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# PORTLAND CEMENT CONCRETE PRACTICES

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## PORTLAND CEMENT CONCRETE PRACTICES

1. Williams, F. H. P. BITUMEN-SAND MIXES FOR ROAD BASES. Gt. Brit. Road Research Laboratory (Crowthorne, Berkshire, England), RRL Rept. 239, 1968. 12 pp. 4 figs. HR Abstracts, October 1969.

The cost of bitumen-sand mixes can be reduced by using less bitumen than is necessary for surface durability, provided they are surface-dressed to protect them from abrasion. To determine whether a road built using this technique gives adequate performance, a series of experimental mixtures was laid on the Maiduguri-Bama road in Northern Nigeria early in 1960. The mixtures were made with unheated sand and three cutback bitumens of different viscosity. Two sections of cement-stabilized sand were laid for comparison. This report contains a brief description of the experiment together with the conclusions that emerged from observations made during mixing and laying and during 6 years under traffic. The results suggest that, with the light traffic on this type of road, sand mixes made with low binder contents and surface-dressed shortly after laying are very satisfactory. Bitumen contents of 2 to 3 percent could be used with a viscous cutback bitumen provided that the sand is warmed to a temperature of 40 to 50 C.

2. Powers, Treval C. THE PROPERTIES OF FRESH CONCRETE. John Wiley and Sons (605 Third Ave., New York, N.Y. 10016), 1968. 663 pp. $29.50. HR Abstracts, March 1969.

This book describes the properties of fresh concrete, and by systematic analytical discussion explains the nature of concrete mixtures in terms of structure and inter-particle forces. It presents old data in a new way, as well as some not previously published. Subjects include terminology, data on materials and development of a method of analysis of mixtures, a review of the principal schemes for formulating concrete mixtures, and an analysis of theoretical aspects of mix design. The role played by interparticle forces in fresh concrete is described; settlement, bleeding and shrinking of fresh concrete are discussed. Based on experience in the actual production of concrete, as well as many years of experiment and study, the book combines the practical viewpoint with the academic.

3. Waddell, Joseph J., ed. CONCRETE CONSTRUCTION HANDBOOK. McGraw-Hill Book Co. (330 W. 42nd St., New York, N.Y. 10036), 1968. 898 pp. $27.50. HR Abstracts, March 1969.

The handbook is a practical, concise volume designed to serve as a ready reference book. Presenting the industry's most recent advances, the book discusses the use of plastics in formwork, the latest developments in machinery and equipment, slip-form pavers and plastics used in the repair of concrete. Also detailed are geophysical and aerial aggregate surveying methods, aggregate beneficiation, new elastomers for joint sealants, the use of adhesives, new studies in concrete toughness and creep, and the application of statistical methods to concrete testing. Other topics include resistance welding of reinforcing steel, a detailed discussion of the properties of concrete as related to materials and performance, sampling and testing materials, and methods of computing size and number of batchers, mixers, and batch trucks.

4. Sargious, Michel A. WARPING AT THE EDGES OF PRESTRESSED AND REINFORCED CONCRETE PAVEMENT. Journal of the American Concrete Institute (P.O. Box 4754, Redford Sta., Detroit, Mich. 48219), Vol. 65, No. 11, pp. 952-958, Nov. 1968. HR Abstracts, April 1969.

Deformations at the corners of prestressed and reinforced concrete slabs were measured to study warping and its effect on the strength of pavement at Kuwait International Airport. The principal variables for the prestressed pavement were the length of slab, concrete strength, and compressive stresses through prestressing forces. For the reinforced concrete pavements the principal variables were the location of the corners at which the measurements were taken. The observations of the vertical movement due to warping at different times and different days were recorded and plotted in curves for comparison between the vertical movement at the corners of the different slabs. A limited study for the extension of the warping along the two perpendicular edges meeting at the corner was done in one case. Also, a loading test at the corner of one slab was done for investigating the value of the load required to bring the corner down to contact point and to find out if any failure could take place at the corner under the design load.

5. Sherwood, P. T. THE PROPERTIES OF CEMENT STABILIZED MATERIALS. Gt. Brit. Road Research Laboratory (Crowthorne, Berkshire, England), RRL Rept. LR. 205. 1968. 31 pp. HR Abstracts, July 1969.

This report summarizes the research carried out at the Road Research Laboratory on the properties of cement-stabilized materials used under British conditions. It deals with methods of assessing the suitability of stabilized materials for road base and subbase construction and describes the types of materials that can be stabilized with cement and how their chemical and physical properties affect their suitability for stabilization. The infulence of other factors such as temperature, time and the amount of cement to use are also discussed.

6. Larsen, T. D., Cady, P. D. and Carrier, R. E. METHODS FOR ANALYSIS OF HARDENED CONCRETE: EARLY FROST DAMAGE TO PROTLAND CEMENT CONCRETE. Pennsylvania State Univ., Dept. of Civil Eng., Special ept. 1, Feb. 1969, Available: Clearinghouse for Fed. Sci. and Tech. Info. (Springfield, Va 22151), PB 183 602. $3.00. HR Abstracts, September 1969.

With the increase of winter construction, protection against early freezing in concrete structures is vital. Yet very little is known about frost-damaged concrete. A great deal of the literature on winter concreting and early frost damage comes from the Scandinavian countries. This literature has had little exposure in the United States. The purpose of this report is to bring much of the early frost-damage information together under one cover and to answer the following questions: What is early frost damage in concrete and how does it affect a concrete structure? What temperature-time conditions are necessary for damage to occur? What information is needed to determine if damage has occurred? How can early frost damage be identified? An extensive bibliography containing articles discussing both theoretical and practical aspects of early frost damage is presented.

7. Swenson, E. G., ed. PERFORMANCE OF CONCRETE: RESISTANCE OF CONCRETE TO SULPHATE AND OTHER ENVIRONMENTAL CONDITIONS. Univ. of Toronto Press (Toronto 5, Ont.) 1968. 243 pp. $10,00. HR Abstracts, February 1969.

This book on concrete is a compilation of scientific and technical papers presented at a symposium held in honor of a Canadian Scientist of international stature, the late Thorbergur Thorvaldson. Contributors of papers were asked to emphasize field performance. The literature on sulphate resistance is almost entirely based on results of laboratory experiments and on the nature of the destructive action. Concrete performance in highly sulphated soils have received relatively little attention. It was also considered desirable to include an up-to-date review of the nature of sulphate attack. The papers dealing with durability aspects of concrete other than sulphate resistance are pertinent and timely, particularly as they also concern field performance.

8. Gill, V. L. and Morgan, J. G. D. BRITISH SYSTEM FOR SLIP-FORMING CONCRETE PAVEMENTS. Concrete (60 Buckingham Gate, London SW1) Vol. 2, No. 9, pp. 352-354, Sept. 1968. HR Abstracts, February 1969.

The slip-form paver described is of unusual interest in two aspects of its design. The first is its purpose--it is intended for the construction of minor roads, such as roads for subdivisions, as opposed to roadways. Relatively short lengths of pavement can be conveniently constructed. Slabs about 12 ft in width are laid by the new paving machine. The second aspect of interest lies in the theoretical background of its design. A new approach to the way in which fresh concrete flows under the influence of vibration has had a decisive influence on the design of this machine. The result is that the kind of concrete that is needed for slabs--harsh mixes of poor workability--can be laid and compacted by the paver at acceptable rates of progress.

9. WINTER CONCRETING. Concrete (60 Buckingham Gate, London SW1), Vol. 1, No. 10, pp. 339-350, Oct. 1967. HR Abstracts, March 1968.

Four papers on the problems of winter concreting are presented. The first: Winter Concreting: Specification and Quality Control, by T. N. W. Akroyd, deals with the technical requirements essential to insure the setting and hardening of the concrete, the need for a suitable working environment, and the necessity for economical working. The second: Concrete Production and Protection in Winter, by J. V. Tagg, discusses heating of mixing water, heating of aggregates, protection of aggregate stockpiles, formwork, and newly placed concrete. Winter Concreting, a miscellany, presents new developments in the heating of newly placed concrete, electrical heating of formworks, and the control of the environment by protable heaters. The last paper, Economics of Winter Concreting, by J. R. Smith, contrasts the costs of continuing work with proper precautions with the costs of having to cease work and then start again.

10. Lieber, W. EFFECT OF ZINC OXIDE ON SETTING AND HARDENING OF PORTLAND CEMENT. Zement-Kalk-Gips (Bauverlag GmbH, Kleine Wilhelmstrasse 7, 62 Wiesbaden, Germany), Vol. 20, No. 3, pp. 91-95, 1967. Building Science Abstracts, Vol. 40, No. 7, p. 193, July 1967. HR Abstracts, February 1968.

The setting of cement is much retarded by AnO, which acts only on the $C_3S$ to inhibit initially its hydration and hydrolysis. The retarding action is inversely proportional to cement fineness and $C_3S$ content. The initial combination of sulphate with aluminate and ferrite phases immediately after gaging a retarded cement with water is unaffected by the retarding action; only the subsequent reaction of the gypsum is retarded. There is formed during retardation of Ca hydroxyaquo zincate that is subsequently decomposed, the zinc apparently entering the crystal lattice of the silicate hydrates, which are developing into the high-lime fibrous phases. Final strengths of ZnO-containing cements are higher that those of ZnO-free cements.

11. Burke, John E. and Dhamrait, Jagat S. A TWENTY-YEAR REPORT ON THE ILLINOIS CONTINUOUSLY-REINFORCED PAVEMENT. Illinois Division of Highways. Presented at the Highway Research Board meeting, January 1968.

This paper presents the results of a study of the behavior of an experimental continuously-reinforced concrete pavement built in 1947 and 1948 on US 40 west of Vandalia, Ill. It covers a 20-yr span of service of the pavement and is intended as the final report of the study.

Transverse cracking, longitudinal cracking, pumping, steel stress, traffic, and performance data are presented, discussed, and evaluated in the paper. Design recommendations are included.

12. Gillis, L. R. and Spickelmire, L. S. SLIP-FORM PAVING IN THE UNITED STATES. American Road Builders Association (525 School St. S. W., Washington, D. C. 20024) Technical Bulletin No. 263, 1967. 75 pp. $2.00. HR Abstracts, September 1967.

Introductory sections present an epitome of events in the origin, development and deployment characterizing highway slip-form paving technology in the United States, together with an analytical discussion of methodology. Several sections are devoted to the salient benefits and problems incidental to routine use of the new methods. Construction practices circa 1965 are then discussed. Particular attention is given to the important matters of preparing an adequate pavement subgrade and of delivering uniform concrete to the paver. Finishing procedures and techniques of correcting undesirable surface conditions are also reviewed. Concluding sections present production and cost data which will provide prospective users a basis for evaluating economic factors.

13. Scholer, Charles H. and Best, Cecil H. CONCRETE CURING AND SURFACE PROTECTION WITH LINSEED OIL. Kansas Eng. Exp. Sta., State University of Kansas (Manhattan, Kansas), Spec. Rept. No. 60. July 1965. 22 pp. HR Abstracts, April 1966.

Tests of the durability of reinforced, air-entrained concrete samples under conditions of freezing and thawing in an aqueous solution of 2 percent sodium chloride are described. Conditions of test include 3,000- and 5,000-psi concretes containing crushed dense sandstone coarse aggregate and 3,000-psi concrete containing crushed porous limestone coarse aggregate.

Deterioration of all three concretes protected with one or more coatings of linseed oil in mineral spirits is compared with the same concretes without protection. Deterioration of the 3,000-psi concrete containing crushed porous limestone coarse aggregate and protected with a coating of water-emulsifiable linseed oil applied as a curing compound is compared with the same concrete without protection.

It is apparent from the photographic record that both types of protection are effective in impeding the progress of freeze-thaw damage and that periodic retreatment with linseed oil further arrests the damage under the conditions of test noted.

14. Cordon, William S. and Thorpe, Derle J. CONTROL OF RAPID DRYING OF FRESH CONCRETE BY EVAPORTATION CONTROL. Journal of American Concrete Institute (P.O. Box 4754 Redford Sta., Detroit, Mich, 48219), Proc. Vol. 62, No. 8, pp. 977-985, Aug. 1965. HR Abstracts, April 1966.

Rapid drying on the exposed surface of concrete may result in finishing problems such as stickiness, sponginess, and unevenness; plastic shrinkage and cracking; or a compacted surface which creates a layered structure subject to scaling. These undesirable characteristics may be corrected by control of evaporation with a monomolecular film on the surface of bleeding water. Laboratory tests and field experiences are discussed.

15. Lettier, J. A. and Metcalf, C. T. APPLICATION OF DESIGN CALCULATIONS TO "BLACK BASE" PAVEMENTS. Proc. Association of Asphalt Paving Technologists (Secy.-Treas., 1224 E. Engineering Bldg., Box 619, Ann Arbor, Mich.), Vol. 33, pp. 221-240, 1964. HR Abstracts, October 1965.

A method of flexible pavement design based on principles of the theoretical three-layer elastic system has been proposed by Dormon. An outline of the method including design curves was presented to the International Conference on the Structural Design of Asphalt Pavements. Subsequently, the method was modified to include fatigue factors which permit the method to be used in the design of pavements for different traffic volumes.

Design by this method is based on limiting the magnitudes of strain at critical locations in the pavement to permissible values. Critical strains for design purposes are the compressive strain in the subgrade and the tensile strain at the base of the asphalt layer. Control of these values provides control over the pavement's ability to resist deformation of the subgrade and cracking of the surface. A brief resume of the principles of the method demonstrates its application to design.

Theoretical design curves of the method show the combinations of thickness of asphalt layers and granular layers at which the strain values in the pavement are within acceptable limits. Because the method involves the relationship between separate layers, it provides a basis for preparation of alternate designs. These offer information by which specified thicknesses of granular material can be replaced by smaller thicknesses of black base.

Investigation of alternate designs provides additional information on equivalency ratios between asphalt and granular materials. Curves demonstrate that equivalent ratios do not remain constant but vary according to the thickness of asphalt layers and the strength of the subgrade. Calculations show that black bases have their greatest economic advantage in areas of weak subgrades. In addition, maximum equivalency ratios are developed by complete replacement of granular bases by black bases.

16. Ray, Gordon K. and Halm, Harold J. FIFTEEN YEARS OF SLIP-FORM PAVING. Journal of American Concrete Institute (Box 4754, Redford Sta., Detroit, Mich. 48219), Proc. Vol. 62, No. 2, pp. 145-159, Feb. 1965. HR Abstracts, July 1965.

The development of slip-form concrete paving in the United States is traced from 1949 when the first half-mile project was built in Iowa through the 1963 construction season when several hundred miles of paving were built with slip-form pavers. The early developmental machines are described and the newer improved and electronically controlled slip-form pavers which are now being used to build high-speed turnpikes, expressways, and interstate highways as well as light traffic secondary roads are also discussed.

The principles of slip-form paving are described, the requirements for adequate subbase preparation are discussed, and some of the important considerations for proper mix proportioning are outlined. Illustrations demonstrating the versatility of slip-form pavers for a wide variety of projects are presented. Also included are some of the data which prove the excellent riding qualities obtained through the use of slip-form construction.

17. Rosenberg, Arnold M. STUDY OF THE MECHANISM THROUGH WHICH CALCIUM CHLORIDE ACCELERATES THE SET OF PORTLAND CEMENT. Journal of the American Concrete Institute (P.O. Box 4754, Redford Sta., Detroit, Mich. 48219), Proc. Vol. 61, No. 10. pp. 1261-1269, Oct. 1964. HR Abstracts, March 1965.

A kinetic study of the reaction between calcium chloride and portland cement was made. It was found that: (a) although calcium chloride reacts with $C_3A$, the reaction rate, particularly in the presence of gypsum, is too slow to account for the set acceleration; (b) $CaCl_2$ definitely accelerates strength development in hydrating $C_3S$ but does not react chemically with $C_3S$; and (c) electron micrographic evidence suggests that $CaCl_2$ alters the shape of the hydration products formed when cement sets.

18. 3 PILOT PROGRAMS USING BLACK BASE CONSTRUCTION UNDERWAY IN MICHIGAN. Michigan Contractor and Builder (1040 West Fort St., Detroit 26, Mich.), Vol. 58, No. 20, pp. 24, 94, Aug. 1964 (Public Works Issue). HR Abstracts, February 1965.

The Michigan State Highway Department now has three pilot programs under way in an attempt to solve the problem of reflective cracking in bituminous overlays by the use of black base construction with an asphalt resurfacing. On Mich. 15, 6 1/2 miles are being paved with 4-inch black base utilizing local aggregates stabilized with a small amount of asphalt cement. A wearing and leveling course of 1 3/4 inches is being laid over the black base. Besides attempting to prevent reflective cracking, the paving will correct a rough riding, badly warped pavement and will widen the highway from 20 to 24 feet. The project calls for laying 14,326 tons of black base and an overall total of 33,000 tons of base, leveling and wearing courses.

The specification design for the black base uses MSHD Spec. 22A Modified aggregate containing a minimum of 50 percent crushed material. The aggregate, a local gravel with a large percentage of fines, has been stabilized with approximately 2 percent asphalt cement. This small amount of asphalt cement, in contrast to the average of 6 percent found in either bituminous aggregate (MSHD Spec. 4.11) or bituminous concrete (MSHD Spec. 4.12) is only sufficient to stabilize the material. After the black base is compacted with rollers which follow the paver, it can be used without damage for construction traffic.

19. Dixon, John D. and Marshall, Harry E. OHIO'S FIRST EXPERIENCE WITH SLIP-FORM PAVING. Ohio Department of Highways. Presented at the Highway Research Board meeting, January 1965.

The successful construction is described of approximately 8 mi of plain concrete pavement on the secondary highway system in Ohio using the slip-form technique. Design features, as well as construction experiences, are reported. The pavement was constructed on earth subgrade on fills and all cuts except for rock cuts where a 4-in. subbase was specified. The grade was prepared using an automatic subgrader. Concrete was produced in a central mix plant erected on the project and hauled to the paving site in trucks with dump bodies. A slip-form paver, without automatic controls, was used to extrude the concrete into a 24-ft by 7-in. concrete pavement.

20. Clauson, L. M. SLIP-FORM PAVING--CONSTRUCTION PRACTICES ON IOWA'S SECONDARY ROADS. Iowa State Highway Commission. Presented at the Highway Research Board meeting, January 1965.

Since 1949 over 1,000 miles of slip-form pavement have been constructed in Iowa. Most of these miles are on secondary roads. Several considerations for such construction are presented. Paving on narrow grades, poor soils, subgrade construction, mixing and placing operations, concrete mixes, and smoothness are also discussed.

21. Kawala, Edward L. FINISHING SUBBASES FOR SLIP-FORM PAVING. Portland Cement Association. Presented at the Highway Research Board meeting, January 1965.

An accurately graded, stable subbase is essential in slip-form paving to provide a smooth pavement slab of proper depth. Finishing subbases for slip-form paving requires different construction techniques than are normally used for pavements with side forms. The subbase must be constructed in advance without the advantage of using previously set paving forms as a guide. Equipment and methods that have been used successfully for finishing subbases are described. Three methods of finishing are commonly used (a) clipping "blue tops" with motor graders, (b) "finegrading" from an accurately placed reference line, and (c) placing a controlled depth of loose material so that after compaction only minor grade adjustments are required. Both untreated and cement-treated granular subbases are discussed.

22. Gillis, Lyman R. and Spinkelmire, Leigh. SLIP-FORM PAVING--CONSTRUCTION PRACTICES FOR 3 LANES AT A TIME PAVING IN CALIFORNIA. California Division of Highways. Presented at the Highway Research Board meeting, January 1965.

After 5 yr of use, slip-form paving now accounts for more than 80 percent of all concrete paving in California. It provides significant production advantages to the contractor and benefit of less cost to the highway user, as compared with side-form paving. Three different types of slip-form pavers have been successfully employed, but only one is capable of paving three lanes at a time. The procedures utilized are not significantly different than those utilized when paving narrower widths with the same type of equipment. Successful use of this type of equipment is dependent on: (a) standard operating procedures established through a logical analysis of cause and effect; (b) technically qualified field-level supervision; (c) experienced operators and mechanics; (d) properly maintained equipment; (e) uniform concrete at the pavers; and (f) close attention to operational details before, during, and after concrete placement.

23. Zulian, Adolph. SLIP-FORM PAVING--CONSTRUCTION PRACTICES ON COLORADO INTERSTATE SYSTEM. Colorado Department of Highways. Presented at the Highway Research Board meeting, January 1965.

Construction of the latest project on Colorado I-25 immediately south of the Wyoming border is described. It was constructed with some of the newest and most modern equipment. The 16.7 mi of four-lane divided highway was completed in 40 paving days. In one 14-hr day, the contractor placed 9,354 ft of 8-in. thick nonreinforced concrete pavement.

24. Lyon, Oscar T., Jr. SLIP-FORM PAVING ON AN URBAN INTERSTATE PROJECT. Arizona Highway Department. Presented at the Highway Research Board meeting, January 1965.

Arizona's first, and highly successful, use of the slip-form concrete paver had several noteworthy features. Profilograph readings averaged 2.5 in. per mi; one 1/2-mi section indicated a value of 1.1 in. per mi by the Hveem profilograph--the smoothest riding concrete pavement in the state. The width of the Guntert-Zimmerman machine was changed to pave both 24-ft and 36-ft wide roadways. Polyethylene strip was used for all longitudinal joints; in one test section it was unsuccessfully used for the skewed, transverse contration joint. A central plant setup, using dump trucks as concrete haul units, was established.

25. Burke, John E. and Mascunana, I. SLIP-FORM PAVING WITH MESH AND DOWELS IN ILLINOIS. Illinois Division of Highways. Presented at the Highway Research Board meeting, January 1965.

The first use of the slip-form paving process in constructing a portland cement concrete pavement on the primary highway system in Illinois is discussed. The pavement contains the transverse joints, dowels, tie bars, and distributed welded-wire fabric reinforcement employed by Illinois in standard formed construction. Details of the construction process, and the results that were achieved are described and evaluated. (Motion picture presentation.)

26. Swanson, Walfred E. A CONTRACTOR LOOKS AT SLIP-FORM PAVING. Roberts Construction Company, Lincoln, Nebraska. Presented at the Highway Research Board meeting, January 1965.

This paper covers the contractor's experience with early bidding and construction, agency acceptance, and job quality. It discusses efficiency, production capabilities, capital equipment and labor involved. It reviews the competitive position of slip-form paving.

27. Halm, Harold J. SLIP-FORM TODAY AND TOMORROW. Portland Cement Association, Chicago, Illinois. Presented at the Highway Research Board meeting, January 1965.

The latest slip-form paving developments and techniques are discussed and illustrated. Among these are the compatibility of slip-form pavers with centrally mixed concrete and the most recent technique of using two slip-form pavers to construct concrete pavements having mesh dowel designs. New equipment and recent modifications to current slip-form pavers are also described in order to present the latest results of research and development by all slip-form manufacturers.

Equipment manufacturers, contractors, and highway engineers predict that within a few years slip-form paving will be the standard method of concrete pavement construction. In only 15 years, the slip-form paver has proved itself.

28. Plowman, J. M. YOUNG'S MODULUS AND POISSON'S RATIO OF CONCRETE CURED AT VARIOUS HUMIDITIES. Magazine of Concrete Research (52 Grosvenor Gardens, London, S.W.1), Vol. 15, No. 44, pp. 77-82, July 1963. HR Abstracts, July 1964.

Tests are described designed to determine values of E and :- for concretes of various mix proportions and water/cement ratios. The influence of age (maturity and humidity of curing have also been investigated.

Conclusions reached indicate that concrete cured in water at 64 F tends to obey the following maturity law.

Percentage of Young's modulus which is obtained at a maturity of 35,600 F h = A + B $\log_{10}$ (maturity/1,000) up to maturities of about 40,000 F h. Values of the constants A = 69 and B = 20 five values of E in close agreement with the test results. Concrete cured at 90, 65 and 40 percent relative humidity has a value of E which increases with maturity up to approximately 60,000 F h and thereafter increases at a slower rate, finally decreasing. Young's modulus for concrete is independent of mix proportions but may be dependent upon the concrete strength. Poisson's ratio is independent of mix proportions, strength, maturity, and humidity of curing.

29. Childs, L. D. TESTS OF CONCRETE PAVEMENT SLABS ON CEMENT-TREATED SUBBASES. Portland Cement Association. Presented at the Highway Research Board meeting, January 1965.

A research program is in progress at the PCA laboratories to determine the structural contribution of cement-treated subbases to the load-carrying capacity of concrete pavements, and to develop the optimum thickness relationship between the two materials for various classes of traffic. After preliminary tests of 8-in. concrete on 5-in. soil-cement for comparison with granular subbase results, a program was established to test concrete thicknesses of 3, 5, 7, and 9 in. with subbases of 3-, 6-, 9-, and 12-in. thicknesses in all combinations. This test series will be duplicated to provide data both with and without bond at the interlayer. The load-carrying capacities of these panels are evaluated by comparing strains, deflections and subgrade pressures obtained from static load tests on cement-treated subbases with similar data from slabs on granular subbases. Retention of bond will be assessed by the rapid application of repetitive loads of high intensity.

This paper, the first of a series of progress reports, is concerned with concrete thicknesses of 3, 5, and 7 in. on cement-treated subbases of 3-, 6-, and 9-in. thickness, some with bond and some without bond. Data for both the bonded and unbonded slabs evaluate the reduction in strain and deflection of cement-treated subbases as compared with granular subbases of equal thickness due to the higher modulus of subgrade reaction. For unbonded slabs there was good agreement between measured data and data computed using the Westergaard equations. However, for bonded slabs the reduction in strain and deflection was somewhat larger than indicated by Westergaard's theory. These data relate particularly to the construction of relatively thin concrete surfaces on appropriate thicknesses of soil-cement for secondary roads and city streets.

30. Spigolon, Silvio J. BEHAVIOR OF EXPERIMENTAL CONTINUOUSLY-REINFORCED CONCRETE PAVEMENTS IN MISSISSIPPI. Engineering Experiment Station, University of Mississippi. Presented at the Highway Research Board meeting, January 1964.

The first two continuously-reinforced concrete pavements constructed by the Mississippi State Highway Department have been designated as experimental sections and are being observed by the University of Mississippi Engineering Experiment Station. These pavements contain several design features which are relatively new in this type of construction. This paper describes the performance of the pavements to date.

A brief description of the design features and the construction methods used for both pavements is presented. Longitudinal movements of the pavement have been measured periodically, as have crack width changes. Crack surveys have been performed, particularly in the early weeks after construction. Data on end movements, crack widths, cnd crack frequency and methods used for obtaining the data are presented and discussed.

Both pavements are in excellent condition. On the basis of the limited, but very satisfactory, performance of these pavements, several new projects using continuously-reinforced concrete pavement are being constructed and others planned in Mississippi.

31. Jones, R. FOLLOWING CHANGES IN THE PROPERTIES OF ROAD BASES AND SUB-BASES BY THE SURFACE WAVE PROPAGATION METHOD. Civil Engineering and Public Works Review (8 Buckingham St., London, W. C. 2), Vol. 58, No. 682, pp. 613-617, May 1963. No. 683, pp. 777-780, June 1963. HR Abstracts, October 1963.

The surface wave propagation method has been developed at the Road Research Laboratory for obtaining the elastic properties and, where possible, the thicknesses of the constituent layers of a road. By this method, measurements are made of the wavelength and velocity of the vibrations at the surface of the road at frequencies in the range of 30 to 30,000 cycles per second and the relation between velocity and wavelength is analyzed theoretically to yield the required information. Repetitive tests on experimental roads over a period of about five years have emphasized the particular usefulness of the method as a nondestructive method of following the changes in the properties of the base materials caused by time and traffic.

Examples are given which show that: (1) under favorable conditions, considerable increases (threefold or more) can be obtained in the elastic modulus of a sand subbase or a wet-mix-slag base material because of compaction by traffic. These increases lead to improvements in the load-spreading properties of these materials. (2) Cement-bound bases usually have extremely high elastic moduli in their uncracked condition. The development of cracks in these bases can be detected by the surface wave propagation method and it has been found that when weak or thin cement-bound bases become extensively cracked their effective elastic moduli become comparable with those of a well-compacted crushed-stone or wet-mix base. (3) The surface wave propagation method has detected stripping in bituminous materials which also leads to a decrease in the effective elastic modulus and load-spreading properties of the base.

32. Shaffer, R. K. and Jensen, C. D. CONTINUOUSLY-REINFORCED CONCRETE PAVEMENTS IN PENNSYLVANIA--A SIX-YEAR PROGRESS REPORT. Pennsylvania Department of Highways. Presented at the Highway Research Board meeting, January 1963.

After five and six years of service life, the two continuously-reinforced concrete pavements in York and Berks Counties, Pa., have supplied data sufficient for evaluating the effects of the variables under which the pavements were constructed. These projects, on Interstate 83 and 78, respectively, are located on heavily-traveled arteries where approximately one-third of the traffic is rated as heavy truck.

The background history of the two projects is reviewed briefly and the design variables of each pavement are described. Significantly different data are obtained from these variables and particularly from the season of paving, because the York County pavement was placed in the fall whereas the Berks County section was constructed in the summer.

Included are data recorded from crack frequency, crack width, traffic count, and roughness surveys. Annual end movement and performance of the terminal joints are described.

Shortly after completion of the Berks County project, several wide cracks developed and a subsequent investigation showed these to be lap failures, for the most part. Satisfactory repairs were made but in 1960, a portion of the 7-in. pavement, whose failure was due essentially to foundation failure and subbase densification, had to be replaced. The investigation accompanying this repair work is reported in detail.

The York County pavement so far has performed adequately. The relative performance of both pavements is described and a suggested design for future continuously-reinforced pavements is offered.

33. Mooney, William G. THE SECOND GENERATION OF SLIPFORM PAVERS. Construction Methods and Equipment (330 W. 42nd St., New York 36, N.Y.), Vol. 44, No. 5, pp. 89-93, May 1962. HR Abstracts, July 1962.

Eighteen States already use slipform pavers to place highway pavement. Another 24 States are planning to try the equipment in the near future or are studying its possibilities. Without a doubt, slipform paving is here to stay.

The slipform paver is essentially a traveling form that extrudes a ribbon of concrete pavement. Because it spreads, vibrates, forms, and finishes concrete in a continuous operation, this type of paver reduces both equipment and manpower requirements. It eliminates fixed forms, replaces several machines in the conventional paving train, and cuts the size of the paving crew in half.

The cost of slipformed pavement can be as much as 40 cents per sq yd less than that placed with fixed forms.

Since its crude beginnings some 12 years ago, the slipform paver has come a long way. Originally used only to widen pavement or to place base slabs, it now is gaining acceptance as a way to place finished highway pavement that must meet high standards.

Slipform paving still has its limitations. So far, slipform pavers have been used almost exclusively for non-reinforced pavement. This drawback soon will be eliminated. Already, some contractors have devised machines to place reinforcing with slipform pavers, and manufacturers are introducing similar machines.

There are several requirements that must be met to obtain good results with a slipform paver. The surface smoothness of the pavement depends directly on the accuracy of the subgrade on which the paver travels. Because of this, the acceptance of slipform paving has hinged on the development of equipment that can fine-grade to within a fraction of an inch. Now that equipment--electronically controlled graders, automatic roadbuilders, long-wheel-base land-planers is available.

The big breakthrough in slipform paving will come with the development of a machine to place reinforcing in the slab. Already, some machines have been devised and others are on the way.

One company is developing an attachment for its slipform paver that will place reinforcing mesh on a job in Rhode Island.

34. Chamblin, Brooke B., Jr. COMPACTION CHARACTERISTICS OF SOME BASE AND SUBBASE MATERIALS. Highway Research Board Bulletin, No. 325, pp. 1-21.

Laboratory dynamic and vibratory compaction methods were utilized to study the compaction characteristics of 23 reprssentative base and subbase materials; several comparisons with field compaction were obtained. The gradation and the water content of the materials were varied and their effect on vibrated dry unit weight was determined. Results indicate that vibratory compaction produces higher unit weights than does dynamic compaction, and that laboratory vibration tests may approximate the densities attainable by field methods.

35. Davidson, Donald T. MOISTURE-DENSITY, MOISTURE-STRENGTH AND COMPACTION CHARACTERISTICS OF CEMENT-TREATED SOIL MIXTURES. Highway Research Board Bulletin, No. 353, pp. 42-63.

A laboratory investigation was conducted to find relationships between strength and density for cement-treated soil mixtures compacted at different moisture contents. A dune sand and three clays were used to prepare sand-clay mixtures having different amounts and dominant kinds of clay minerals. Test specimens of each cement-treated mixture were molded to near standard and modified Proctor density, moist cured 7 or 28 days, and then immersed in water for 24 hr before being tested for unconfined compressive strength.

Test results show that the optimum moisture content for maximum density and the optimum moisture content for maximum unconfined compressive strength of cement-treated sand-clay mixtures are not necessarily the same. The moisture contents for maximum strengths are to the dry side for sand-clay mixtures dominant in sand, and to the wet side for sand-clay mixtures dominant in clay. As clay content increases, the optimum moisture content for both maximum density and maximum strength increases, and maximum density and maximum strength values decrease. Also presented are the increase in density and in strength for the different soils when the compaction effort is increased from standard to modified. The influence of different kinds of clay minerals on the relationships studied does not appear to be significant.

36. Childs, L. D. EFFECT OF GRANULAR AND SOIL-CEMENT SUBBASES ON LOAD CAPACITY OF CONCRETE PAVEMENT SLABS. Journal of the Research and Development Laboratories, Portland Cement Assoc. (5420 Old Orchard Rd., Skokie, Ill.), Vol. 2, No. 2, pp. 11-20, May 1960. HR Abstracts, May 1961.

A laboratory evaluation of the contribution of subbases to the load-carrying capacity of concrete pavements has been in progress for several years. Concrete slabs were built on three thicknesses of each of four granular materials and on two thicknesses of soil-cement. Static loads were applied to the slabs and the resulting deflections, strains, and reactive pressures were compared with those obtained when a slab was built directly on a clay subgrade.

Detailed reports on dense- and open-graded gravel have been published. This paper compares critical results from these early studies with corresponding data from subsequent tests to show the relative benefits of each subbase material. It was found that soil-cement subbases 4 and 5 in. thick made significant contributions to the load-carrying capacity of pavements but similar benefits from granular subbases demanded uneconomical thicknesses.

Measured strains and deflections compared favorably with results predicted by theory. Subgrade pressures were found to be low under loads at all positions except extreme edges and corners. Stresses due to edge loads were reduced appreciably as the load was moved inward from the slab edge, and the critical stress location for wide slabs appeared to be at the transverse joint.

37. Plowman, J. M. CONCRETE STRENGTH NEAR FREEZING POINT. Engineering (36 Bedford St., London, W. C. 2), 1960, 189 (4891), 78-9. Road Abstracts, Vol. 27, No. 10, p. 229, October 1960. HR Abstracts, April 1961.

Description is given of research carried out at King's College, London. Tests were designed to determine the relation between compressive strength and maturity of Portland cement concrete from ages of a few hours to 28 days. Specimens less than 24 hours old usually suffer damage when withdrawn from the steel mould, but this was prevented by means of a paper lining. The cubes tested were cured at a relative humidity of 95 percent and at a temperature of either 62 F or 36 F. The maturities at which cubes were tested were arranged so that a uniform spread was given when plotted on a logarithmic time base. Four grades of concrete were made, designed to have 28-day strengths of 3500, 4500, 5500 and 6500 psi. The average of three results were taken for the lower strength concrete and of two results for the higher strength concrete. From the results obtained, it was concluded that at temperatures near 60 F after 24 hours the strength of concrete is proportional to the logarithm of its maturity and that at temperatures near 32 F the growth of strength is retarded, this delay being made up after about 7 days.

38. Miles, George N. CONSTRUCTION PROCEDURES OF SLIP-FORM PAVEMENT. Highway Research Board Bulletin, No. 295, pp. 1-5.

For purposes of discussion it is necessary to define the paver as the simple, basic slip-form unit first introduced to the construction industry in the early 1950's. Modifications have taken place since that time, but the machine is essentially the same. It travels over a deposit of fresh pre-mixed concrete, vibrating, tamping and forcing it through an orfice which gives dimension, shape and density to the concrete. Critical to these operations and the best functioning of the paver are:

1. The subgrade to be paved must be an accurate presentation of the plane of the finished concrete pavement.

2. The concrete itself must be of proper and uniform consistency and may be a specially designed mixture for best results with the slip-form machine.

3. Best over-all results will accrue to an operation so synchronized that the paver is fed at a constant rate and starting and stopping are reduced to a minimum. These phases of the paving operation are a joint engineer-contractor responsibility, best handled by team operation dedicated to both volume and quality

The paver presents one of the greatest strides in the production of concrete paving for many years, and shows such a potential toward volume production at minimum cost as to bring about greater use of portland cement concrete paving, heretofore considered too costly by many highway construction agencies.

39. Shelby, M. D. and McCullough, Benjamin F. EXPERIENCE IN TEXAS WITH CONTINUOUSLY-REINFORCED CONCRETE PAVEMENT. Highway Research Board Bulletin, No. 274, pp. 1-29.

This paper summarizes the results of nine years of experience with continuously-reinforced concrete pavement in Texas. Data and conclusions based on physical measurements and observations of new and old projects are reviewed, and the possible reasons for variations of the crack patterns are discussed.

With these data and observations and reported experience in other states as a background, the current design policies and practices followed by the Texas State Highway Department in the design and construction of continuously-reinforced concrete pavements are enumerated.

In addition, a short summary of projects constructed and proposed for construction is reported. The table used in the summary covers the characteristics peculiar to each project, such as the use of air, use of concrete with a low modulus of elasticity, various pavement thicknesses, and variations of bond area for a given percentage of steel.

40. Barbee, J. F. CONSTRUCTION PRACTICES FOR PLACING, FINISHING AND CURING CONCRETE PAVEMENT. Highway Research Board Bulletin, No. 265, pp. 17-26.

A portland cement concrete pavement must be so constructed that it will (a) provide a smooth riding surface satisfactory to the traveling public, (b) be durable when subjected to natural weathering and chemicals used for snow and ice control, and (c) be capable of sustaining the traffic it is intended to carry.

Although the quality of the riding surface is the element of construction by which the public either approves or condemns a pavement, this element is of no greater importance than durability and structural strength. All desirable elements of a good pavement are a product of the workmanship of the contractor and his forces and the engineering and inspection personnel assigned to the work.

The actual construction is the culmination of all previous effort, involving many ideas covering research, traffic study, safety, construction materials (including soils), design, and finance. The entire procedure is finally judged, however, by how well the construction work is done and this responsibility falls directly upon the contractor and his forces and upon the engineer and his assistants.

Every step of construction, from the preparation of the subgrade and subbase through curing and opening to traffic, has a definite effect on the rideability, durability and structural integrity of the finished pavement. This paper attempts to point out and emphasize the purpose and importance of the various stages of a portland cement concrete paving operation. The composition of the mix and the elements of concrete control are not included.

41. Childs, L. D. and Kapernick, J. W. TESTS OF CONCRETE PAVEMENTS ON GRAVEL SUBBASES. Proc., American Society of Civil Engineers (33 W. 39th St., New York 18, N.Y.), Vol. 84, No. HW 3, Journal of the Highway Division, Pt.1, p. 1800-1--1800-31, October 1958. HR Abstracts, February 1959.

Concrete pavement slabs 8 in. by 12 ft by 18 ft joined by 1-in. round dowels were subjected to static loads to study the effect of various thicknesses of open-graded sand and gravel subbases upon the strength of the composite pavement structure. Deflections and strains in the concrete and pressures on the subbase and subgrade were measured for eight load positions when the slab was flat and when it was curled upward at corners and edges.

This is the second phase of a comprehensive study which is concerned primarily with subbases and secondarily with slab deflections and stresses and with interface pressures. Where load conditions permitted comparisons, it was found that trends reported in the first phase in testing 6-in. slabs on dense-graded sand and gravel subbases were supported by the present study, although magnitudes were affected by subbase material and slab dimensions.

The present experiments showed that open-graded sand and gravel subbases under flat slabs were more effective in reducing free-corner and free-edge deflections than in reducing strains. Computations based upon the test data and a theoretical treatment showed that under free-corner loads the deflection of an 8-in. slab on a 7.5-in. subbase would be about equal to that for a 9-in. slab with no subbase. However, a subbase 17 in. thick would hold corner strains in an 8-in. slab equal to those in a 9-in. slab with no subbase. Under edge loads the subbases were less effective in reducing deflections and strains than under corner loads.

Deflections and strains for loads at doweled corners of flat slabs were reduced to 60 and 70 percent, respectively, of corresponding values at free corners. A load 1 ft inward transversely from the free corner position further reduced deflections to 40 percent of the free corner value. A load 1 ft inward from the free edge reduced both deflections and strains to 70 percent of the free edge value.

Pressures between the slab and subbase increased with subbase thickness but pressures on the subgrade diminished slightly as subbase thickness increased. Subgrade pressures under typical pavement loads were of the order of 5 to 6 psi for extreme edge loads and 2 to 3 psi for interior loads.

Experimental deflections and strains for interior, edge, and corner loads were compared with theoretical curves based upon the liquid subgrade hypothesis. Both deflections and strains obtained under interior loads on curled and flat slabs were slightly greater than those computed by Westergaard's 1926 or 1947 equations. Test deflections and strains at edges due to edge loads were close to those computed from Westergaard's 1947 equations for both flat and curled slabs. Under free corner loading the test deflections for flat slabs were in good agreement with Westergaard's 1926 equation but were greater than indicated by theory for curled slabs. Test strains near corners were between those computed by the 1926 equation and Pickett's equation when the slabs were flat but were in better agreement with the latter when the slabs were curled.

42. Taylor, I. J. and Eney, W. J. SECOND YEAR PROGRESS REPORT ON CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS IN PENNSYLVANIA. Highway Research Board Bulletin, No. 238, pp. 23-38.

This paper summarizes the results of three years of sponsored research on continuously reinforced concrete pavements as conducted by the Fritz Engineering Laboratory of Lehigh University.

Test data and conclusions based on instrumentation, physical measurements and observations of two current pavement projects are reviewed and a general pattern of behavior for continuous pavements is established.

Some of the weaknesses found in existing pavements are described and given consideration in suggestions for design and construction improvements in continuous pavements.

43. Witkoski, F. C. and Shaffer, R. K. PROGRESS REPORT ON CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS IN PENNSYLVANIA. Highway Research Board Bulletin, No. 238, pp. 1-22.

The Hamburg project in Berks County, Pa., has attained one year of service performance. The York project is now two years old, although it, too, has been opened to traffic only one year. This report describes the general condition of each project and presents the combined results of a comprehensive crack frequency and width survey on both pavements. A study is made of the different patterns evolved as a result of paving in opposite seasons of the year. Further analysis is made of the effect of various pavement thicknesses upon service performance of the Hamburg roadway and of the effect of various depths of subbase material.

A scattered number of detrimental transverse cracks appeared on the Hamburg project within several months after completion. The nature of these cracks and the investigation to determine their cause is described, together with an account of the subsequent repair of these damaged areas. The specifications for these repairs are outlined, emphasizing the necessary precautions required for this work. A detailed description is given of the methods employed in pavement removal, in restoring the continuity of the steel, and in replacing the damaged concrete.

42. Fordyce, Phil and Geesaman, J. D. PERFORMANCE OF CONCRETE PAVEMENTS AS RELATED TO SUBBASE CONSTRUCTION METHODS. Highway Research Board Bulletin, No. 229, pp. 1-10.

Field studies of the performance of concrete pavements built on subbases of various designs and materials show that the method of subbase construction is an important factor. Uniformity of gradation was found to be the one subbase quality having the most influence on pavement performance. Subbase materials having a small maximum size were found generally to perform better than coarser materials, because segregation is less likely to occur during placement.

Information was obtained during the construction of 28 projects in many parts of the country representing typical subbase construction methods. The effects on subbase density and gradation by various construction operations are discussed. These include methods of subgrade compaction, subbase mixing, placement and compaction, and fine-grading.

Heavy construction traffic on the completed subbase nullifies the efforts expended to obtain uniformity and results in substandard pavement performance.

43. Walsh, William J. SLIP-FORM PAVER THAN INSERTS MESH. Western Construction (King Publications, 609 Mission St., San Francisco 5, Calif.), Vol. 33, No. 9, p. 40-41, September 1958. HR Abstracts, October 1958.

Since 1955 the Colorado Highway Department has seen the slip-form paver used on six projects, five on the Interstate System.

It was on the Denver-Castle Rock project the highway department policy of not specifying construction methods paid off with a definite step forward in the evolution of the slip-form paver. The construction firms were handed the job of incorporating four test sections in the project. One of these experimental sections was described as follows:

"One mile of concrete pavement with welded wire fabric reinforcement. One-half mile of this section is to include style 6 x 12 1/4 fabric with sawn joints spaced at 61 1/2-ft centers as presently specified in the plans. The other half-mile is to include welded wire fabric reinforcement, style 6 x 12-00/4 with sawn joints spaced at 106 1/2-ft centers. The spacing is based on 16-ft long mats with 12-in. overlap and 3-in. unreinforced space to each joint." The reinforcement was to be placed 2 in. from the surface of the 8-in. concrete slab.

As soon as the contract was awarded, there was speculation on how the experimental sections were to be laid with the slip-form which can't back up to permit the laying of a second layer of concrete after the reinforcing steel has been placed.

The construction firms quickly laid the three other test sections: One mile of typical section, 1/2 mile of 10-in. thickness of concrete on 4-in. cement-treated base, and 1/2 mile of experimental section consisting of an 8-in concrete paving placed on a 20-in cement-treated base.

The 4-in. cement-treated base was first laid for the reinforced concrete test section, and the contractors then brought forth a Rube Goldberg type of gadget to be attached to the front of the slip-form paver to handle the wire mesh. The "sled" was in the form of a large U, with outside members of 6-in. steel box girders. The rear ends of these girders were attached to the forward arms of the paver by a 1-in. bolt and were on ball and socket joints.

The front end, welded to the box girder, consisted of a 6-in. I-beam. Wheels were attached under the forward corners and two wheels were placed under the center of the I-beam to facilitate forward movement as the sled was pushed ahead by the paver.

After numerous on-job modifications, the slip-form paver was able to handle the steel fabric, sandwiching it between two layers of concrete in one continuous forward operation.

44. Colley, B. E. and Nowlen, W. J. PERFORMANCE OF SUBBASES UNDER REPETITIVE LOADING. Highway Research Board Bulletin, No. 202, pp. 32-58.

Experimental data are reported on the densification of subbases under the action of 500,000 repetitions of load. The effects on densification of the type and gradation of subbase materials, and the placement conditions relative to density and moisture content were evaluated.

Five granular subbase materials ranging in gradation from an open-graded free-draining material to a dense-graded, low-permeability material were tested. Also included were various combinations or blends of the subbase materials including soil-cement. The materials were placed at densities ranging from approximately 80 percent to 110 percent of standard AASHO density, and at moisture contents ranging from 75 percent to 120 percent of AASHO optimum. Subbases ranging in thickness from 1 in. to 12 in. were investigated, but in most tests the subbase was 6 in. thick.

The subbases were placed on a 2-ft clay subgrade confined in a concrete box 4 ft by 8 ft by 3 ft deep. A 2-in. prestressed concrete slab, jointed at mid-length, was cast on the subbase and loads were applied over the joint at the rate of about 20 applications per minute. The loads were of sufficient magnitude to cause a pressure on the subgrade of about 7 psi. During the repetitive load operations the moisture content of the subbase was increased from the placement moisture to a condition of saturation. The amount of densification that occurred, both in the subbase layer and in the composite subbase-subgrade foundation, was measured.

The data indicated that for the materials investigated, the magnitude of densification of the subbase layer for any of the placement conditions, was related to the permeability and to the percentage of minus 200-mesh material. As the permeability decreased, subbase densification increased. An increase in the placement density reduced subbase densification. For example, an increase in the density from 90 to 108 percent of standard AASHO density reduced subbase densification by at least 60 percent.

The performance of open-graded, high-permeability material was adversely affected by intrusion of subgrade soil into the subbase. A 1-in. filter course of sand prevented the intrusion.

The densification of granular soil-cement subbases was practically nil.

45. Schuyler, James R. PERFORMANCE OF CONCRETE PAVEMENTS AS RELATED TO SUBGRADES, SUBBASES AND STRUCTURAL DESIGN. Highway Research Board Proceedings 1957, pp. 433-442.

The evolution of concrete pavement in New Jersey over the past 35 years is traced to show how the current empirical design criteria were derived. In trying to remedy the pavement failures caused by an ever-increasing number of heavy trucks, it became apparent that the economical solution to the problem was to construct a more stable foundation rather than to increase the surface thickness. The influence of stabilized shoulders on pavement performance has also been recognized.

Sections of pavement on two of the major trucking routes are evaluated in this paper. For each section, pertinent information regarding the subgrade, subbase, pavement, shoulder, and traffic is included.

46. Potocki, F. P. MEASUREMENT OF LONG TERM STRAIN IN FULL-SCALE EXPERIMENTAL CONCRETE SLABS. Road Research Laboratory, RRL Report LR 259.

Long term dimensional changes in concrete under field conditions have been observed by measuring the static strains in reference slabs laid in connection with full-scale experimental reinforced concrete roads on A.1 at Alconbury Hill, Hunts., and the Grantham by-pass, Lincs. and the prestressed concrete road on A.46 at Winthorpe, Notts.

The results show that the concrete tends to swell at first, expansion reaching a value of about 150 microstrains in some cases, and that after about 6 months this process is reversed, and contraction takes place. Shrinkage in concrete of the order of 300 microstrains was observed in 10 year old reference slabs also developed high vertical shrinkage gradients (over 150 microstrains in a 225 mm slab), which are thought to contribute to failures in road slabs.

At intervals during the first ten years of life of a selected number of the reinforced concrete slabs on A.1 at Alconbury Hill, measurements were made of the horizontal strain developed close to the underside of the slab and in its central area by a loaded lorry standing with twin rear wheels directly above the strain gauge. The resultant strain was over 50 percent higher in a slab of normal strength than in one of high compressive strength. A slab 150 mm. thick gave greater strains under the lorry load than were measured under any of the 200 and 250 mm slabs. Visual inspection of the experimental road showed that cracks formed at a greater rate in the 150 mm slab than in the thicker slabs. The surface loading tests also showed that, for the central area of a concrete slab, the tensile strains produced close to the underside by vehicle loading are algebraically additive to those resulting from thermal warping during hot afternoons.