beaker. A watch glass was placed on top of the beaker and contents which were allowed to digest for 16 hours.

After 16 hours of digestion, 15 mls. of 3% hydrogen peroxide and 0.5 mls. of 0.5N sulfuric acid was added to the sample. The sample was tested with blue litmus paper to be sure the mixture was acidic. If mixture is basic, 0.5N sulfuric acid is added until the mixture becomes acid (this process was repeated after each addition of 3 mls. of methylene blue test solution).

The sample mixture was boiled gently for 10 minutes. Sample was checked again to see if it was acidic or basic. The sample and flask were then placed on a magnetic stirrer and the sample was stirred while the methylene blue test solution was added 1 ml. at a time. After each addition of 1 ml. the sample was allowed to stir for 30 seconds. While the solids were still suspended, one drop of liquid was removed from the flask by a stirring rod and placed on a #30 filter paper. The end point of the titration is reached when dye appears as a greenish-blue surrounding the dyed solids.

When the blue tint spreading from the spot was detected, the sample was stirred an additional 2 minutes and another drop placed on the filter paper. If the ring does not appear, the process continues as before until a drop taken after stirring 2 minutes shows the blue tint.

Appendix IV

Texas Highway Department Method for the Determination of the Ion Exchange Capacity of Pulverized Hardened Portland Cement Concrete (A Modification of the Baroid Division of the National Lead Co's. Standard Method of Test No. M-1-59 for the Determination of Base Exchange Capacity, B.E.C. of Montmorillonite).

A 2.5 gram sample of pulverized material was weighed out and transferred to a pear shape centrifuge tube provided with stopper. Each sample was dispersed in 30 ml. of normal ammonium acetate solution (77 grams of ammonium acetate/1 liter distilled water) and agitated for 5 minutes. The tube and sample were then placed in the centrifuge at 1980 RPM for 20 minutes and then removed. The clear liquid portion was decanted. The solid portion was suspended again in 30 mls. of ammonium acetate solution, and the shaking, centrifuging, and decanting operations repeated twice more.

After the last washing with ammonium acetate and decanting, the solid portion was suspended in 30 mls. of 200 proof alcohol and agitated. The tube and sample were then placed in the centrifuge for 20 minutes. The clear liquid was decanted and the solid portion treated three additional times with 200 proof alcohol each time with alternate shaking and centrifuge described above.

After the last washing with alcohol and decanting, the solid portion was suspended in 30 mls. distilled water and washed into a Kjeldahl flask using about 150 mls. of distilled water. The Kjeldahl flask was then placed on a Kjeldahl distillation rack and 25 mls. of 20% sodium hydroxide and several small pieces of boiling stones were added to the contents of the flask. The mixture was stoppered and agitated by a swirling motion. Any ammonium displaced during agitation was neutralized by 50 ml. of 0.1N sulfuric acid and 100 mls. distilled water in a 250 ml. gradulate placed beneath the condenser of the distillation set-up. The burner was lit and the flame adjusted so that the mixture began to boil in about 15 minutes. Distillation was continued until a total of 100 mls. of distillate had been carried over into the gradulate.

The distillate-neutralization solution mixture was then transferred to a 400 ml. beaker and titrated using 0.1 N sodium hydroxide with four drops of methyl red as an indicator.

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APPROVED AS
AMERICAN STANDARD A1.22-1961
BY AMERICAN STANDARDS ASSOCIATION
UDC 666.94:620.168
AMERICAN ASSOCIATION STATE
HIGHWAY OFFICIALS STANDARD
AASHO NO.: T 178

Standard Methods of Test for

CEMENT CONTENT OF HARDENED PORTLAND CEMENT CONCRETE[1]

ASTM Designation: C 85 – 54 (1961)

ADOPTED, 1936; LAST REVISED, 1954; REAPPROVED, 1961

This Standard of the American Society for Testing and Materials is issued under the fixed designation C 85; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision.

Scope

1. This method of test for determining the cement content of concrete is applicable to hardened portland cement concretes ***except those containing certain aggregates or admixtures which liberate soluble silica under the conditions of the test, such as slag, diatomites, and sodium silicate.***

Reagents

2. (*a*) *Hydrochloric Acid* (*1:3*).—Add 200 ml of HCl (sp gr 1.19) to 600 ml of distilled water.

(*b*) *Hydrochloric Acid* (*1:9*).—Add 100 ml of HCl (sp gr 1.19) to 900 ml of distilled water.

(*c*) *Sodium Hydroxide Solution* (*40 g NaOH per liter*).—Dissolve 20 g of NaOH in 200 ml of distilled water and dilute to a volume of 500 ml.

~~(*d*) *Hydrofluoric Acid* (*48 per cent*).~~

~~(*e*) *Sulfuric Acid* (*sp gr 1.84*).~~

Preparation of Sample[1]

3. Every precaution shall be taken to have the sample of concrete used for analysis truly representative of the material under consideration. ~~Several portions weighing at least 10 lb each shall be taken to avoid all but slight inequalities of the concrete mix. These portions shall then be broken up, crushed in a suitable machine to about $\frac{1}{2}$ in. in size, and reduced to a fineness of approximately 150- to 200-mesh in a ball mill, disk pulverizer, or other device. Care shall be taken that the finer fractions of the broken sample, which are richer in cement, are not discarded or lost.~~ After thorough mixing and quartering, a portion approximating 100 g shall be taken and carefully freed, by means of a strong magnet, from particles of metallic iron abraded from the pulverizer or ball mill. The clean sample then shall be dried at 105 C for at least 2 hr.

See
Procedure
Change 1.

Procedure

4. (*a*) Weigh into each of three 250-ml beakers not less than a 2-g portion of the prepared sample. Moisten with

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[1] Under the standardization procedure of the Society, this method is under the jurisdiction of the ASTM Committee C-9 on Concrete and Concrete Aggregates.

a stream of hot water, while stirring to prevent adhesion to the beaker or the formation of lumps in the mass. Slowly add 100 ml of HCl (1:3) and stir thoroughly. The lumps which tend to form should be reduced with the glass rod. After the evolution of CO_2 has ceased and the reaction is apparently complete, heat gently for a few minutes and allow the contents of the beaker to settle. ~~Decant through a Gooch crucible fitted snugly with a disk of No. OK Munktell's filter paper. Once the filtration has begun, care shall be taken so that the mat and accumulated residue do not dry out completely until the filtration process is complete. Regulate the suction so as to maintain a rapid rate of dropping during the greater part of the filtration.~~ Retain as much of the residue in the beaker as possible. Wash by decantation twice with hot water. Add 75 ml of the NaOH solution to the residue while stirring and heat to about 75 C. Decant as before and wash twice with hot water. Transfer the residue to the crucible and wash with at least 60 ml of hot water.

See
Procedure
Change 2.

(*b*) The filtrate now contains the silica in the form of silicic acid, either in true solution or in suspension in the hydrochloric acid medium. If the aggregates of the original sample are largely calcareous or dolomitic, add 10 ml of HCl (sp gr 1.19) to the solution. Transfer to a suitable beaker, with several rinsings of the filter flask. Evaporate to dryness with great care to minimize spattering, bake at not over 120 C for 1 hr, moisten with HCl (sp gr 1.19), evaporate and bake again, and take up for filtration in 75 ml of HCl (1:3) heated to boiling. Filter through an ashless filter paper, and wash the residue with 50 ml of hot HCl (1:9) and then with hot water until the washings are free from chlorides. Repeat the evaporation and filtering processes to recover the small amounts of silica dissolved and add these to the first residue. ~~Determine the silica present in the sample by treatment with HF and H_2SO_4 in accordance with the procedure given in Section 8 of the Methods of Chemical Analysis of Hydraulic Cement (ASTM Designation: C 114).[2]~~

(Use
Whatman
#42 filter
paper)

(*c*) The filtrate from the silica determination contains the soluble constituents from the aggregates and the cement. Determine the soluble calcium oxide in the filtrate (after removal of the iron and aluminum hydroxides) in accordance with either Section 13 of Methods C 114 ~~or Section 12 of the Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (ASTM Designation: C 25).~~[2] If the tests thus far have indicated that the aggregates are largely siliceous, use the entire filtrate for the calcium oxide determination; otherwise, use an aliquot thereof. ------------

Go to page 94,
Sect. 12 of
Chemical Analysis of Portland
Cement, ASTM
C 114 for
Ammonium
Hydroxide Group
(Referee Method)

Correction Factors

5. Whenever the aggregates are available that were used in the concrete being analyzed, blank tests shall be run on these aggregates to determine their content of silica and of calcium oxide, soluble under the conditions of the test (Section 4). These contents of soluble silica and calcium oxide shall then be used as correction factors and be subtracted from the total soluble silica and calcium oxide found in the concrete, the difference being due to the cement contained in the specimen.

Calculation

6. Calculate the percentage of cement in the sample by dividing the corrected percentage of soluble silica found by the factor 0.2175,[3] and the corrected per-

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[2] Appears in this publication.

[3] For the correctness of this factor as an average silica content of American cements, see Report of Subcommittee I on Definitions and Chemical Limitations, of Committee C-1 on Cement, *Proceedings*, Am. Soc. Testing Mats., Vol. 28, Part I, pp. 238 to 243 (1928).

centage of soluble calcium oxide found by the factor 0.630, provided it is not known that the silica and calcium oxide contents of the cement differ from these values. Whenever possible, the *known values* shall be taken as the factors.

Acceptance of Results

7. When the cement content determinations by the soluble silica and the soluble calcium oxide procedures differ from each other, the analyst is directed to accept the *lower* value.

PROCEDURE CHANGES

Change 1

The following procedures shall be followed in preparing the samples to be analyzed.

Concrete Cores

1. Break up by hand and remove any portions of reinforcing steel present.
2. Crush entire core to pass 1/4 inch screen.
3. At this point, carefully quarter the sample to obtain approximately 400 grams.
4. Crush and grind the entire 400 grams of sample to pass a 170 mesh screen.

Coarse Aggregate

1. Quarter the sack of aggregate.
2. Crush one quarter to pass a 1/4 inch screen.
3. At this point, carefully quarter the sample to obtain 400 grams.
4. Grind the entire 400 grams to pass a 170 mesh screen.

Fine Aggregate (Sand)

1. Quarter the sack of sample to obtain approximately 400 grams.
2. Crush and grind the entire 400 grams to pass a 170 mesh screen.

Change 2

Decant through an analytical, 60 degree fluted funnel fitted with Whatman No. 30 filter paper. Care should be taken to fit the paper into the funnel so that a solid column of filtrate can be maintained in the funnel stem.

Change 3

Carefully fold the filter papers containing the silica residues and place in a tared platinum crucible. Dry the filter paper and residue at approximately 100 degrees C. and then burn off the filter paper utilizing a meeker burner. After burning off all the carbon possible with the meeker burner, place in the muffle furnace for 30 minutes, then remove, cool and weigh. This procedure should be repeated until constant weight is obtained. The residue weight shall be considered silica.

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BY AMERICAN STANDARDS ASSOCIATION
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Standard Methods for
CHEMICAL ANALYSIS OF HYDRAULIC CEMENT[1]

ASTM Designation: C 114 – 65

ADOPTED, 1939; LAST REVISED, 1965

This Standard of the American Society for Testing and Materials is issued under the fixed designation C 114; the final number indicates the year of original adoption as standard, or in the case of revision, the year of last revision.

1. Scope

~~1.1 These methods cover the chemical analysis of hydraulic cements. The methods are divided into two main groups, referee and optional.~~

2. Number of Chemical Determinations and Permissible Variations of Described Methods

~~2.1 *Referee Methods*—The referee methods are required for referee analysis in those cases where chemical specification requirements are questioned. In these cases, the cement shall not be rejected for failure to conform to a chemical requirement unless all determinations of constituents involved and all separations prior to the determination of any one constituent are made entirely by referee methods prescribed in the appropriate sections.~~

2.1.1 Referee analyses, when there is a question regarding acceptance, shall be made in duplicate and the analyses shall be made on different days. If the two results do not agree within the permissible variation given in Table 1, the determination shall be repeated until two or three results agree within the permissible variation. When two or three results do agree within the permissible variation, their average shall be accepted as the correct value. When an average of either two or three results can be calculated, the calculation shall be based on the three results. For the purpose of comparing analyses and calculating the average of acceptable results, the percentages shall be calculated to the nearest 0.01 (or 0.001 in the case of chloroform-soluble organic substances), although some of the average values are reported to 0.1 as indicated in the methods. When a blank determination is specified, one shall be made with each individual analysis or with each group of two or more samples analyzed on the same day for a given component.

~~2.2 *Optional Methods*—The optional~~

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[1] Under the standardization procedure of the Society, these methods are under the jurisdictions of the ASTM Committee C-1 on Cement.

~~TABLE 1—MAXIMUM PERMISSIBLE VARIATIONS IN RESULTS.~~

Component	Difference Between two Results	Difference Between the Extreme Values in Three Results
Silicon dioxide, SiO_2	0.16	0.24
Aluminum oxide, Al_2O_3	0.20	0.30
Ferric oxide, Fe_2O_3	0.10	0.15
Calcium oxide, CaO	0.20	0.30
Magnesium oxide, MgO	0.16	0.24
Sulfur trioxide, SO_3	0.10	0.15
Sulfide sulfur, S	0.01	0.02
Loss on ignition	0.10	0.15
Sodium oxide, Na_2O	0.03	0.05
Potassium oxide, K_2O	0.03	0.05
Water-soluble alkali[a]	$\frac{0.75}{w}$	$\frac{1.00}{w}$
Titanium dioxide, TiO_2	0.02	0.03
Phosphorus pentoxide, P_2O_5	0.03	0.05
Manganic oxide, Mn_2O_3	0.03	0.05
Insoluble residue	0.10	0.15
Chloroform-soluble organic substances	0.004	0.006
Free calcium oxide	0.20	0.30

[a] w = weight of sample used for tests.

~~methods are provided for those who wish to use procedures shorter or more convenient than the referee methods for the routine determination of certain constituents (Note 1). Test results by optional methods may be used as the basis for acceptance or rejection of a cement when there is no question as to whether the cement does or does not meet the specification requirements.~~

~~NOTE 1—It is not intended that the use of referee methods be confined to referee analysis. A referee method may be used in preference to an optional method when so desired. A referee method must be used where an optional method is not provided.~~

2.2.1 Duplicate analyses and blank determinations are not required when using the optional methods. If, however, a blank determination is desired for an optional method, one may be used and it need not have been obtained concurrently with the analysis. The final results, when corrected for blank values, should, in either case, be so designated.

2.3 The methods appear in the following order:

REFEREE METHODS

	Sections
Silicon Dioxide	9 to 11
Ammonium Hydroxide Group	12 to 14
Ferric Oxide	15 to 18
Aluminum Oxide	19
Calcium Oxide	20 to 22
Magnesium Oxide	23 to 26
Sulfur Trioxide	27 to 29
Sulfide Sulfur	30 to 34
Loss on Ignition—Portland Cement	35 to 37
Loss on Ignition—Portland Blast-Furnace Slag Cement and Slag Cement	38 to 40
Sodium Oxide and Potassium Oxide	41 to 48
Water-Soluble Alkali	49 and 50
Titanium Dioxide	51 to 56
Phosphorus Pentoxide	57 to 60
Manganic Oxide	61 to 64
Insoluble Residue	65 to 68
Chloroform-Soluble Organic Substances	69 to 72
Free Calcium Oxide	73 to 77

~~OPTIONAL METHODS~~

Silicon Dioxide	78 to 81
Calcium Oxide	82 to 85
Magnesium Oxide	86
Method A—Gravimetric	87 and 88
Method B—Hydroxyquinoline	89 to 91
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~~Titanium Dioxide. . . . . 104 to 108~~
~~Phosphorus Pentoxide. . . . . 109 to 112~~
~~Manganic Oxide. . . . . 113 to 116~~
~~Free Calcium Oxide. . . . . 117 to 120~~

3. Interferences and Limitations

3.1 These methods were developed primarily for the analysis of portland cements. However, except for limitations noted in the procedure for specific constituents, the referee methods provide for accurate analyses of other hydraulic cements that are completely decomposed by hydrochloric acid or where a preliminary sodium carbonate fusion is made to ensure complete solubility. Some of the optional methods may not always provide accurate results because of interferences from elements which are not removed during the procedure.

4. Apparatus and Materials

4.1 *Balance* (Note 2)—The analytical balance used in the chemical determinations shall conform to the following requirements:

NOTE 2—Information on analytical balances and weights, to supplement the requirements for balances and weights prescribed in these methods, has been prepared and is published as information.[2]

4.1.1 The balance shall have a capacity of not more than 200 g. It may be of conventional design, either with or without "quick-weighing" devices, or it may be a constant-load, direct-reading type. It shall be capable of reproducing results within 0.0002 g with an accuracy of ±0.0002 g. Direct-reading balances shall have a sensitivity not exceeding 0.0001 g (Note 3). Conventional two-pan balances shall have a maximum sensibility reciprocal of 0.0003 g. Any rapid weighing device that may be provided, such as a chain, damped motion, or heavy riders, shall not increase the basic inaccuracy by more than 0.0001 g at any reading and with any load within the rated capacity of the balance.

NOTE 3—The sensitivity of a direct-reading balance is the weight required to change the reading one graduation. The sensibility reciprocal for a conventional balance is defined as the change in weight required on either pan to change the position of equilibrium one division on the pointer scale at capacity or at any lesser load.

4.2 *Weights*—Weights used for analysis shall conform to Class S-1 requirements of the National Bureau of Standards as described in NBS Circular 547. They shall be checked at least once a year, or when questioned, and adjusted to within allowable tolerances for Class S-1 weights. For this purpose each laboratory shall also maintain, or have available for use, a reference set of standard weights from 50 g to 10 mg, which shall conform to Class S requirements and be calibrated at intervals not exceeding 5 years by the National Bureau of Standards (Note 4). All new sets of weights purchased shall have the weights of 1 g and larger made of stainless steel or other corrosion-resisting alloy not requiring protective coating, and shall meet the density requirements for Class S.

NOTE 4—After initial calibration, recalibration by the National Bureau of Standards may be waived provided it can be shown by documented data obtained within the time interval specified that a weight comparison between summations of smaller weights and a single larger weight nominally equal to that summation, establishes that the allowable tolerances have not been exceeded.

4.3 *Glassware and Laboratory Containers*—Standard volumetric flasks, burets, and pipets should be of precision grade or better. Standard-taper, interchangeable, ground-glass joints are recommended for all volumetric glassware and distilling apparatus, when available. Wherever applicable, the use of special types of glassware, such as colored glass

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[2] See the compilation of ASTM Standards Relating to Cement, December, 1962, p. 267.

for the protection of solutions against light, alkali-resistant glass, and high-silica glass having exceptional resistance to thermal shock is recommended. Polyethylene containers are recommended for all aqueous solutions of alkalies and for standard solutions where the presence of dissolved silica or alkali from the glass would be objectionable. Such containers shall be made of high-density polyethylene having a wall thickness of at least 1 mm.

4.4 *Desiccators*—Desiccators shall be provided with a good desiccant, such as magnesium perchlorate, activated alumina, or sulfuric acid. Anhydrous calcium sulfate may also be used provided it has been treated with a color-change indicator to show when it has lost its effectiveness. Calcium chloride is not a satisfactory desiccant for this type of analysis.

4.5 *Filter Paper*—Filter paper shall conform to the requirements of ASTM Specification D 1100, for Filter Paper For Use in Chemical Analysis,[3] Type II, Quantitative. When medium-texture paper is required, Class F paper shall be used and when retentive paper is required, Class G shall be used.

4.6 *Crucibles*—Platinum crucibles for ordinary chemical analysis should preferably be made of pure unalloyed platinum and be of 15 to 30-ml capacity. Where alloyed platinum is used for greater stiffness or to obviate sticking of crucible and lid, the alloyed platinum should not decrease in weight by more than 0.2 mg when heated at 1200 C for 1 hr.

4.7 *Muffle Furnace*—The muffle furnace should be capable of continuous operation up to 1200 C, and should have an indicating pyrometer accurate to ±25 C (Note 5).

NOTE 5—Muffle furnaces with heating elements of Nichrome wire do not normally meet this requirement. However, for ignition temperatures up to 1000 C such muffles are satisfactory and may be used provided a method is available for heating the designated residues to the required temperatures above 1000 C.

5. Purity of Reagents

5.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.[4] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5.2 Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to ASTM Specifications D 1193, for Reagent Water.[5]

6. Concentration of Reagents

6.1 *Concentrated Acids and Ammonium Hydroxide*—When acids and ammonium hydroxide are specified by name or chemical formula only, it shall be understood that concentrated reagents of the following specific gravities or concentrations by weight are intended:

Acetic acid ($HC_2H_3O_2$)	99.5 per cent
Hydrochloric acid (HCl)	sp gr 1.19
Hydrofluoric acid (HF)	48 per cent
Nitric acid (HNO_3)	sp gr 1.42
Phosphoric acid (H_3PO_4)	85 per cent
Sulfuric acid (H_2SO_4)	sp gr 1.84
Ammonium hydroxide (NH_4OH)	sp gr 0.90

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[3] *1966 Book of ASTM Standards*, Part 15.

[4] "Reagent Chemicals, American Chemical Society Specifications," Am. Chemical Soc., Washington, D. C. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," by Joseph Rosin, D. Van Nostrand Co., Inc., New York, N. Y., and the "United States Pharmacopeia"

[5] *1965 Book of ASTM Standards*, Part 23.

6.1.1 The desired specific gravities or concentrations of all other concentrated acids shall be stated whenever they are specified.

6.2 *Diluted Acids and Ammonium Hydroxide*—Concentrations of diluted acids and ammonium hydroxide, except when standardized, are specified as a ratio stating the number of volumes of the concentrated reagent to be added to a given number of volumes of water, for example: HCl (1:99) means 1 volume of concentrated HCl (sp gr 1.19) added to 99 volumes of water.

6.3 *Standard Solutions*—Concentrations of standard solutions shall be expressed as normalities (N) or as equivalents in grams per milliliter of the component to be determined, for example: $0.1N$ $Na_2S_2O_3$ or $K_2Cr_2O_7$ (1 ml = 0.004 g Fe_2O_3). The average of at least 3 determinations shall be used for all standardizations. When a material is used as a primary standard, reference has generally been made to the standard furnished by the National Bureau of Standards. However, when primary standard grade materials are otherwise available they may be used or the purity of a salt may be determined by suitable tests.

6.4 *Nonstandardized Solutions*—Concentrations of nonstandardized solutions prepared by dissolving a given weight of the solid reagent in a solvent shall be specified in grams of the reagent per liter of solution, and it shall be understood that water is the solvent unless otherwise specified, for example: NaOH (10 g/liter) means 10 g of NaOH dissolved in water and diluted with water to 1 liter. Other nonstandardized solutions may be specified by name only, and the concentration of such solutions will be governed by the instructions for their preparation.

6.5 *Indicator Solutions: Methyl Red*—Prepare the solution on the basis of 2 g of methyl red/liter of 95 per cent ethyl alcohol. *Phenolphthalein*—Prepare the solution on the basis of 1 g of phenolphthalein/liter of 95 per cent ethyl alcohol.

7. Sampling

7.1 Samples of the cement shall be taken and prepared as prescribed in ASTM Methods C 183, Sampling Hydraulic Cement.[6]

8. General Procedures

8.1 *Weighing*—The calculations included in the individual procedures assume that the exact weight specified has been used. Accurately weighed samples, which are approximately but not exactly equal to the weight specified may be used provided appropriate corrections are made in the calculations. Unless otherwise stated, weights of all samples and residues should be recorded to the nearest 0.0001 g.

8.2 *Tared or Weighed Crucibles*—The tare weight of crucibles shall be determined by preheating the empty crucible to constant weight at the same temperature and under the same conditions as shall be used for the final ignition of a residue and cooling in a desiccator for the same period of time used for the crucible containing the residue.

8.3 *Constancy of Weight of Ignited Residues*—To definitely establish the constancy of weight of an ignited residue for referee purposes, the residue shall be ignited at the specified temperature and for the specified time, cooled to room temperature in a desiccator, and weighed. The residue shall then be reheated for at least 30 min, cooled to room temperature in a desiccator, and reweighed. If the two weights do not differ by more than 0.2 mg, constant

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[6] Appears in this publication.

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weight is considered to have been attained. If the difference in weights is greater than 0.2 mg, additional ignition periods are required until two consecutive weights agree within the specified limits. For ignition loss, each reheating period shall be 5 min.

8.4 *Volatilization of Platinum*—The possibility of volatilization of platinum or alloying constituents from the crucibles must be considered. On reheating if the crucible and residue lose the same weight (within 0.2 mg) as the crucible containing the blank, constant weight can be assumed. Crucibles of the same size, composition, and history shall be used for both the sample and the blank.

8.5 *Calculations*—In all operations on a set of observed values such as multiplying or dividing, where possible, retain the equivalent of two more places of figures than in the single observed values. For example, if observed values are read or determined to the nearest 0.1 mg, carry numbers to the nearest 0.001 mg in calculation.

8.6 *Rounding Off Figures*—Rounding off of figures to the number of significant places required in the report should be done after calculations are completed, in order to keep the final results substantially free from calculation errors. The rounding-off procedure should follow the principle outlined in ASTM Recommended Practices E 29, for Designating Significant Places in Specified Limiting Values[7,8] (Note 6).

NOTE 6—The rounding off procedure referred to in 8.6, in effect, drops all digits beyond the number of places to be retained if the next figure is less than 5. If it is more than 5, or equal to 5 and subsequent places contain a digit other than 0, then the last retained digit is increased by one. When the next digit is equal to 5 and all other subsequent digits are 0, the last digit to be retained is unchanged when it is even and increased by one when it is odd. For example 3.96(50) remains 3.96 but 3.95(50) becomes 3.96.

REFEREE METHODS

~~SILICON DIOXIDE~~
~~(*Referee Method*)~~

~~9. Scope~~

~~9.1 This method is based on a double evaporation of the hydrochloric acid solution of the cement to dryness to convert SiO_2 to the insoluble form. The solution is filtered and the insoluble siliceous residue is ignited and weighed. Silicon dioxide is volatilized by hydrofluoric acid and the loss of weight is reported as pure SiO_2.~~

~~10. Procedure~~

~~10.1 Transfer 0.5 g of the sample to an evaporating dish, preferably of platinum for the sake of faster evaporation, and disperse with 10 ml of cold water, using a swirling motion. While still swirling, add 5 to 10 ml of HCl all at once. Digest with the aid of gentle heat and agitation until decomposition is complete. Decomposition may be aided by light pressure with the flattened end of a glass rod. Evaporate the solution to dryness on a steam bath (there is no longer a gelatinous appearance). Without heating the residue any further, treat it with 5 to 10 ml of HCl, wait at least 2 min, and then add an equal amount of water. Cover the dish and digest for 10 min on the steam bath or a hot plate. Dilute the solution with an equal volume of hot water, immediately filter through medium-textured paper and wash the separated SiO_2 thoroughly with hot HCl (1:99), then with hot water. Reserve the residue.~~

~~10.2 Again evaporate the filtrate to dryness, and bake the residue in an oven~~

~~[7] *1966 Book of ASTM Standards*, Part 32.~~

~~[8] See also the ASTM Manual on Quality Control of Materials, Part 2, Section 7 (1951).~~

~~for 1 hr at 105 to 110 C. Cool, add 10 to 15 ml of HCl (1:1), and digest on the steam bath or hot plate for 10 min. Dilute with an equal volume of water, filter immediately on a fresh filter paper, and wash the small SiO_2 residue thoroughly as described in 10.1. Stir the filtrate and washings and reserve for the determination of the ammonium hydroxide group in accordance with 12.1 through 14.1.~~

~~10.3 Transfer the papers containing the residues (from 10.1 and 10.2) to a weighed platinum crucible. Dry and ignite the papers, first at a low heat until the carbon of the filter paper is completely consumed without inflaming, and finally at 1100 to 1200 C until the weight remains constant.~~

~~10.4 Treat the SiO_2 thus obtained, which will contain small amounts of impurities, in the crucible with 0.5 to 1 ml of water, 2 drops of H_2SO_4 (1:1), and about 10 ml of HF. Evaporate cautiously to dryness. Finally, heat the small residue at 1050 to 1100 C for 5 min, cool in a desiccator, and weigh (see 10.4.1 to 10.4.3). The difference between this weight and the weight previously obtained represents the amount of SiO_2. Add 0.5 g of sodium or potassium pyrosulfate ($Na_2S_2O_7$ or $K_2S_2O_7$) to the crucible and heat below red heat until the small residue of impurities is dissolved in the melt (Note 7). Cool, dissolve the fused mass in water, and add it to the filtrate and washings reserved for the determination of the ammonium hydroxide group.~~

~~10.4.1 If the HF residue in the analysis of portland cement weighs over 0.0020 g, the silica determination should be repeated, taking necessary steps to ensure complete decomposition of the sample, and the balance of the analysis (Al_2O_3 plus Fe_2O_3, CaO, and MgO) determined on the new silica filtrate, provided the new silica determination has an HF residue of 0.0020 g or less.~~

~~10.4.2 If two or three repeated determinations of a sample of portland cement consistently show HF residues higher than 0.0020 g, it is evidence that contamination has occurred in sampling or the cement has not been burned properly during manufacture. In such a case, do not fuse the large HF residue with pyrosulfate for subsequent addition to the filtrate from the silica separation. Instead, report the value obtained for the HF residue. Do not ignite the ammonium hydroxide group in the crucible containing this abnormally large HF residue.~~

~~10.4.3 In the analysis of cements other than portland, it may not always be possible to obtain HF residues under 0.0020 g. In such cases, fuse the HF residue with pyrosulfate, dissolve it, and add it to the filtrate obtained from the separation of silica, prior to precipitating the ammonium hydroxide group.~~

~~NOTE 7—A supply of nonspattering pyrosulfate may be prepared by heating some pyrosulfate in a platinum vessel below red heat until the foaming and spattering cease, cooling, and crushing the fused mass.~~

~~10.5 *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.~~

~~11. Calculation~~

~~11.1 Calculate the percentage of SiO_2 to the nearest 0.1 by multiplying the weight in grams of SiO_2 by 200 (100 divided by the weight of sample used (0.5 g)).~~

AMMONIUM HYDROXIDE GROUP
(*Referee Method*)

12. Summary of Method

12.1 In this method aluminum, iron, titanium and phosphorus are precipi-

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Begin here
for Calcium
Analysis

tated from the filtrate, after SiO_2 removal, by means of ammonium hydroxide. With care, little if any manganese will be precipitated. The precipitate is ignited and weighed as the oxides.

13. Procedure

13.1 To the filtrate reserved in accordance with 10.4 (Note 8) which should have a volume of about 200 ml, add HCl if necessary to ensure a total of 10 to 15 ml of the acid. Add a few drops of methyl red indicator and heat to boiling. Then treat with NH_4OH (1:1) (Note 9), dropwise until the color of the solution becomes distinctly yellow, and add one drop in excess (Note 10). Heat the solution containing the precipitate to boiling and boil for 50 to 60 sec. In the event difficulty from bumping is experienced while boiling the ammoniacal solution, a digestion period of 10 min on a steam bath, or on a hot plate having the approximate temperature of a steam bath, may be substituted for the 50 to 60-sec boiling period. Allow the precipitate to settle (not more than 5 min) and filter using medium-texture paper (Note 11). Wash, from twice for a small precipitate to four times for a large one, with hot ammonium nitrate (NH_4NO_3, 20 g/liter) (Note 12).

(Use Whatman #40 filter paper)

NOTE 8—If a platinum evaporating dish has been used for the dehydration of SiO_2, iron may have been partially reduced. At this stage, add about 3 ml of saturated bromine water to the filtrate and boil the filtrate to eliminate the excess bromine before adding the methyl red indicator. If difficulty from bumping is experienced during boiling, the following alternate techniques may be helpful: (1) a piece of filter paper, approximately 1 cm² in area, positioned where the bottom and side of the beaker merge and held down by the end of a stirring rod may solve the difficulty, and (2) use of 400-ml beakers supported inside a cast aluminum cup has also been found effective.

NOTE 9—The NH_4OH used to precipitate the hydroxides must be free of contamination with CO_2.

NOTE 10—It usually takes one drop of NH_4OH (1:1) to change the color of the solution from red to orange and another drop to change the color from orange to yellow. If desired, the addition of the indicator may be delayed until ferric hydroxide ($Fe(OH)_3$) is precipitated without aluminum hydroxide ($Al(OH)_3$) being completely precipitated. In such a case, the color changes may be better observed. However, if the content of Fe_2O_3 is unusually great, it may be necessary to occasionally let the precipitate settle slightly so that the color of the supernatant liquid can be observed. If the color fades during the precipitation, add more of the indicator. Observation of the color where a drop of the indicator strikes the solution may be an aid in the control of the acidity. The boiling should not be prolonged as the color may reverse and the precipitate may be difficult to retain on the filter. The solution should be distinctly yellow when it is ready to filter. If it is not, restore the yellow color with more NH_4OH (1:1) or repeat the precipitation.

NOTE 11—To avoid drying of the precipitate with resultant slow filtration, channeling, and poor washing, the filter paper should be kept nearly full during the filtration and should be washed without delay.

NOTE 12—Two drops of methyl red indicator should be added to the NH_4NO_3 solution in the wash bottle, followed by NH_4OH (1:1) added dropwise until the color just changes to yellow. If the color reverts to red at any time due to heating, it should be brought back to yellow by the addition of a drop of NH_4OH (1:1)

~~13.2 Set aside the filtrate and transfer the precipitate and filter paper to the same beaker in which the first precipitation was effected. Dissolve the precipitate with hot HCl (1:2). Stir to thoroughly macerate the paper and then dilute the solution to about 100 ml. Reprecipitate the hydroxides as described in 13.1. If difficulty from bumping is experienced while boiling the acid solution containing the filter paper, it may be obviated by diluting the hot 1:2 solution of the mixed oxides with 100 ml of boiling water and thus eliminate the need for boiling. Filter the solution and wash the precipitate with about four 10-ml portions of hot NH_4NO_3 (20 g/liter) (Note 11). Combine the filtrate and washings~~

Go to pp. 97, paragraph 20 of ASTM C 114 for Calcium Oxide (Referee Method) with the filtrate set aside and reserve for the determination of CaO in accordance with 21.1.

13.3 Place the precipitate in a weighed platinum crucible, heat slowly until the papers are charred, and finally ignite to constant weight at 1050 to 1100 C with care to prevent reduction, and weigh as the ammonium hydroxide group.

13.4 *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

14. Calculation

14.1 Calculate the percentage of ammonium hydroxide group to the nearest 0.01 by multiplying the weight in grams of ammonium hydroxide group by 200 (100 divided by the weight of sample used (0.5 g)).

FERRIC OXIDE
(*Referee Method*)

15. Summary of Method

15.1 In this method, the Fe_2O_3 content of the cement is determined on a separate portion of the cement by reducing the iron to the ferrous state with stannous chloride ($SnCl_2$) and titrating with a standard solution of potassium dichromate ($K_2Cr_2O_7$). This determination is not affected by any titanium or vanadium that may be present in the cement.

16. Reagents

16.1 *Barium Diphenylamine Sulfonate Indicator*—Dissolve 0.3 g of barium diphenylamine sulfonate in 100 ml of water.

16.2 *Potassium Dichromate, Standard Solution (1 ml = 0.004 g Fe_2O_3)*—Pulverize and dry primary standard potassium dichromate ($K_2Cr_2O_7$) reagent, the current lot of NBS 136, at 180 to 200 C to constant weight. Weigh accurately an amount of dried reagent equal to 2.45700 g times the number of liters of solution to be prepared. Dissolve in water and dilute to exactly the required volume in a single volumetric flask of the proper size. This solution is a primary standard and requires no further standardization (Note 13).

NOTE 13—Where large quantities of standard solution are required, it may be desirable for certain laboratories to use commercially produced primary standard potassium dichromate for most determinations. Such a material may be used provided that the first solution made from the container is checked, as follows: Using a standard solution of NBS 136, prepared as described in 16.2, analyze, in duplicate, samples of NBS 1016 portland cement by the procedure given in 17.1 and 17.2. Repeat using a similar solution prepared from the commercial primary standard dichromate. The average percentages of Fe_2O_3 found by each method should not differ by more than 0.06 per cent.

16.3 *Stannous Chloride Solution*—Dissolve 5 g of stannous chloride ($SnCl_2 \cdot 2H_2O$) in 10 ml of HCl and dilute to 100 ml. Add scraps of iron-free granulated tin and boil until the solution is clear. Keep the solution in a closed dropping bottle containing metallic tin.

17. Procedure

17.1 Weigh 1 g of the sample into a 500-ml Phillips beaker or other suitable container. Add 40 ml of cold water and, while the beaker is being swirled, add 10 ml of HCl. If necessary, heat the solution and grind the cement with the flattened end of a glass rod until it is evident that the cement is completely decomposed. Heat the solution to boiling and treat it with the $SnCl_2$ solution, added dropwise while stirring and boiling, until the solution is decolorized. Add one drop in excess and cool the solution to room temperature by placing the beaker in a pan of cool water. After cooling and without delay, rinse the

~~inside of the vessel with water, and add all at once 10 ml of a cool, saturated $HgCl_2$ solution. Stir the solution vigorously for 1 min by swirling the beaker and add 10 ml of H_3PO_4 (1:1) and 2 drops of barium diphenylamine sulfonate indicator. Add sufficient water so that the volume after titration will be between 75 and 100 ml. Titrate with the standard $K_2Cr_2O_7$ solution. The end point shall be taken as the point at which a single drop causes an intense purple coloration that remains unchanged on further addition of standard $K_2Cr_2O_7$.~~

~~17.2 *Blank*—Make a blank determination following the same procedure and using the same amounts of reagents. Record the volume of $K_2Cr_2O_7$ solution required to establish the end point as described in 17.1. As some iron must be present to obtain the normal end point, if no definite purple color is obtained after the addition of four drops of the standard $K_2Cr_2O_7$, record the blank as zero.~~

~~18. Calculation~~

~~18.1 Calculate the percentage of Fe_2O_3 to the nearest 0.01 (to be reported to the nearest 0.1) as follows:~~

$$Fe_2O_3\text{, per cent} = E(V - B) \times 100$$

~~where:~~

~~E = Fe_2O_3 equivalent of the $K_2Cr_2O_7$ solution, g/ml,~~

~~V = milliliters of $K_2Cr_2O_7$ solution required by the 1-g sample used, and~~

~~B = milliliters of $K_2Cr_2O_7$ solution required by the blank determination.~~

~~ALUMINUM OXIDE~~
~~(*Referee Method*)~~

~~NOTE 14—The difference between the total ammonium hydroxide group and Fe_2O_3 is reported as Al_2O_3. P_2O_5 or TiO_2 if present, will be counted as Al_2O_3 by this procedure. In judging conformance to specifications and in calculating compound composition, corrections should not be made for these constituents except in cases of dispute. For research purposes where the most accurate Al_2O_3 determination is desired, both corrections should be made.~~

~~19. Calculation~~

~~19.1 Calculate the percentage of Al_2O_3 by deducting the percentage of Fe_2O_3 determined in accordance with 15.1 through 18.1, and expressed to the nearest 0.01, from the percentage of ammonium hydroxide group, determined in accordance with 12.1 through 14.1 and expressed to the nearest 0.01. When corrections for TiO_2 and P_2O_5 are required, also deduct the percentages of these compounds, determined in accordance with 51.1 through 60.1 and expressed to the nearest 0.01. Report to the nearest 0.1.~~

CALCIUM OXIDE
(*Referee Method*)

20. Summary of Method

20.1 In this method, manganese is removed from the filtrate after the determination of the ammonium hydroxide group. Calcium is then doubly precipitated as the oxalate. The precipitate is converted to CaO by ignition and weighed.

21. Procedure

21.1 Acidify the combined filtrates obtained in the precipitations of the ammonium hydroxide group (13.2). Neutralize with HCl to the methyl red end point, make just acid, and add 6 drops of HCl in excess. Evaporate to a volume of about 100 ml. Add 40 ml of saturated bromine water to the hot solution and immediately add NH_4OH until the solution is distinctly alkaline. Addition of 10 ml of NH_4OH is generally sufficient. A piece of filter paper, about 1 cm^2 in area, placed in the heel of the beaker and held down by the end of a stirring rod aids in preventing bumping and initiating precipitation of hydrated manganese oxides. Boil the solution for 5 min or more, making certain that the solution is distinctly alkaline at all times. Allow the precipitate to settle, filter using medium texture paper, and wash with hot water. If a precipitate does not appear immediately, allow a settling period of up to 1 hr before filtration. Discard any manganese dioxide that may have been precipitated. Acidify the filtrate with HCl using litmus paper as an indicator, and boil until all the bromine is expelled (Note 15). Add 5 ml of HCl, dilute to 200 ml, and add a few drops of methyl red indicator and 30 ml of warm ammonium oxalate solution (50 g/liter). Heat the solution to 70 to 80 C, and add NH_4OH (1:1) dropwise, while stirring until the color changes from red to yellow (Note 16). Allow the solution to stand without further heating for 60 ± 5 min (no longer), with occasional stirring during the first 30 min. Filter using a retentive paper and wash moderately with cold ammonium oxalate solution (1 g/liter). Reserve the filtrate and washings.

NOTE 15—Potassium iodide starch paper may be used to indicate the complete volatilization of the excess bromine. Expose a strip of moistened paper to the fumes from the boiling solution. The paper should remain colorless. If it turns blue bromine is still present.

NOTE 16—This neutralization must be made slowly, otherwise precipitated calcium oxalate may have a tendency to run through the filter paper. When a number of these determinations are being made simultaneously, the following technique will assist in ensuring slow neutralization. Add two or three drops of NH_4OH to the first beaker while stirring, then 2 or 3 drops to the second, and so on, returning to the first beaker to add 2 or 3 more drops, etc., until the indicator color has changed in each beaker.

21.2 Transfer the precipitate and filter paper to the beaker in which the precipitation was made. Dissolve the oxalate in 50 ml of hot HCl (1:4) and macerate the filter paper. Dilute to 200 ml with water, add a few drops of methyl red indicator and 20 ml of ammonium oxalate solution, heat the solution nearly to boiling, and precipitate calcium oxalate again by neutralizing the acid solution with NH_4OH as described in 21.1. Allow the solution to stand 1 to 2 hr (standing for 2 hr at this point does no harm), filter, and wash as before. Combine the filtrate with that already obtained and reserve for the determination of MgO (25.1).

21.3 Dry the precipitate in a weighed, covered platinum crucible. Char the paper without inflaming, burn the carbon at as low a temperature as possible, and, finally, heat with the crucible tightly covered in an electric furnace or over a blast lamp at a temperature of 1100 to 1200 C. Cool in a desiccator and weigh as CaO. Repeat the ignition to constant weight.

21.4 *Blank*—Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly.

22. Calculation

22.1 Calculate the percentage of CaO to the nearest 0.1 by multiplying the weight in grams of CaO by 200 (100 divided by the weight of sample used (0.5 g)).

~~MAGNESIUM OXIDE~~

~~*(Referee Method)*~~

~~23. Summary of Method~~

~~23.1 In this method, magnesium is doubly precipitated as magnesium ammonium phosphate from the filtrate after removal of calcium. The precipitate is ignited and weighed as magnesium pyrophosphate~~ ~~($Mg_2P_2O_7$)~~~~. The MgO equivalent is then calculated.~~

~~24. Reagents~~

~~24.1 *Ammonium Nitrate Wash Solution*—Dissolve 100 g of ammonium~~

APPENDIX E

RESULTS OF X-RAY DEFRACTION ANALYSIS

SAMPLE	SAND		CEMENT		COMMENTS
	SiO_2	$CaCO_3$	$3CaO \cdot SiO_2$	$Ca(OH)_2$	
1. I-B Cement Lone Star 'Dallas'	None	None	Yes	Yes	Mostly 3 $CaO \cdot SiO_2$, partly $Ca(OH)_2$; No evidence of other hydration products.
2. I-A Cement	None	None	Yes	Yes	Ditto, except more $Ca(OH)_2$ than in I-B.
3. II-B Cement	None	None	Yes	Yes	Mostly 3 $CaO \cdot SiO_2$, trace of $Ca(OH)_2$.
4. II-A Cement	None	None	Yes	Yes	Ditto
5. III-B Cement-Ottawa sand-hydrated. (High sand)	Yes	None	Yes	Yes	Standard
6. III-A Cement-Ottawa sand-hydrated (Low sand)	Yes	None	Yes	Yes	Standard
7. Ottawa sand	Yes	None	None	None	Standard
8. Uvalde Sand	Yes	Yes	None	None	Trace of SiO_2
9. Str. 59, Slab 3A B top	Yes	Yes	None	None	$CaCO_3 = SiO_2$; Unknown peak @ 27.8° $2\theta \Rightarrow 3.2063$ Å
10. Str. 54, Slab #33 A top 20-59-33-A (moderate)	Yes	Yes	None	None	$CaCO_3 \approx SiO_2$; Unknown peak @ 27.5°
11. Str. 17, Slab #20 C top 20-17-20-C (moderate)	Yes	Yes	Yes	Yes	$CaCO_3 \approx SiO_2$; trace of cement. Unknown peaks @ 27.5°, 35.9°, 63.2°.

	SAND		CEMENT		
SAMPLE	SiO_2	$CaCO_3$	$3CaO \cdot SiO_2$	$Ca(OH)_2$	COMMENTS
12. Aransas RD-BR B underneath Slab # 1 16-34-1-B (Bad) companion to 16-34-1-A	Yes	Yes	None	None	Mostly SiO_2; Unknown peak @ 27.8°.
13. Dist. 10 Gregg 10 S-1854 (1) 1763-3-1 Graces CK. Br. Structure # 2 Slab 2 Specimen 'A' top	Yes (good) ↙	Yes	None	None	Mostly SiO_2
14. Cow P line underneath Slab #1A 16-34-1-B (Good), companion sample 16-34-1A (Bad)	Yes	Yes	Yes	None	Trace of $3CaO \cdot SiO_2$; Mostly SiO_2.
15. SH. 43 Potter CK. 19-15-3A	Yes	Yes	None	None	$SiO_2 \approx CaCO_3$; Unknown peak @ 27.5°.
16. Concrete Core # 1 (Bad)	Yes	Yes	Yes	Yes	$SiO_2 \approx CaCO_3$; trace of cement
17. Concrete Core # 5 (Bad)	Yes	Yes	None	Yes	Mostly $CaCO_3$; trace of $Ca(OH)_2$; Unknown peak @ 19.1° 2θ.
18. Str. # 59 Slab #35 D top 20-59-35-D (Good)	Yes	Yes	None	?	$SiO_2 \approx CaCO_3$; may be trace of $Ca(OH)_2$
19. Dist. 10 Gregg Co. 5-1854(1) 1763-3-1 Graces CK.Br. Structure # 2, Slab 2 Specimen "A", Bot. (Good)	Yes	Yes	None	None	$SiO_2 \approx CaCO_3$; broad peak centered 22.5° 2θ. Probably background effect of special small sample holder.

SUMMARY OF SAMPLES RUN FOR TEXAS HIGHWAY DEPARTMENT ON CONCRETE FROM BRIDGES

Sample	Description	Comments
#20	Top of core; received as powder.	All diffraction peaks accounted for by SiO_2 and $CaCO_3$.
#21	Middle of core; received as powder.	" "
#22	Bottom of core; received as powder.	" "
#23	Concrete Core # 5 sample scraped from beneath "asphaltic" end of core and run on fines thus obtained.	" ", except one broad peak @ 21.6° 2θ. Constituent unknown.
#24	Concrete Core # 5 sample scraped from "clean" end of core and run on fines thus obtained.	One broad peak @ 22.3° 2θ. All other peaks accounted for by SiO_2 and $CaCO_3$.
#25	Concrete Core # 1; sample scraped from surface adjacent to crack on top of core; pattern run on fines thus obtained.	All peaks accounted for by SiO_2 and $CaCO_3$.
#26	Concrete Core # 5. Similar to sample # 5, to see if broad peak could be re-obtained. Pattern run on fines scraped from core.	No broad peak @ 21.6° 2θ. Calcium Sulfoaluminate peak appeared @ 34.1° 2θ. All other peaks are SiO_2 and $CaCO_3$.
#27	Concrete Core # 5. Similar to sample # 5. Pattern run on fines scraped from core.	Calcium sulfoaluminate peak @ 34.1° 2θ. High background from 20° to 44°.
#28	Cow Bayou Str. # 17 Spec. # A Slab # 4;20-17-4- A; Sample powdered before running pattern.	Found peaks corresponding to Hydrated cement, SiO_2, and $CaCO_3$. (Substantiated by rerun).

Sample	Description	Comments
29	Cow Bayou Str. # 17 Slab # 20 C top 20-17-20-C Sample powdered.	Calcium monosulfoaluminate peak @ 34.1° 2θ. Other peaks correspond to SiO_2 and $CaCO_3$.
30	Concrete Core # 1 Sample scraped from area next to crack, then powdered prior to running pattern.	No peaks attributable to cement. All peaks accounted for by SiO_2 and $CaCO_3$.
31	S. H. 43, Potter CK. Under slab # 3, N. Side of beam. Leaking; 19-15-3-A. Sample powdered	High background to 35° 2θ. No peaks definitely attributable to cement. Perhaps Tobermorite peak.
32	Str. # 39, Slab # 33 A top 20-59-33-A	No peaks definitely attributable to cement.
33	Str. # 59, Slab # 35 D top, 20-59-35-D.	" "
34	Cypress CK. 19-30-2A	$CaCO_3 = SiO_2$; No evidence of cement.
35	Cypress CK. 19-30-3B Relief-top Slab # 5	$CaCO = SiO_2$; No evidence of cement.
36a	Cypress CK. 19-30-3C Slab # 7	All SiO_2; No trace of $CaCO_3$. Unknown peaks.
37b	Ditto	$CaCO_3 = SiO_2$; Possible trace of cement.

Sample No. 15

S.H. 43 Potter Creek 19-15-3A

The sample was separated into four particle sizes and then each particle size was separated by flotation with heavy media.

1. 60-100 mesh: mostly SiO_2, little $CaCO_3$
   a. Heavy solids: mostly SiO_2, little $CaCO_3$
   b. Light solids: equal amounts SiO_2 and $CaCO_3$ with possible cement peaks. Unknown peaks.

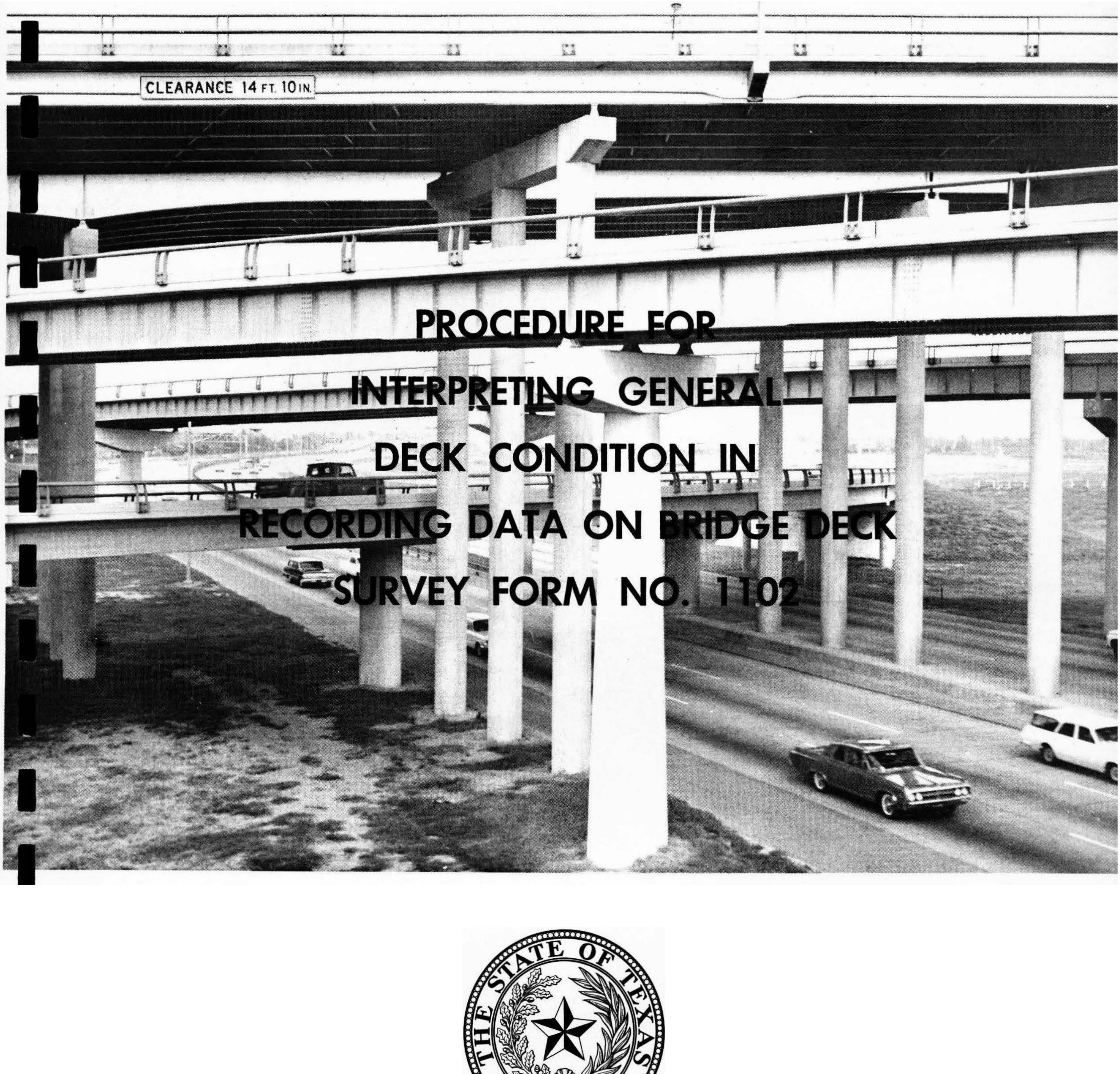
2. 100-120 mesh: mostly SiO_2, little $CaCO_3$ with unknown peak.
   a. Heavy solids: mostly SiO_2, little $CaCO_3$, unknown peaks.
   b. Light solids: equal SiO_2 and $CaCO_3$ with unknown peaks.

3. 120-200 mesh: equal amounts of SiO_2 and $CaCO_3$
   a. Heavy solids: mostly SiO_2, little $CaCO_3$
   b. Light solids: equal SiO_2 and $CaCO_3$

4. 200 mesh: mostly SiO_2, little $CaCO_3$. No separation by flotation.

APPENDIX F

PROCEDURE FOR INTERPRETING GENERAL DECK CONDITION IN RECORDING DATA ON BRIDGE DECK SURVEY FORM NO. 1102



TEXAS HIGHWAY DEPARTMENT
Maintenance Operations Division
Austin, Texas 78701
August, 1965

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Classification 60 32
Summary List 34
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Sample Survey Form 38

Introduction

General Deck Condition classifications as listed on the survey form are outlined herein and illustrated with example photographs. This illustrated outline is presented as an aid, to the individual or team assigned to survey bridge decks, in correctly classifying the decks surveyed to provide uniform data so important to accurate and dependable analysis.

The wide range of possible deck conditions are separated into twelve major classifications. This large number of classifications was chosen to facilitate accurate interpretation of deck condition and to reduce borderline decisions as much as possible.

There is a definite range within each classification as will be noted in the photograph section. Only a limited number of photographs were available for selection. The best of these were chosen; however, there may be some deck conditions which will not be adequately covered by these photographs. In this case, the photographs may be used as a relative guide.

In all instances, the written classifications govern. The photographs are provided to support the classifications and to assist in classification interpretation.

Of the several types of deterioration, only delamination cannot be determined by visual means. It is possible for a deck to appear perfectly sound, with little or no surface deterioration, and yet be delaminated or separated in a layer beneath the surface. The best current means of detecting delamination is by tapping or dragging a light metal object, such as a small hammer, on the deck surface. A marked difference or variation in the resulting sound denotes separated areas. High frequency, platy sounds indicate very thin separations.

Since various types and degrees of deterioration may appear on a single structure, the survey form is designed for entry of the numerical classification data by pours.

Any unusual condition which cannot be adequately covered or described by numerical classification should be entered by note in spaces provided on the survey form. An example of such an entry is when a pour may show several classifications of deterioration. When a single pour presents several classifications, record the most serious classification numerically and indicate in note form the various other conditions which exist.

Curb, walk and sidewall or parapet deterioration should be entered in note form. Existance, type and condition of overlays, patches and other repairs should also be noted.

Leaking cracks which pass water completely through the deck can usually be identified by a white or grey efflorescence or powder deposit along the edges of the crack on the underside of the deck.

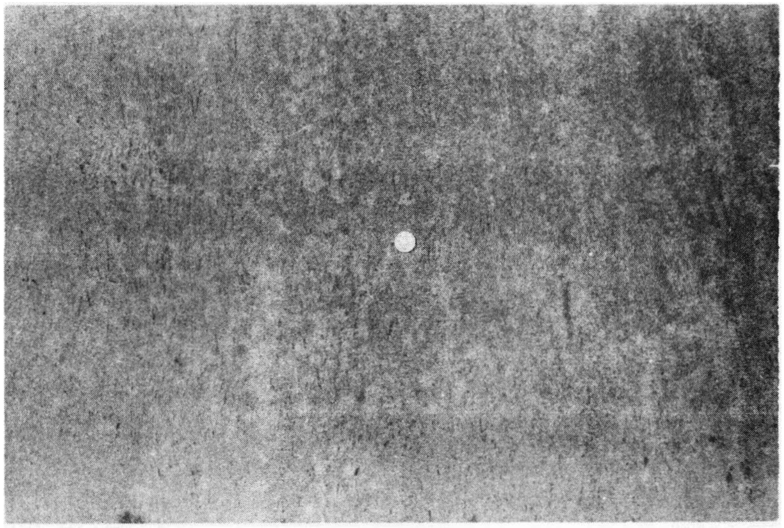
When tension cracking is discovered on the underside of a deck, the cracks should be carefully observed under automobile and truck traffic to determine if the cracks are working and to what degree. Working tension cracks should be recorded by note.

Damage caused by fire, accident, chemical spillage, storm, etc., should be noted.

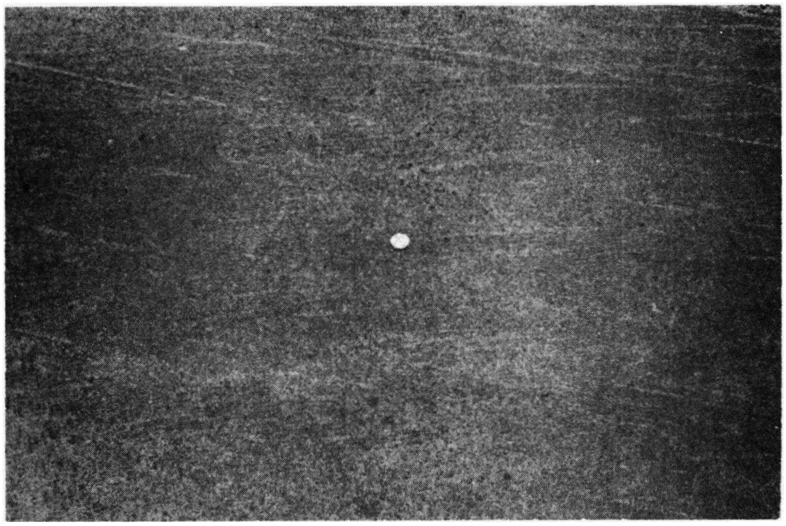
Deck cracking types are diagramatically illustrated in Figure 1. Record degree and type of cracking and approximate average of spacing between cracks. Record the greatest scaling depth encountered. Spalling should be recorded under scaling.

The survey form classifications for Degree of Cracking and Spalling are listed as 1. None, 2. Minor, 3. Moderate, 4. Extensive, 5. Severe and 6. Failure. The General Deck Condition pictures included herein should be used,within parallel classifications, to interpret the Degree of Cracking and Spalling classifications. Figure 2 shows this relationship.

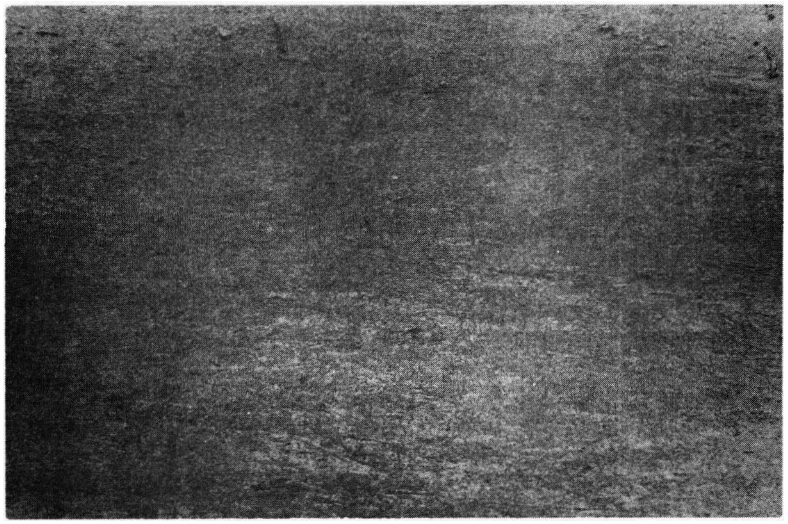
Figure 3 should be used as a guide in determining Degree of Delamination.



10 - A

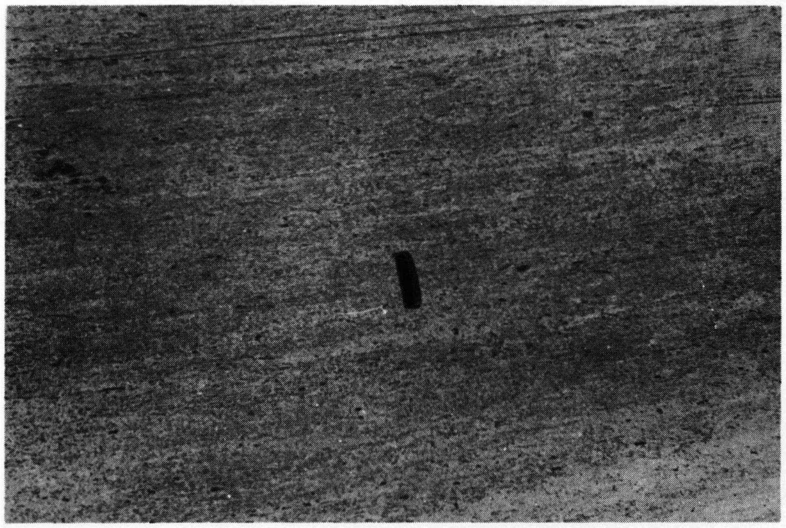


10 - B



10 - C

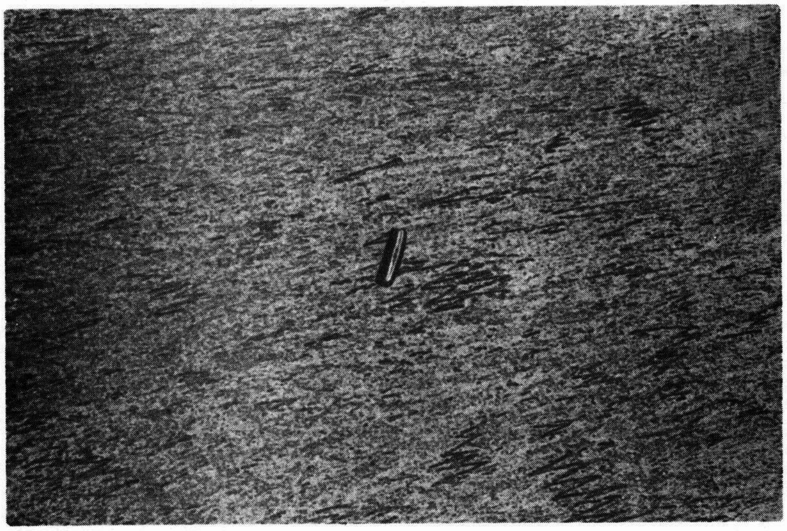
10. GOOD: NO CRACKING, SPALLING, SCALING, DELAMINATION OR ROUGHNESS.



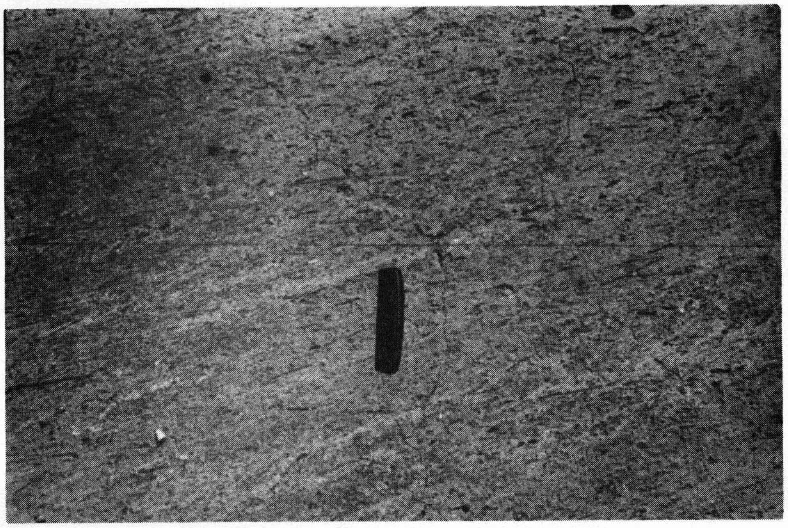
10 - D

10 - E

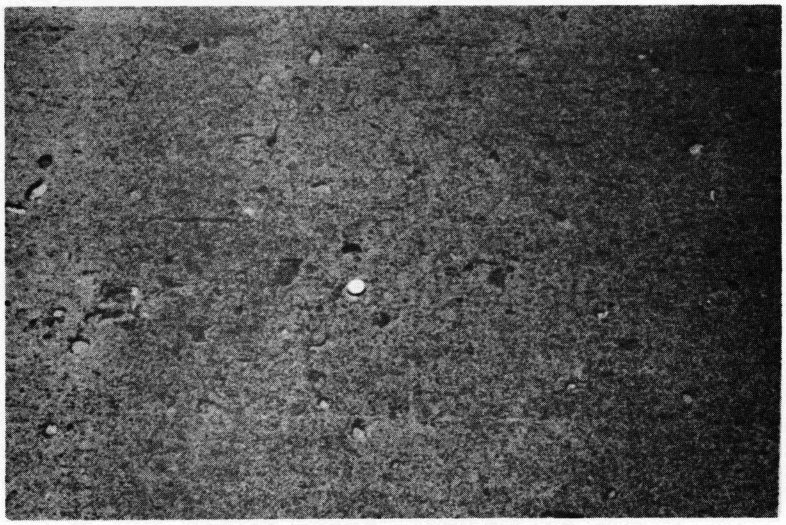
10. GOOD: NO CRACKING, SPALLING, SCALING, DELAMINATION OR ROUGHNESS.



20 - A

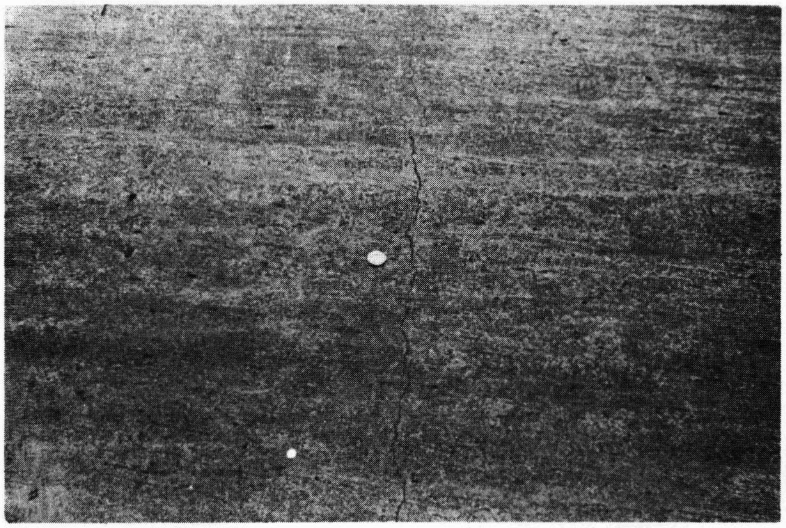


20 - B

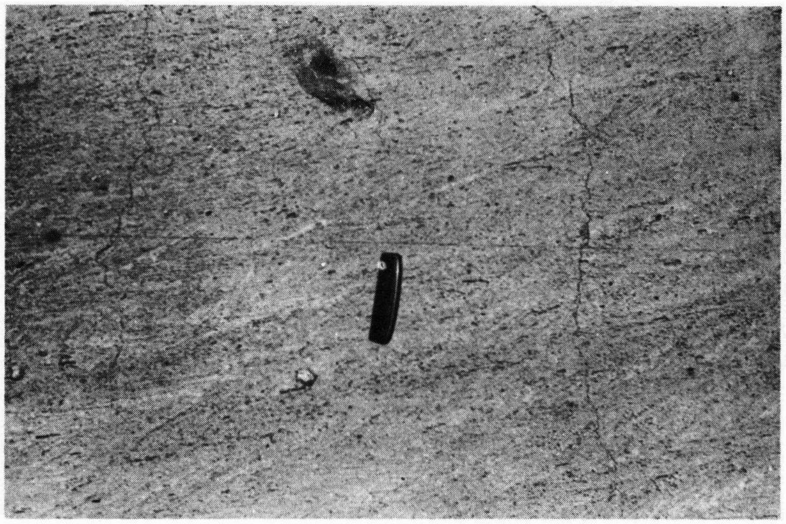


20 - C

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



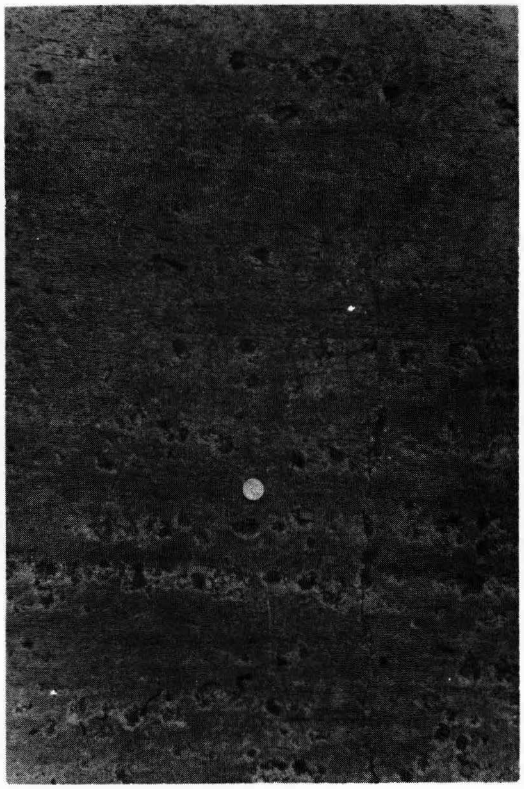
20 - D



20 - E

20 - F

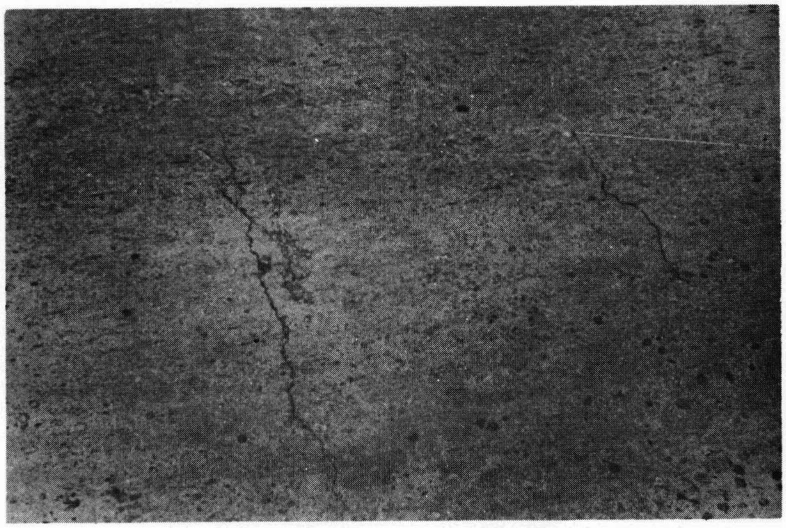
20. MINOR FINE CRACKING, SLIGHT ROUGHNESS OR VERY SLIGHT, SHALLOW AND INFREQUENT SPALLING OR SCALING. OR COMBINATION THEREOF. NO DELAMINATION.



20 - G

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

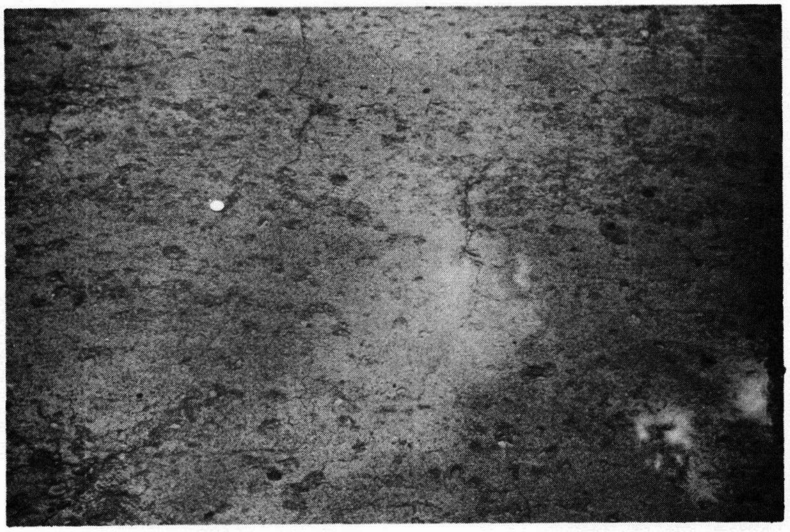
30 - A



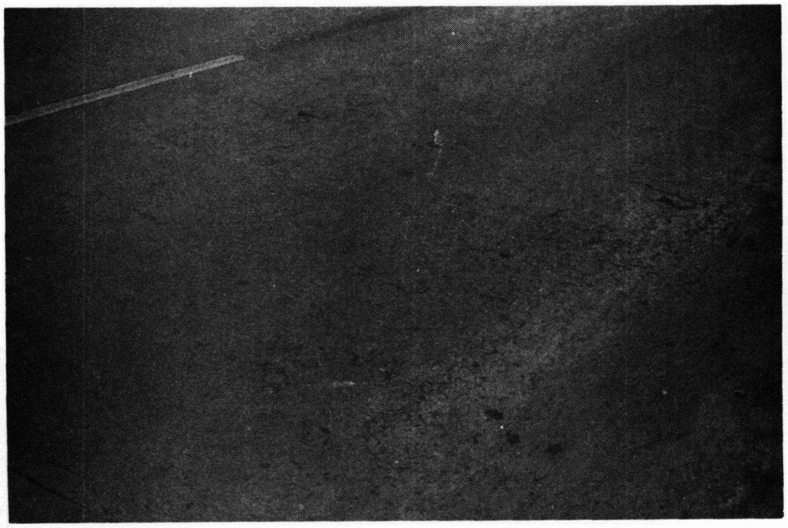
30 - B

30 - C

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



30 - D



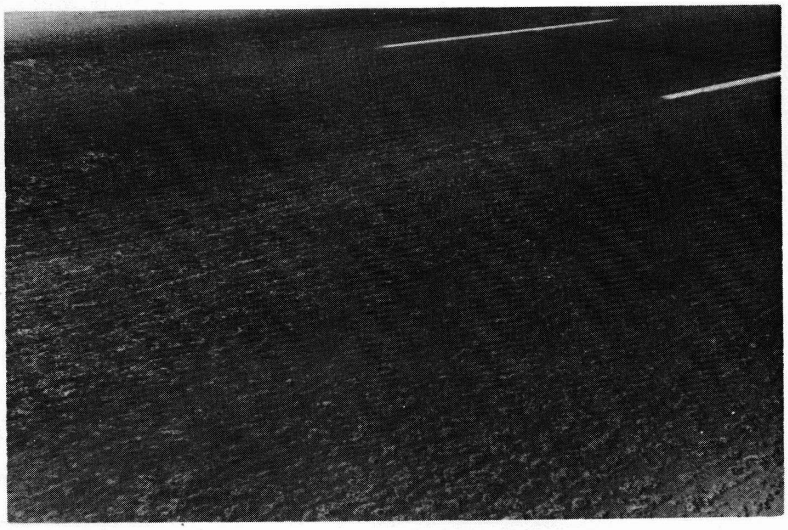
30 - E

30 - F

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

30 - G

30 - H

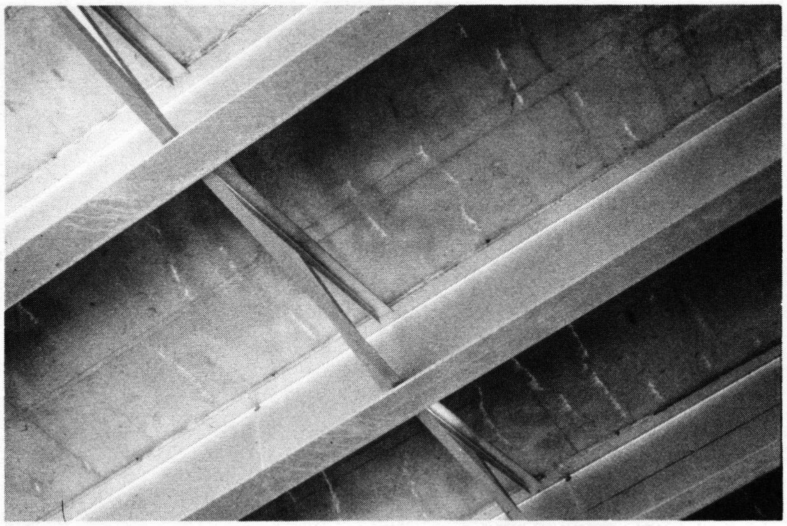


30 - I

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

30 - J

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



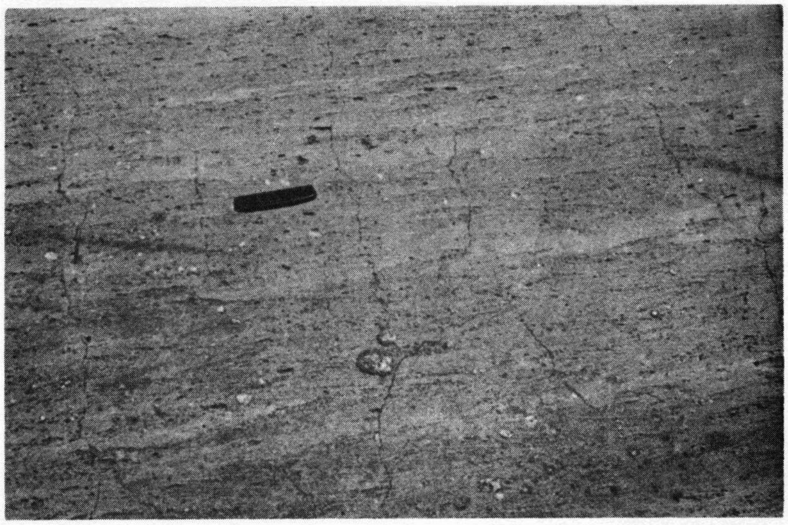
31 - A

31 - B

31. TRANSVERSE CRACKS ON BOTTOM OF DECK SHOWING LEAKAGE.

32 - A

32 - B

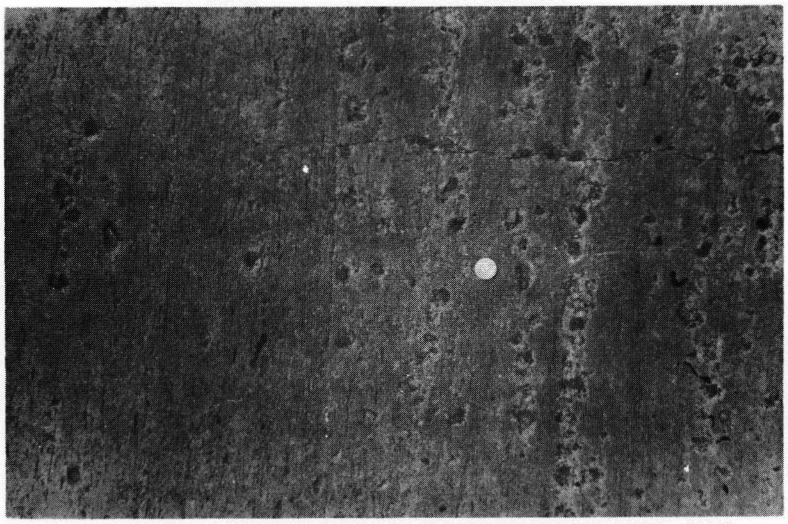


32 - C

32. LEAKING TRANSVERSE CRACKS COMBINED WITH 20.

32 - D

32 - E

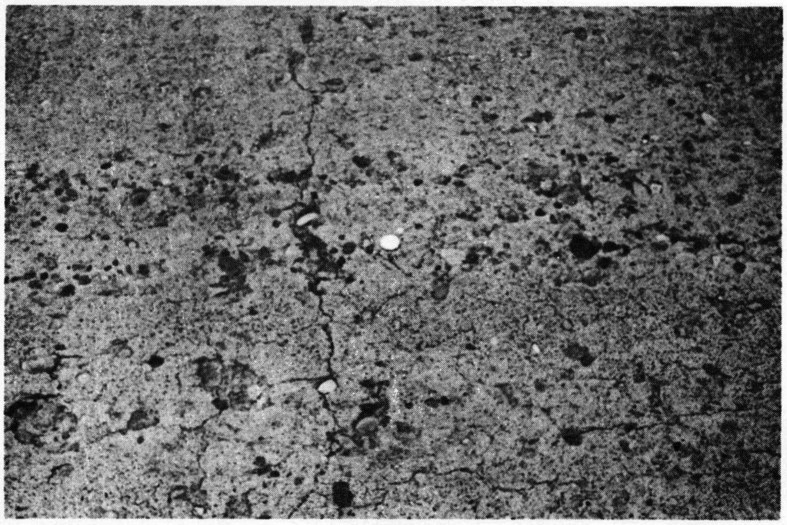


32 - F

32. LEAKING TRANSVERSE CRACKS COMBINED WITH 20.

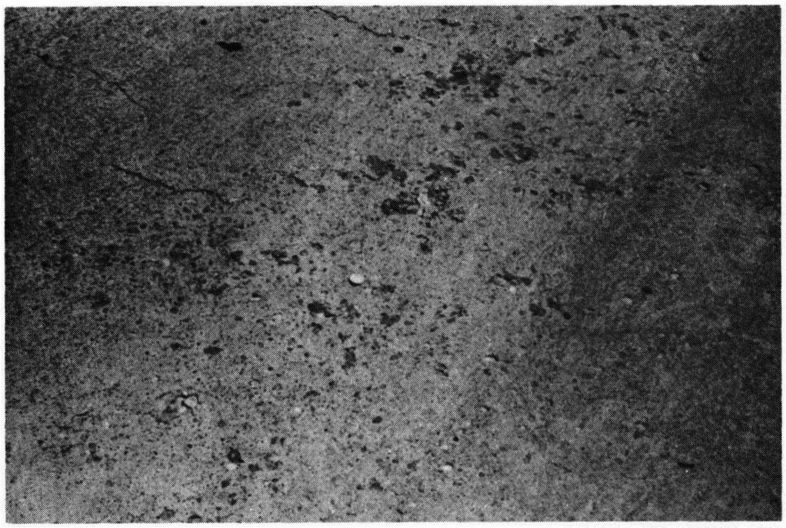
33 - A

33 - B



33 - C

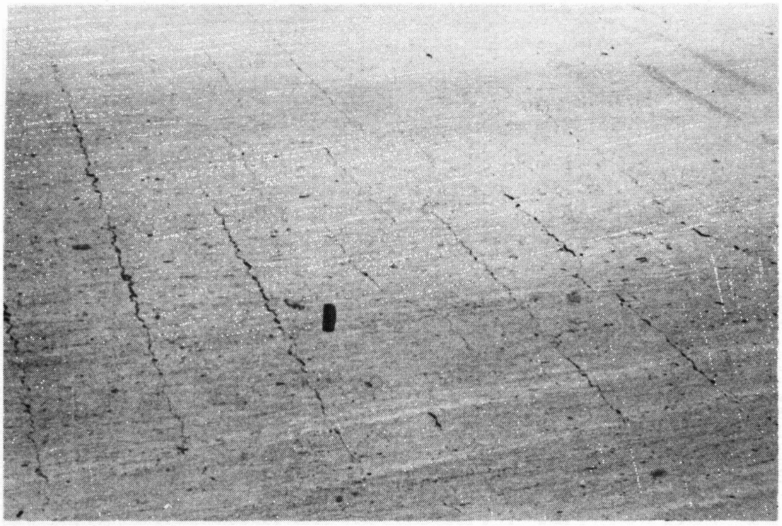
33. LEAKING TRANSVERSE CRACKS COMBINED WITH 30.



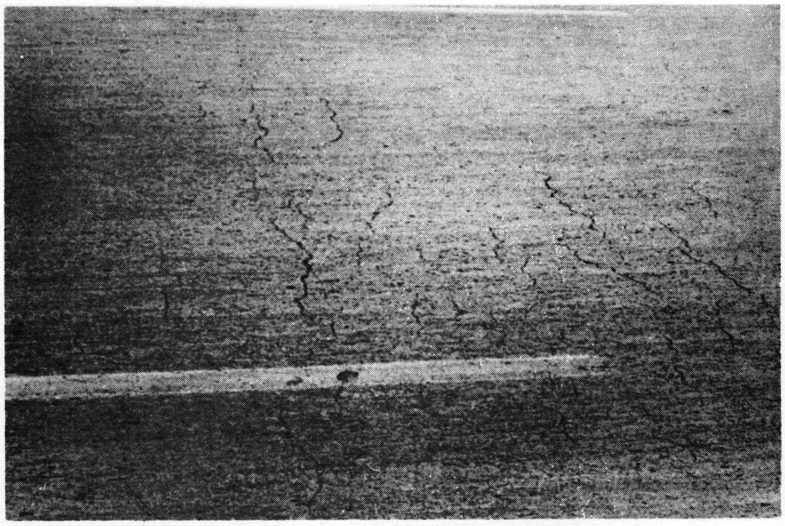
33 - D

33 - E

33. LEAKING TRANSVERSE CRACKS COMBINED WITH 30.



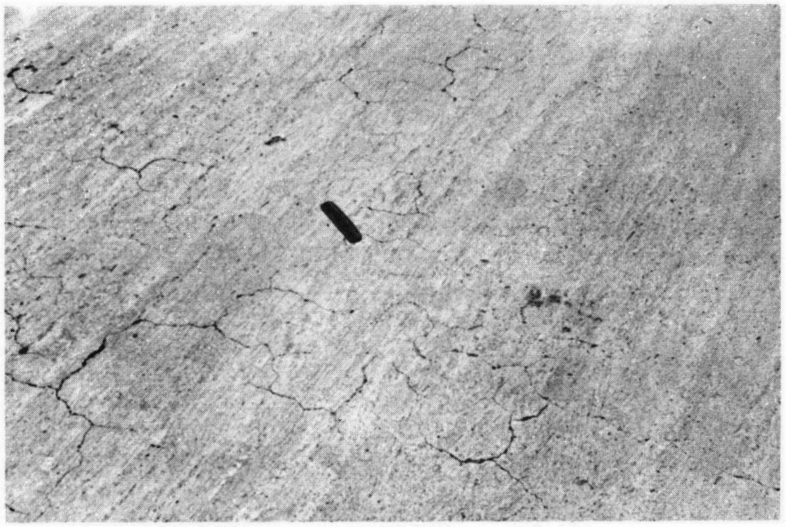
40 - A



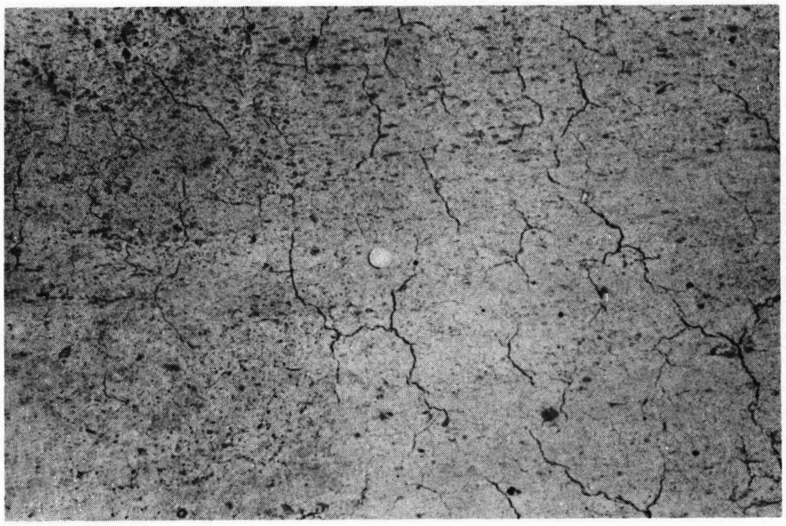
40 - B

40 - C

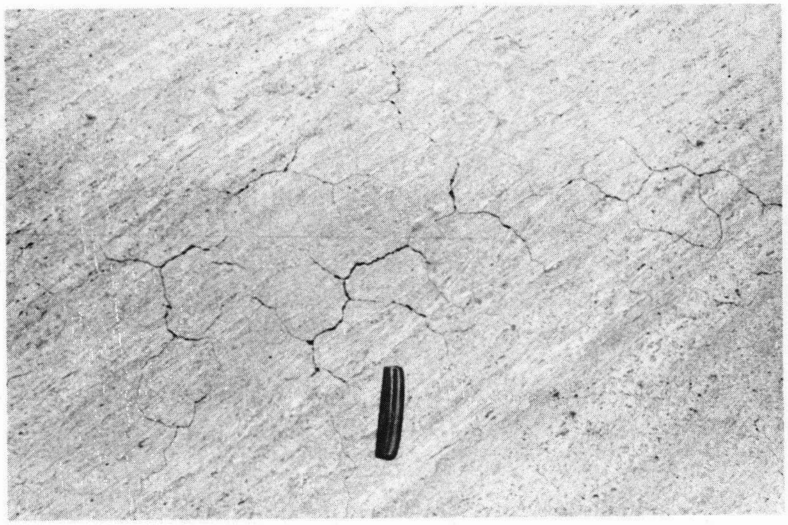
40. EXTENSIVE CRACKING, SPALLING OR SCALING. MODERATE DELAMINATION AND SURFACE LOSS WITH OCCASIONAL POP-OUTS OR POT HOLES. LOOSE OR ROTTEN CONCRETE. OR COMBINATION THEREOF.



40 - D



40 - E



40 - F

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.

40 - G

40 - H

40 - I

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.

40 - J

40 - K

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.

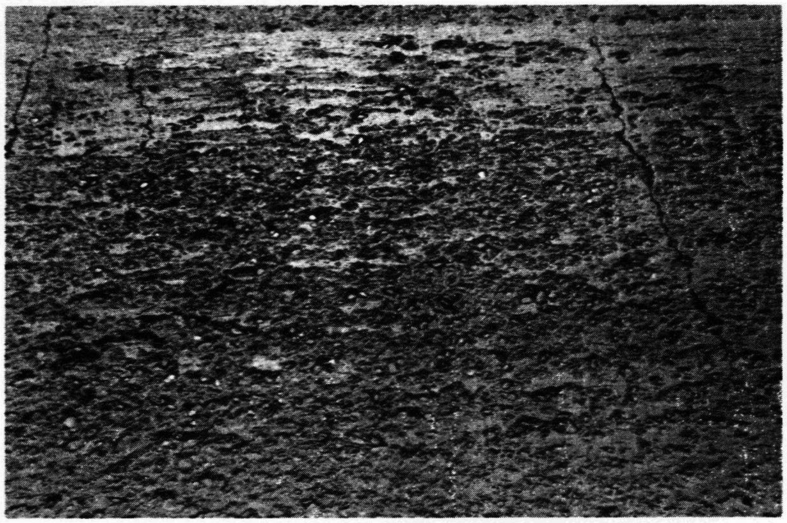
44 - A

44 - B

44 - C

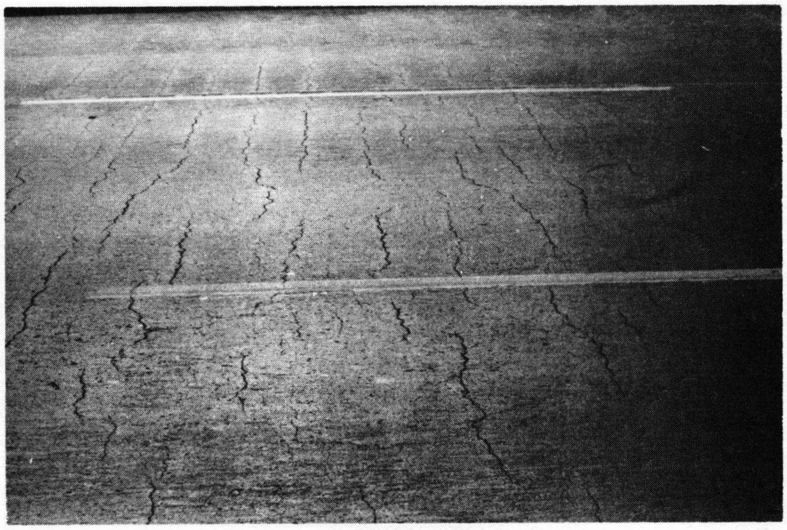
44. LEAKING CRACKS ON BOTTOM OF DECK COMBINED WITH 40.

44 - D



44 - E

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



50 - A

50 - B

50 - C

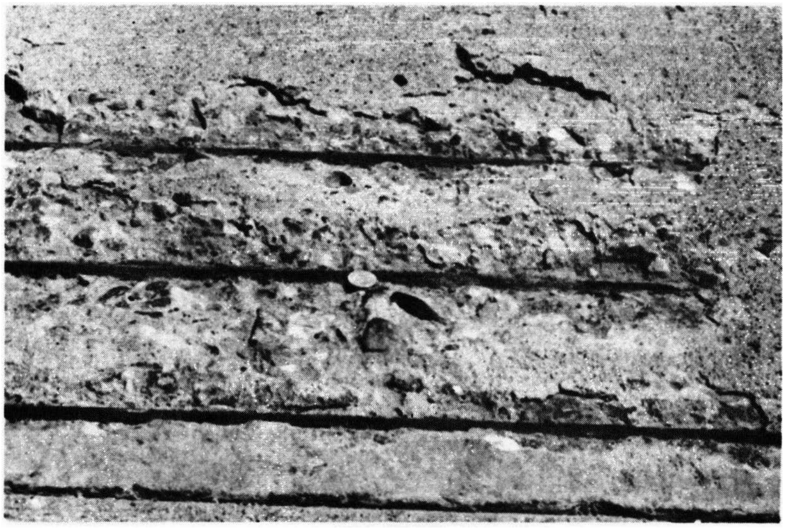
50. SEVERE CRACKING, SPALLING OR SCALING. EXTENSIVE DELAMINATION. EXTENSIVE SURFACE LOSS WITH RUSTY STEEL SHOWING. EXTENSIVE LOOSE OR ROTTEN CONCRETE. EARLY OR BEGINNING TENSION CRACKS ON BOTTOM OF DECK. OR COMBINATION THEREOF.

50 - D

50 - E

50 - F

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.



50 - G

50 - H

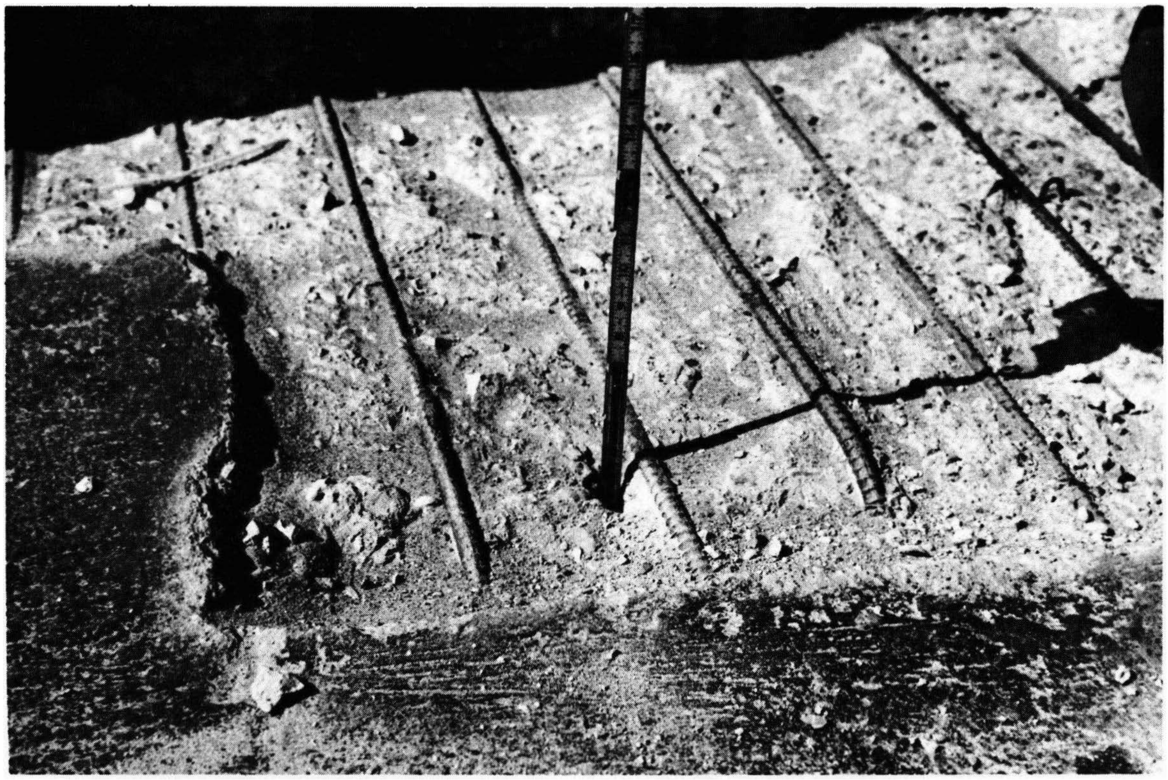
50 - I

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.

50 - J

(Tension Cracking)

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.

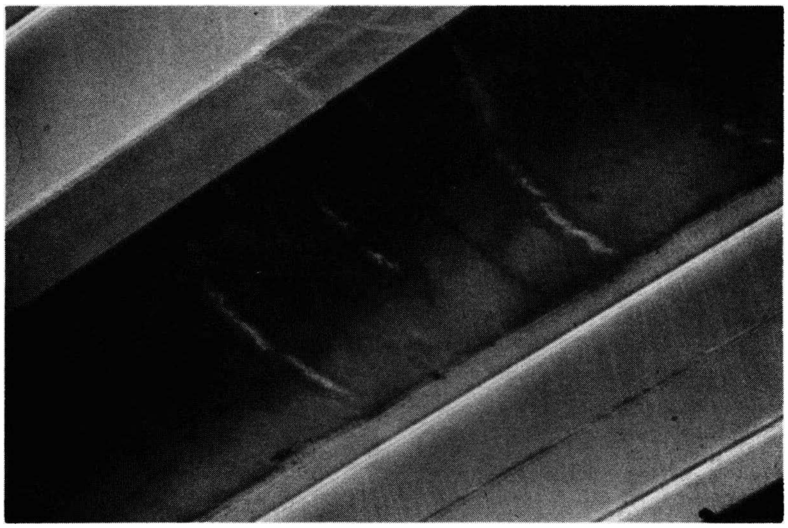


Photographs taken during investigation and removal of separated concrete and showing very extensive delamination.

(50. Cont'd)

Photographs taken during investigation and removal of separated concrete and showing very extensive delamination.

(50. Cont'd)



51 - A

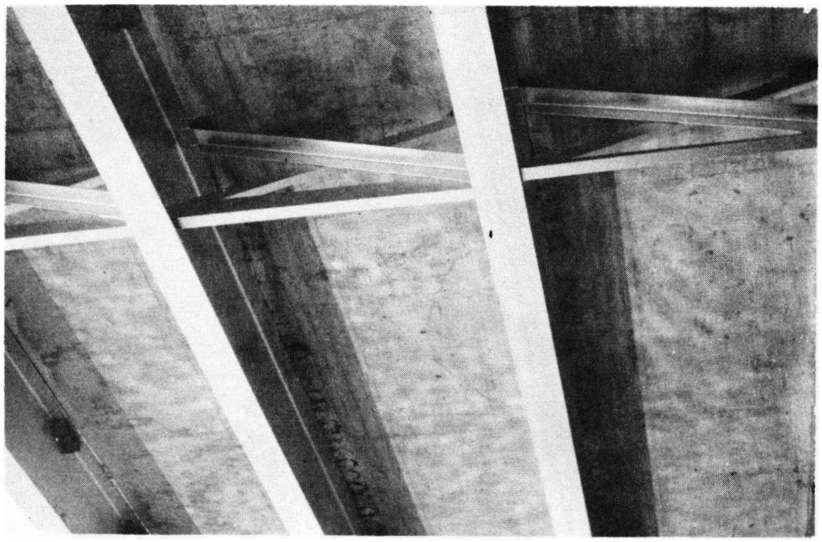
51 - B

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

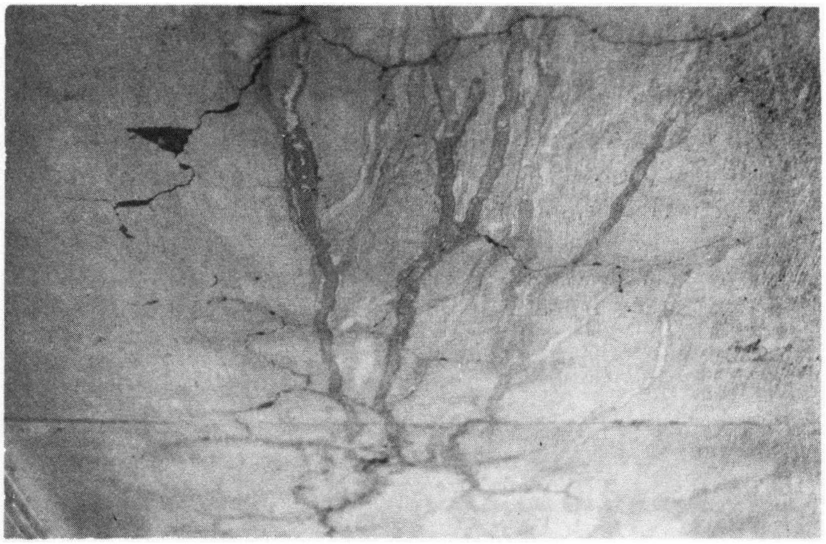
51 - C

51 - D

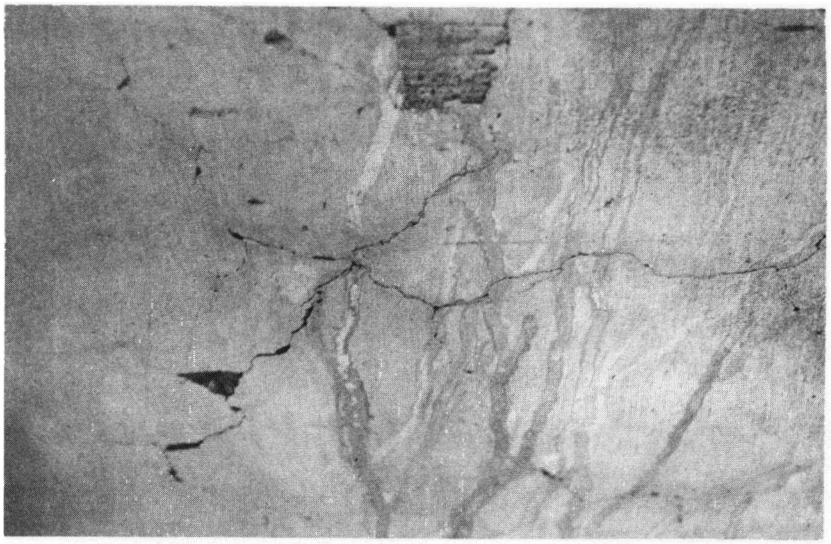
51. LEAKING CRACKS ON BOTTOM OF DECK COMBINED WITH 50.



52 - A

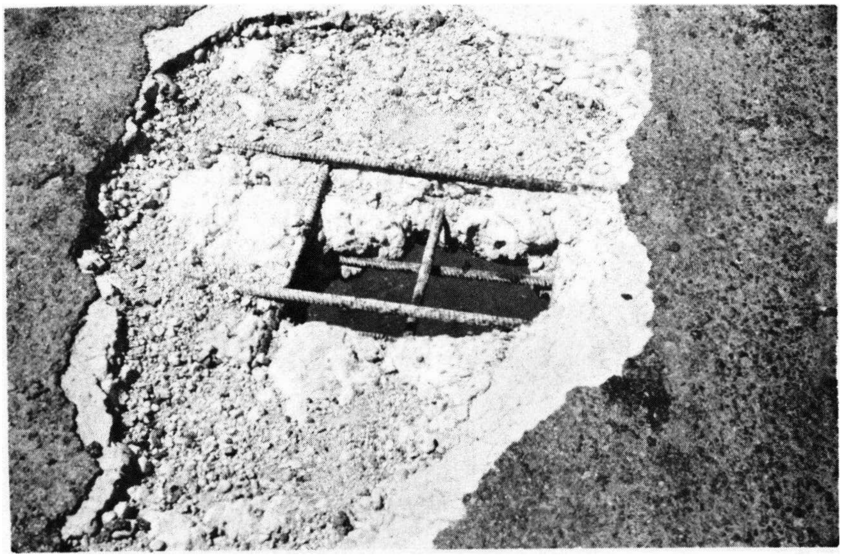


52 - B

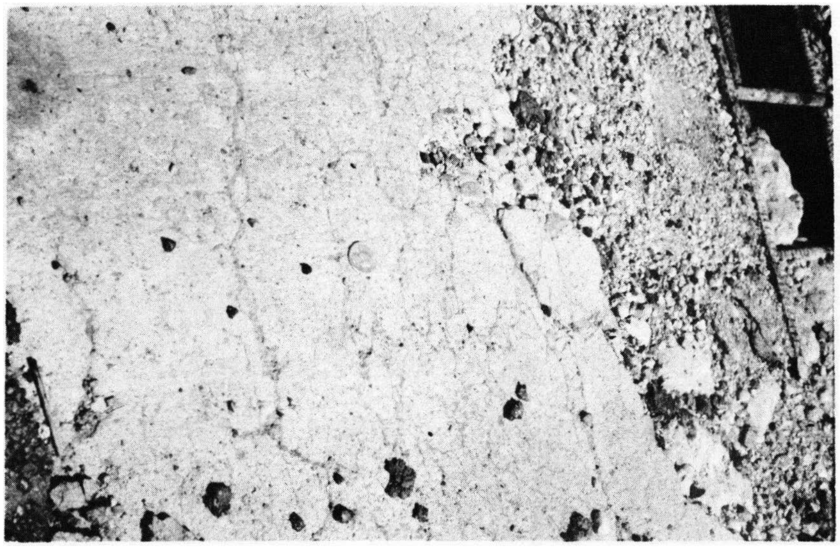


52 - C

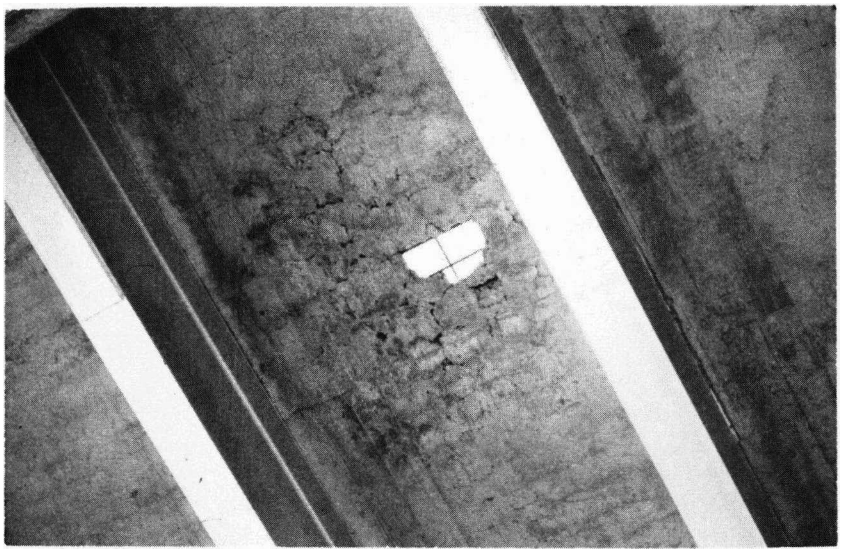
52\. EXTENSIVE OR SEVERE TENSION CRACKING ON BOTTOM OF DECK COMBINED WITH ANY OF THE ABOVE. (REPLACE LAST DIGIT, 2, TO DENOTE COMBINATION. i.e., 54 INDICATES 52 COMBINED WITH 40.



60 - A



60 B



60 - C

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

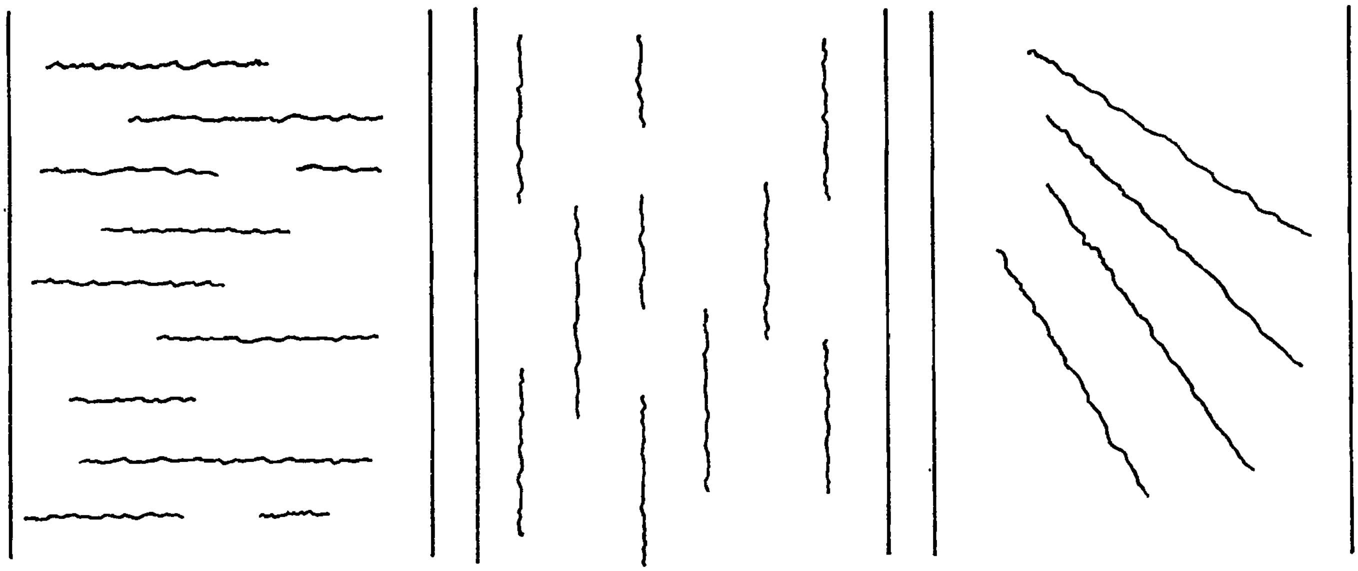
Photograph showing localized deck failure with extensive delamination (uncovered).

(60. Cont'd)

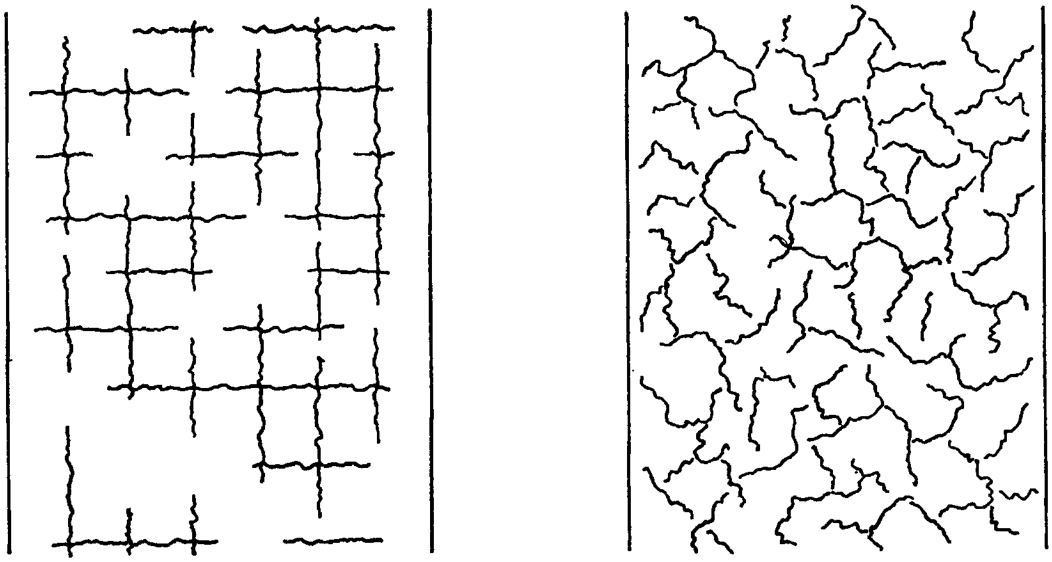
GENERAL DECK CONDITION

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.

Summary List



Transverse Longitudinal Diagonal

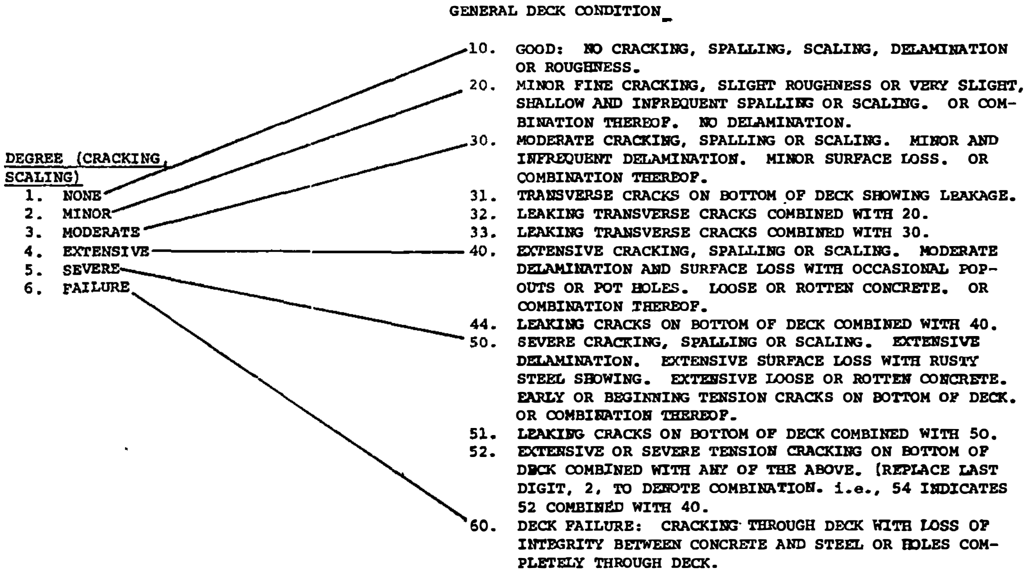


Checkerboard

Map, Alligator
or Random

FIGURE 1

Types of Cracking



GENERAL DECK CONDITION

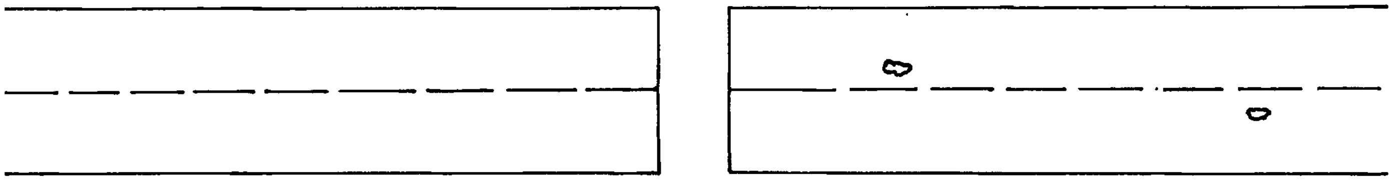
DEGREE (CRACKING, SCALING)

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

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 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.

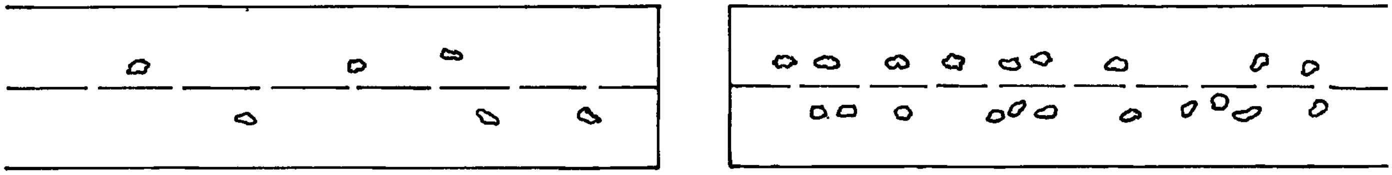
FIGURE 2

Relationship Beween Classifications



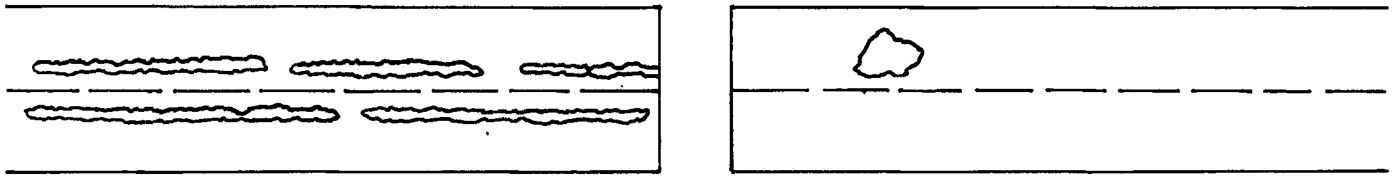
1. NO DELAMINATION

2. SMALL, ISOLATED AREA OR AREAS



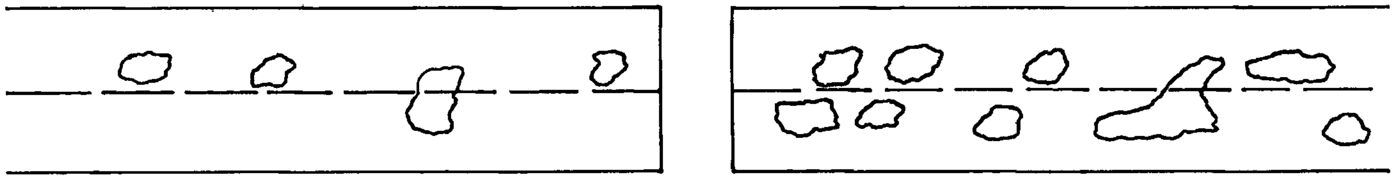
3. SMALL AREAS MODERATELY SPACED

4. SMALL AREAS CLOSELY SPACED



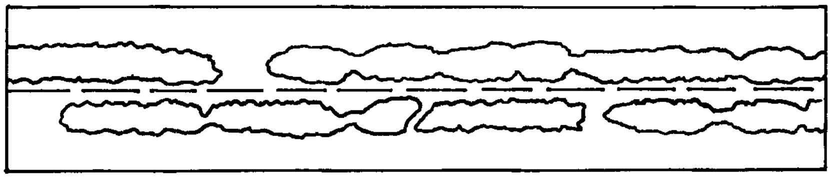
5. SMALL AREA CONTINUOUS

6. LARGE, ISOLATED AREA OR AREAS



7. LARGE AREAS MODERATELY SPACED

8. LARGE AREAS CLOSELY SPACED



9. LARGE AREA CONTINUOUS

FIGURE 3

Degree of Delamination

WEATHER DURING DECK POURING

1. NO RECORD
2. HOT DRY
3. HOT DRY WINDY
4. HOT HUMID
5. HOT HUMID WINDY
6. COOL DRY
7. COOL DRY WINDY
8. COOL HUMID
9. COOL HUMID WINDY
10. COLD DRY
11. COLD DRY WINDY
12. COLD HUMID
13. COLD HUMID WINDY

MOMENT CONDITION

1. SIMPLE SPAN
2. POSITIVE MOMENT AREA.
3. NEGATIVE MOMENT AREA
4. LOW MOMENT AREA

DEGREE (CRACKING, SCALING)

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

TYPE CRACKING

1. TRANSVERSE
2. LONGITUDINAL
3. DIAGONAL
4. CHECKERBOARD
5. MAP (RANDOM)
6. OTHER

LOCATION (CRACKING, SCALING, DELAMINATION)

1. GENERAL
2. PARAPET
3. CURB
4. GUTTER
5. OVER BEAMS
6. BETWEEN BEAMS
7. CENTER OF SPAN
8. OVER PIERS
9. IN WHEEL PATHS

DEGREE (DELAMINATION)

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

TYPE OF JOINT

1. TYPE A (EXPANSION)
2. TYPE B (FIXED, SEALED)
3. FIXED NO SEAL

TYPE JOINT SEAL

0. NONE
1. COLD RUBBER
2. HOT RUBBER
3. TWO COMPONENT POLYMER
4. POURED ASPHALT
5. FORMED NEOPRENE
6. OTHER

JOINT CONDITION

1. GOOD
2. SPALLING
3. LOSS OF SEAL
4. SPALLING & LOSS OF SEAL
5. FIXED JOINTS OPEN & FILLED WITH DIRT, ETC.
6. EXPANSION JOINTS CLOSED
7. EXPANSION JOINTS OPEN EXCESSIVELY

POUR NUMBER	WEATHER DURING DECK POURING	MOMENT COND.	CRACKING				SCALING				DELAM.				GENERAL DECK CONDITION	TYPE JOINT	TYPE JT. SEAL	JOINT CONDITION	% EFFECTIVE SEAL	AMPLITUDE OF VIBRATION (IN) (STANDARD LOAD)	FREQUENCY OF VIBRATION (CPS) (STANDARD LOAD)	DEFLECTION (IN) (STANDARD LOAD)	STRUCTURE DESCRIPTION OR COMMENTS
			DEGREE	TYPE	SPACING EVEN FT.	LOCATION	DEGREE	DEPTH (IN.)	% AREA	LOCATION	DEGREE	VIS. CRACKING	% AREA	LOCATION									Any pertinent information may be placed in space using capital letters, arabic numerals, blank spaces and the special characters /+.(−)$✱,= Each character must occupy a space.
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18	20	22	23	24	26	28	29	30	33	35	36	37	38	40	41	43	44	45	47	49	52	55	59 80

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.
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33. LEAKING TRANSVERSE CRACKS COMBINED WITH 30.
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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.
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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.

NOTES

1. ALL DATES, GIVE MONTH AND YEAR.
2. COUNTY NO. -USE TEXAS HIGHWAY DEPT. COUNTY NO.
3. SUPER STRUCTURE STANDARD-GIVE ACTUAL STANDARD DESIGNATION OR AN "AGREED STANDARD DESIGNATION" IF THE STANDARD DESIGNATION TAKES TOO MUCH SPACE.
4. SPAN LENGTHS (EVEN FEET)
5. NUMBER OF CARDS-GIVE TOTAL NUMBER OF LINES FILLED IN, FRONT AND BACK.
6. DESIGN SPECIFICATION--GIVE YEAR.
7. SIZE STRINGERS--USE 30108 FOR 30WF108 AND SIMILAR ACCEPTED DESIGNATIONS SUCH AS TYPE A, SIZE 54, 42PLG.
8. UNSYMMETRICAL UNIT -- 0 IF NO, 1 IF YES.
9. TRANSIT MIX -- 0 IF NO, 1 IF YES.
10. SULFATE STREAM -- 0 IF NO, 1 IF YES.
11. DELAM; VIS. CRACKING -- 0 IF NO, 1 IF YES.
12. USE A SEPARATE SHEET FOR WIDENED PORTION OF A STRUCTURE IF DESIGN OR CONDITION IS MATERIALLY DIFFERENT FROM ORIGINAL PORTION OF STRUCTURE.
13. USE A SEPARATE SHEET FOR PORTIONS OF STRUCTURE OF DIFFERENT DESIGN OR WHERE OTHER CONFLICT OF DATA MAY EXIST.
14. GENERAL DECK CONDITION -- THE NUMERICAL CLASSIFICATION PROVIDED MAY BE SUPPORTED OR CLARIFIED WHEN NECESSARY BY WRITTEN NOTES SHOWING ANY UNUSUAL CONDITION OR COMBINATION OF CONDITIONS.

Form 1102-2

TEXAS HIGHWAY DEPARTMENT
BRIDGE DECK SURVEY

STRUCTURE NAME ____________________

SURVEYED BY ____________________ DATE __________

CODED BY ____________________ DATE __________

CHECKED BY ____________________ DATE __________

REMARKS ____________________

CONDITION OF STRUCTURE OTHER THAN DECK ____________________

1	DISTRICT
3	COUNTY NO.
6	CONTROL
10	SECTION
12	JOB
15	PERMANENT STR. NO.
18	HIGHWAY DESIGN
19	HIGHWAY TYPE
20	DESIGNED BY
22	HIGHWAY NUMBER
26	DESIGN SPEC.
28	DESIGN LOADING
29	SPAN TYPE
31	STR. TYPE
32	MAIN MEMBER TYPE
34	SUPER STRUCTURE STANDARD
42	STRINGERS: NUMBER
43	STRINGERS: SPACING (FT)
45	STRINGERS: SIZE
50	ROADWAY (FT) RAIL TO RAIL
53	CURB TYPE
54	SKEW (EVEN DEG.)
56	TYPE CROWN
57	TYPE DECK
58	SPAN LENGTH FT.: SIMPLE SPAN OR BEGINNING SPAN OF CONTINUOUS UNIT
61	SPAN LENGTH FT.: SECOND SPAN OF CONTINUOUS UNIT
64	SPAN LENGTH FT.: TOTAL LENGTH CONTINUOUS UNIT
67	NO. OF SPANS (C.U.)
68	UNSYMM. UNIT
69	SUBSTR. TYPE
71	SLAB THICKNESS(IN.)
74	TRAFFIC VOLUME (V.P.D.)
79 80	NO. OF CARDS

DESIGNED BY
- 1 - 25 DISTRICT
  DIRECT NUMERICAL CODING
- 50. BRIDGE DIVISION, D-5
- 60. HOUSTON URBAN
- 70. CONSULTING ENGINEER

HIGHWAY DESIGN
1. TWO-WAY TRAFFIC
2. ONE-WAY TRAFFIC
3. BOULEVARD
4. EXPRESSWAY - NO SERVICE ROAD
5. EXPRESSWAY - ONE SERVICE ROAD
6. EXPRESSWAY - TWO SERVICE ROADS
7. FREEWAY - NO SERVICE ROAD
8. FREEWAY - ONE SERVICE ROAD
9. FREEWAY - TWO SERVICE ROADS

HIGHWAY TYPE
1. INTERSTATE
2. U. S. HIGHWAY
3. STATE HIGHWAY
4. FARM-TO-MARKET
5. RANCH-TO-MARKET
6. PARK ROAD
7. INTERSTATE LOOP
8. U. S. LOOP
9. STATE LOOP

DESIGN LOADING
1. H10 OR LOWER
2. H15
3. H15-S12
4. H20
5. H20-S16
6. OTHER

CEMENT SOURCE:
1. LONE STAR CEMENT CORP., DALLAS, TEXAS
2. GENERAL PORTLAND CEMENT CO., TRINITY DIV., DALLAS
3. IDEAL CEMENT COMPANY, HOUSTON, TEXAS
4. SOUTHWESTERN PORTLAND CEMENT COMPANY, EL PASO, TEXAS
5. LONGHORN PORTLAND CEMENT COMPANY, SAN ANTONIO, TEXAS
6. SAN ANTONIO PORTLAND CEMENT CO., SAN ANTONIO, TEXAS
7. UNIVERSAL ATLAS CEMENT COMPANY, WACO, TEXAS
8. HALLIBURTON CEMENT COMPANY, CORPUS CHRISTI, TEXAS
9. TEXAS PORTLAND CEMENT COMPANY, ORANGE, TEXAS
10. TEXAS INDUSTRIES CEMENT COMPANY, MIDLOTHIAN, TEXAS
11. ARKANSAS CEMENT CORPORATION, FOREMAN, ARKANSAS
12. OKLAHOMA PORTLAND CEMENT CORP., OKLAHOMA CITY, OKLA.
13. DEWEY PORTLAND CEMENT COMPANY, DEWEY, OKLAHOMA

STRUCTURE TYPE
1. DECK TYPE
2. PART THROUGH TYPE
3. THROUGH TYPE

SPAN TYPE
1. ARCH
2. BASCULE
3. CANTILEVER AND SUSPENDED ARCH
4. CANTILEVER AND SUSPENDED SPAN
5. CANTILEVER SPAN
6. COMPLETELY CAST-IN-PLACE
7. COMPLETELY PRE-CAST
8. CONTINUOUS
9. CONTINUOUS COMPOSITE
10. HOLLOW BOX GIRDER
11. LIFT SPANS
12. PAN FORMS
13. PRECAST BEAMS, CAST-IN-PLACE
14. PRECAST SECTIONS
15. RIGID FRAMES, STEEL
16. RIGID FRAMES, CONCRETE
17. SIMPLE
18. SIMPLE COMPOSITE
19. SLAB AND GIRDER CAST-IN-PLACE
20. SLAB SPAN
21. SWING SPAN

MAIN MEMBER TYPE
1. STEEL I-BEAM
2. STEEL PLATE GIRDER
3. STEEL TRUSSES
4. CONCRETE, REINFORCED
5. CONCRETE, PRE-TENSION
6. CONCRETE, POST-TENSION
7. CONCRETE, POST-TENSION & PRE-TENSION
   ALUMINUM
9. PLASTIC, FIBERGLASS
10. PLASTIC, REINFORCED WITH STEEL
11. TIMBER
12. SUSPENSION BRIDGE, STEEL STIFFENER GIRDERS
13. SUSPENSION BRIDGE, CONCRETE STIFFENER GIRDERS
14. STEEL I BEAM AND STEEL PLATE GIRDER
15. STEEL I BEAM AND STEEL TRUSS
16. STEEL I BEAM AND CONCRETE REINF.
17. STEEL I BEAM AND CONCRETE PRE-TENSION
18. STEEL I BEAM AND CONCRETE POST-TENSION
19. STEEL I BEAM AND OTHER
20. STEEL PLATE GIRDER AND STEEL TRUSS
21. STEEL PLATE GIRDER AND CONCRETE REINF.
22. STEEL PLATE GIRDER AND CONCRETE PRE-TENSION
23. STEEL PLATE GIRDER AND CONCRETE POST-TENSION
24. STEEL PLATE GIRDER AND OTHER
25. STEEL TRUSS AND CONCRETE REINF.
26. STEEL TRUSS AND CONCRETE PRE-TENSION
27. STEEL TRUSS AND CONCRETE POST-TENSION
28. STEEL TRUSS AND OTHER
29. CONCRETE REINFORCED AND PRE-TENSION
30. CONCRETE REINFORCED AND POST-TENSION
31. CONCRETE REINFORCED AND OTHER

TYPE DECK
1. CONCRETE, LIGHTWEIGHT
2. CONCRETE, HARD ROCK
3. TIMBER
4. STEEL GRID
5. METAL DECK PLATE

TYPE CROWN
1. NORMAL CROWN
2. CONSTANT SLOPE OR SUPERELEVATED
3. SPECIAL CROWN
4. VARYING SUPERELEVATION

CURB TYPE
- 0. NO CURBS, WALKS, OR MEDIANS, OR NO INFO.
- 1. ONE SIDE ONLY
- 2. ON BOTH SIDES
- 3. MEDIAN ONLY
- 4. ONE SIDE AND MEDIAN
- 5. ON BOTH SIDES AND MEDIAN

SUBSTRUCTURE TYPE
1. CONCRETE COLUMN BENTS
2. CONCRETE PILE BENTS
3. CONCRETE "T" BENTS
4. CONCRETE PIERS
5. CONCRETE PIER AND CONCRETE COLUMN BENTS
6. STEEL FLOOR BEAM BENTS
7. STEEL PILE BENTS
8. TIMBER BENTS
9. OTHER

18	HEAVIEST WHEEL LOAD (KIPS)
20	TRANS-MIX
21	% AIR E.
22	TYPE ADMIX.
23	TYPE CEMENT
24	CEMENT SOURCE
26	CEMENT, SACKS PER C.Y.
28	TYPE AGGREGATE
30	TYPE FINISH
31	DATE SLAB PLACED
35	DATE OPEN TO TRAFFIC
39	TYPE-OVERLAY
40	DATE OVERLAY APPLIED
44	COND. OF OVERLAY
45	FIRST YEAR SALT USED
47	SALT APPLICATIONS PER YEAR
49	TYPE AREA
50	SULFATE STREAM
51	SUB-STRUCTURE CONDITION
53	SLAB DRAINAGE
54	WIDENING
56 – 80	NAME OF STRUCTURE (Capital letters, arabic numerals, blank spaces, and the special characters /+, (–) $*,= may be used in this space. Each character must occupy a space.)

TYPE CEMENT
1. TYPE I
2. TYPE II
3. TYPE III

TYPE ADMIX
- 0. NONE
- 1. WATER REDUCING
- 2. RETARDING
- 3. AIR ENTRAINING
- 4. COMBINATION

TYPE FINISH
1. BELT
2. FLOAT
3. OTHER

TYPE OF AGGREGATE
1. SILICEOUS COARSE, SILICEOUS FINE
2. CRUSHED STONE COARSE, SILICEOUS FINE
3. STAFFORD L. W. COARSE, SILICEOUS FINE
4. DALLAS L. W. COARSE, SILICEOUS FINE
5. EASTLAND L. W. COARSE, SILICEOUS FINE
6. RANGER L. W. COARSE, SILICEOUS FINE
7. CONVERSE L. W. COARSE, SILICEOUS FINE
8. STAFFORD L. W. COARSE, STAFFORD FINE
9. DALLAS L. W. COARSE, DALLAS FINE
10. EASTLAND L. W. COARSE, EASTLAND FINE
11. RANGER L. W. COARSE, RANGER FINE
12. CONVERSE L. W. COARSE, CONVERSE FINE
13. OTHER

CONDITION OF OVERLAY
1. GOOD
2. MINOR CRACKING
3. MAJOR CRACKING
4. RAVELLING
5. LOSS OF ADHESION
6. DISPLACEMENT OR SHOVING
7. SMALL PORTIONS MISSING
8. EXTENSIVE PORTIONS MISSING
9. COMBINATION OF THE ABOVE (EXPLAIN IN NOTE AREA)

TYPE OVERLAY OR SEAL
- 0. NONE
- 1. LINSEED OIL
- 2. EPOXY
- 3. POLYESTER
- 4. ASPHALT SEAL
- 5. ASPHALTIC CONCRETE
- 6. OTHER

CONDITION OF SUBSTRUCTURE
1. GOOD
2. DAMAGE FROM MOVEMENT
3. DAMAGE FROM LEAKAGE
4. DAMAGE FROM SALT APPLICATION
5. OTHER
6. COMBINATION OF 2 & 3
7. COMBINATION OF 2 & 4
8. COMBINATION OF 2 & 5
9. COMBINATION OF 3 & 4
10. COMBINATION OF 3 & 5
11. COMBINATION OF 4 & 5

TYPE OF AREA
1. URBAN (DOWNTOWN)
2. URBAN (INDUSTRIAL)
3. URBAN (RESIDENTIAL)
4. RURAL (INDUSTRIAL)
5. RURAL (RESIDENTIAL)
6. RURAL (GENERAL)
7. OTHER

WIDENING
- 0. NO
- 1. YES
- 2. YES - EVALUATED SEPARATELY

SLAB DRAINAGE
1. GOOD
2. FAIR
3. POOR

Form 1102-1

"Rules of Thumb"
Bridge Deck Survey Condition

Classifications

General Deck Condition (GDC) Classifications are listed in the booklet "Procedure for Interpreting General Deck Condition in Recording Data on Bridge Deck Survey Form No. 1102." This is a long title which we will shorten here for convenience to "Deck Condition Interpretation Booklet".

The GDC classifications listed and used in this program are 10, 20, 30, 31, 32, 33, 34, 40, 44, 50, 51, 52, 53, 54, 55, and 60. Definitions with representative pictures of these classifications are shown in the above booklet. The written classification descriptions govern and should always be used as the basis for rating; the pictures are furnished secondarily as an aid in rating.

The task at hand is to interpret and rate bridge deck conditions as uniformly and accurately as possible on the survey sheets, or to put it another way, to translate actual bridge deck conditions into representative numerical classifications. This, of course, includes cracking, scaling and delamination ratings as well as GDC classifications.

Various "rules of thumb" developed through study and practice are outlined here to assist in the rating of bridge decks, some of which pose unusual and complex problems in determining accurate classifications.

GDC classifications 10 and 20 are considered not deteriorating. Although minor widely spaced cracking and some very shallow surface roughness may appear, class 20 decks are sound with solid surfaces. The minor cracks are tight and shallow and there are no leaking cracks, tension cracks or other cracks on bottom of deck.

Sometimes it may be difficult to distinguish between surface roughness caused by finishing (especially where an overly wet cement laitance mixture was deposited on the surface and subsequently worn away by traffic) and surface roughness caused by light or very shallow scaling of the surface. In either case where the average depth of roughness is less than 2/10 of an inch over less than 10% of the pour area and the deck is otherwise sound and solid, the pour may be rated class 20.

Deterioration is considered to begin with GDC Class 30, with classes 31, 32 and 33 showing the more serious condition of cracks completely through the deck slab. Because of the cracking completely through the deck, class 31 is more serious than class 30 even though the class 30 will show more surface irregularities.

Class 31 indicates cracks completely through the deck with the digit "1" indicating a generally class 10 deck surface between the cracks which go through the deck. This classification is usually used where leaking cracks are widely spaced, 8 feet or more, and it is relatively easy to study the deck area between these cracks. Where leaking cracks are more closely spaced and it is difficult to distinguish between shallow cracks and leaking cracks, the deck should be rated class 32 (5 to 8 feet crack spacing) or class 33 (3 to 5 feet crack spacing).

To summarize the class 30 ratings, decks in this category show surface deterioration of shallow depth not approaching the reinforcing steel with the deck sound and solid past this shallow surface deterioration. Also, the cracks completely through the deck, which may be leaking water, are tight and solid and are not "working" as are the tension cracks listed in the higher classifications. Class 30 ratings show little or no delamination. Only Delamination Degree 2 (small isolated area or areas, page 37 of Deck Interpretation Booklet), should ever be placed in the 30's category. Higher Delamination Degree ratings will go into the 40 and 50 classifications. GDC 30's classification defines light to moderate deterioration.

More extensive deterioration goes into the 40's class where unsound surfaces may extend down to the top reinforcing steel. Delamination of degree 3, 6 and 7 fall into class 40. Also, loose or rotten concrete may be in evidence.

Generally if class 4 cracking is in evidence, the deck will be eligible for GDC class 40 rating. However, in isolated instances it may be possible to have class 4 or even class 5 cracking on a deck which is indicated by tapping to be exceptionally tight and sound with no spalling or delamination. In such cases this may be shown either by rating the GDC one step lower than the rated cracking or by indicating the apparent deck soundness by note for the particular pour or pours concerned.

Where class 4 spalling or scaling is observed, the pour should be rated GDC class 40.

GDC class 44 is described in the Deck Condition Interpretation Booklet as leaking cracks on bottom of deck combined with class 40 on top. Class 44 should also be recorded when leaking cracks are closely spaced (1 to 3 feet) indicating a more serious condition than GDC 33, even though the deck surface may appear sound.

Tension cracks on the deck bottom start with GDC class 50. A note should always be used in comments column to indicate tension cracking. This is the only method available of actually showing these tension cracks on the form since class 50 generally represents heavy deterioration on the deck surface. A modification may be made to the numerical classifications in the future to better represent early or beginning tension cracking.

Tension cracks may be leaking but can be distinguished from regular transverse leaking cracks by some slight or greater loss of concrete chips indicating that the crack is working, or sometimes by the random pattern of the tension cracks.

Class 50 GDC denotes heavy visible deterioration or severe hidden deterioration, such as delamination degrees 4, 5, 8 and 9, or separation of the concrete at both top and bottom steel. The latter generally will escape detection unless core samples are taken. Depth of class 50 deterioration may go well below the top reinforcing steel in some areas, however, deterioration to the top steel or even to a lesser depth may be recorded class 50 if the damage covers nearly the total pour area. i.e. picture 50-D, shallow; picture 50 I, deep.

Again, there may be an instance where class 5 cracking could be recorded with class 40 GDC to show that the cracking is relatively tight although severe in extent. This arrangement should always be supported by explanatory notes.

GDC 52 through 55, page 31, gets into heavier cracking on the deck bottom, approaching a most serious condition and possible future failure. Along with this, the condition of the deck top can be shown. For example, class 52 would indicate a class 20 on top where class 54 would indicate a class 40 on top.

GDC class 60 defines a failure of some sort in the pour. This can either be a hole through the deck, or cracking so severe that the concrete and reinforcing steel are no longer bonded together allowing some portion of the slab to deflect in excess of design criteria. This excessive deflection can usually be observed from the bottom of these badly cracked decks.

Basically, the actual deck condition should be described as accurately as possible using the available classification and degree ratings. Use notes extensively to delineate special conditions and to support or clarify general conditions. The items Cracking, Scaling and Delamination provide detail analysis of deck condition where GDC gives a general overall rating for the entire pour.

Decks should be carefully inspected both top and bottom and all details of condition recorded.

1. SIMPLE SPAN
2. POSITIVE MOMENT AREA
3. NEGATIVE MOMENT AREA
4. LOW MOMENT AREA

8. COMB. 1 & 5
9. COMB. 2 & 5
10. COMB. 3 & 4
11. COMB. 3 & 5
12. OTHER

5. SMALL AREA CONTINUOUS
6. LARGE, ISOLATED AREA OR AREAS
7. LARGE AREAS MODERATELY SPACED
8. LARGE AREAS CLOSELY SPACED
9. LARGE AREA CONTINUOUS

3. LOSS OF SEAL
4. SPALLING & LOSS OF SEAL
5. FIXED JOINTS OPEN & FILLED WITH DIRT, ETC.
6. EXPANSION JOINTS CLOSED
7. EXPANSION JOINTS OPEN EXCESSIVELY

POUR NUMBER	WEATHER DURING DECK POURING	MOMENT COND.	CRACKING				SCALING				DELAM				GENERAL DECK	CONDITION	TYPE JOINT	TYPE JT. SEAL	JOINT CONDITION	% EFFECTIVE SEAL	AMPLITUDE OF VIBRATION (IN) (STANDARD LOAD)	FREQUENCY OF VIBRATION (CPS) (STANDARD LOAD)	DEFLECTION (IN) (STANDARD LOAD)	STRUCTURE DESCRIPTION OR COMMENTS Any pertinent information may be placed in space using capital letters, arabic numerals, blank spaces and the special characters /+.(−)$*,= Each character must occupy a space.
			DEGREE	TYPE	AVG. SPACING FEET	LOCATION	DEGREE	DEPTH (IN.)	% AREA	LOCATION	DEGREE	VIS. CRACKING	% AREA	LOCATION										
01			X	XX	X.X	X	X	X.XX	XX	X	1	0	00	0	X	X								No delamination on top, no deterioration on bottom.
02			X	XX	X.X	X	X	X.XX	XX	X	1	0	00	0	3	1								Minor leaking cracks on bottom.
03			X	XX	X.X	X	X	X.XX	XX	X	1	0	00	0	3	2								Moderate leaking cracks on bottom.
04			X	XX	X.X	X	X	X.XX	XX	X	1	0	00	0	3	3								Extensive leaking cracks on bottom.
05			X	XX	X.X	X	X	X.XX	XX	X	1	0	00	0	4	4								Severe and closely spaced leaking cracks on bottom.
06			X	XX	X.X	X	X	X.XX	XX	X	2	X	02	9	3	0								Class 2 delamination.
07			X	XX	X.X	X	X	X.XX	XX	X	3	X	10	9	4	0								Class 3, 6 and 7 delamination.
08			X	XX	X.X	X	X	X.XX	XX	X	4	X	25	1	5	0								Class 4, 5, 8 and 9 delamination.
09			X	XX	X.X	X	X	X.XX	XX	X	9	X	90	1	6	0								Extensive Class 9 delamination.
10			X	XX	X.X	X	X	X.XX	XX	X	1	0	00	0	5	0								Beginning tension cracking on bottom.
11			X	XX	X.X	X	X	X.XX	XX	X	1	0	00	0	5	2								Advanced tension cracks on bottom.
12			X	XX	X.X	X	X	X.XX	XX	X	3	X	10	9	4	4								Class 3, 6 and 7 delamination with leaking cracks.
13			X	XX	X.X	X	X	X.XX	XX	X	4	X	25	9	5	1								Class 4, 5, 8 and 9 delamination with leaking cracks.
14			X	XX	X.X	X	X	X.XX	XX	X	4	X	25	9	5	5								Class 4, 5 and 8 delamination with advanced tension cracks
15			X	XX	X.X	X	X	X.XX	XX	X	9	X	50	1	6	0								Class 9 delamination with advanced tension cracks.
16																								
17																								
18																								
19																								
20																								
21																								
22																								
23																								
24																								
25																								

18 20 22 23 24 26 28 29 30 33 35 36 37 38 40 41 43 44 45 47 49 52 55 59 80

FOR DECKS OVERLAID WITH ASPHALT

The above examples will assist in classifying decks which are overlaid and cannot be visually examined on top. Survey for delamination on top and carefully examine bottom. General Deck Condition can then be determined as indicated. Although all possible combinations are not shown, the above conditions and GDC classifications include practically all basic problem conditions. Minimum area and degree quantities are shown.

GENERAL I
10. GC
OF
20. MI
SI
BI
30. MC
IN
CC
31. TF
32. LE
33. LE
40. EX
DE
OC
CC
44. LE
50. SE
DE
ST
EA
OR
51. LE
52. EX
DE
DI
52
60. DE
IN
PI

NOTES
1. ALL
2. COU
3. SUP
OR .
DES
NO
4. SPA
5. NUM
PRO
6. DES
7. SIZ
DES
8. UNS
9. TRA
10. SUL
11. VIS
12. USE
IF
ORI
13. USE
DES
14. GEN
PRO
WRI
OF
15. ENT
DET
BLA

APPENDIX G

SALT, ROCK, SODIUM CHLORIDE (95% MINIMUM), ROAD BUILDING (AND DE-ICING)

1. Scope - This specification covers the minimum requirements for rock salt (NaCl) to be used for road stabilization, de-icing of sidewalks, roadways, etc. This specification is derived from the American Society for Testing Materials Standard Specification No. D632 (Standard Specifications for Sodium Chloride) and the American Association of State Highway Officials Standard Specification No. M143-54 (Standard Specifications of Sodium Chloride). (See Section 3c, "Rejection".)

2. Applicable Specifications and Standards - Reference to specifications and standards shall be to those issues in effect on the date of the Invitation to Bid.

3. Requirements - Rock salt furnished to these specifications shall meet the following minimum requirements:

3a. Chemical Composition - Rock salt furnished to this specification shall be composed of a minimum of 95.0 per cent sodium chloride (NaCl) when tested according to Paragraph 6a.

3b. Particle Size - Rock salt, (NaCl) furnished to this specification shall conform to the particle size requirements as shown in Table I, when tested according to Paragraph 6b.

TABLE I

Sieve Designation	Sieve Opening (Inch-Approx. Equiv.)	Per Cent Retained
No. 0.265 inch	0.265	20 (Maximum)
No. 8	0.0937	50 to 95
No. 30	0.0232	90 (Minimum)

3c. Rejection - The rock salt (NaCl) shall be rejected if it fails to conform to any of the requirements of this specification. The material shall be rejected if not received in a free flowing usable condition.

4. Pre-delivery Samples - When specified on the Invitation to Bid, bidder must submit a sample of the rock salt (NaCl) he proposes to furnish to this specification to the State agency for which the purchase is made and/or to the State Board of Control in the amount and to whom it is specified on the Invitation to Bid.

(Continued on Page 2)

5. Sampling and Inspection - Sampling and inspection shall be by and at the discretion of the State agency for which the purchase is made and/or the State Board of Control after delivery or at point of origin. Generally, sampling shall be by the following methods (although the State agency for which the purchase is made and/or the State Board of Control reserve the right to utilize such other methods as they may deem necessary).

5a. Not less than three containers shall be selected at random from the lot. Each of the containers shall be sampled by scraping aside the top layer to a depth of approximately 1 inch and taking 1 pound samples by means of a sampling thief or other method that will insure a sample that is representative of a cross-section of the material in the container to a depth of at least 6 inches. In the case of bulk shipments at least three samples shall be taken, so as to be representative of each shipment. The individual samples shall be thoroughly mixed to form a representative composite sample of the materials.

5b. Every facility shall be provided the purchaser should he elect to have his representative sample the material at the producer's plant. If the purchaser decides to sample the material after delivery, it is understood that the sample will be taken directly from the freight car or truck and a 5 per cent tolerance be allowed in gradation and a 0.5 per cent variation in content of sodium chloride from the chemical composition prescribed in Section 3 shall be permissable.

6. Testing - The testing of rock salt (NaCl) furnished, or proposed to be furnished to this specification shall generally be done according to the following methods; however, the State agency for which the purchase is made and/or the State Board of Control reserve the right to utilize any additional methods or to require any additional tests they may deem necessary.

6a. Analysis - In making any chemical analysis in examining or testing samples such analysis shall be made in accordance with the method specified for "Salt" in the current "Official Methods of Analysis for the Association of Official Agricultural Chemists".

6b. Particle Size - The particle size of rock salt (NaCl) furnished to this specification shall be determined according to "American Society for Testing Materials" Standard Specification No. C-136-61T (Sieve or Screen Analysis of Fine or Coarse Aggregate).

7. Packaging - Shall be according to the best recognized commercial practices, and according to the following manner, as specified on the Invitation to Bid:

7a. 50 pounds - in multi-walled paper bags
7b. 100 pounds - in multi-walled paper bags
7c. Bulk truckload lots
7d. Bulk carload lots

8. Marking and Labeling - Each container shall be marked as follows (or in the case of bulk shipments, on the shipping report):

8a. Producer's name and address.
8b. Name of product.
8c. This specification number.
8d. Net weight of contents.

9. Compliance - Failure on the part of the bidder to comply with any and all requirements of this specification may subject his bid to rejection. No exceptions to or deviations from this specification will be considered unless each exception or deviation is specifically stated as a part of the bid. Any exception must be specifically stated by the bidder as an exception, with a detailed statement completely defining the exception and/or exceptions. If no exceptions or deviations are shown, the bidder will be required to furnish material exactly as specified herein. The burden of proof of compliance with this specification will be the responsibility of the vendor. In the event any product submitted to this specification fails to meet any and all conditions and requirements of this specification, then the cost of the samples and the cost of the testing shall be borne by the supplier.

10. Ordering Data - When ordering rock salt (NaCl) to this specification, thet ordering agency need only specify the following:

10a. This specification number.
10b. Quantity desired.
10c. Size packaging (See Section 7).
10d. When pre-delivery sample is desired, state amount of sample desired and address to which sample is to be sent.