Performance of Continuously Reinforced Concrete Pavements Volume I: Summary of Practice and Annotated Bibliography

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FOREWORD

This report is one volume of a seven-volume set presenting the results of a study to provide the state-of-the-art for the design, construction, maintenance and rehabilitation of Continuously Reinforced Concrete Pavements (CRCP). Through a through literature review of current and past research work in CRCP and extensive field and laboratory testing of 23 in-service CRC pavements, the effectiveness of various design and construction features were assessed; performance of CRCP was evaluated; and procedures for improving CRC pavement technology were recommended. The 23 test pavements were located in six states that participated in this national pooled fund study. In addition the data available for 83 CRCPs included in the General Pavement Study (GPS) number 5 of the Long Term Pavement Performance (LTPP) Program was presented and analyzed. A number of CRCP maintenance and rehabilitation techniques that have been used over the years, including joint and crack sealing, cathodic protection of reinforcing bars, full-depth patching, resurfacing, etc., were also evaluated. This report will be of interest to engineers and researchers concerned with the state-of-the-art design, construction, maintenance and rehabilitation of CRCP including predictive models. The study was made possible with the financial support of Arizona, Arkansas, Connecticut, Delaware, Illinois, Iowa, Louisiana, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas and Wisconsin.

Sufficient copies of this report are being distributed to provide two copies to each FHWA regional office and three copies to each FHWA division office and each state highway agency. Direct distribution is being made to the division offices. Additional copies for the public are available from the National Technical Information Service (NTIS), United States Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Charles J. Nemmers, P.E.
Director, Office of Engineering
Research and Development

NOTICE

Technical Report Documentation Page

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16. Abstract

This report is one of a series of reports prepared as part of a recent study sponsored by the Federal Highway Administration (FHWA) aimed at updating the state-of-the-art of the design, construction, maintenance, and rehabilitation of CRC pavements. The scope of work of the FHWA study included the following:

1. Conduct of a literature review and prepare an annotated bibliography on CRC pavements and CRC overlays.
2. Conduct of a field investigation and laboratory testing related to 25 existing inservice pavement sections. This was done to evaluate the effect of various design features on CRC pavement performance, to identify any design or construction related problems, and to recommend procedures to improve CRC pavement technology.
3. Evaluation of the effectiveness of various maintenance and rehabilitation strategies for CRC pavements.
4. Preparation of a Summary Report on the current state of the practice for CRC pavements.

Each of the above four items is addressed in a separate report. The following reports have been prepared under this study:

Performance of CRC Pavements
- Volume I - Summary of Practice and Annotated Bibliography
- Volume II - Field Investigation of CRC Pavements
- Volume III - Analysis and Evaluation of Field Test Data
- Volume IV - Resurfacings for CRC Pavements
- Volume V - Maintenance and Rehabilitation of CRC Pavements
- Volume VI - CRC Pavement Design, Construction, and Performance
- Volume VII - Summary

This report is volume I in the series and presents an annotated bibliography on CRC pavements. Each publication included in the bibliography is identified as belonging to one of the following categories: Design, Construction, Maintenance and Rehabilitation, Performance Evaluation, CRC Overlays, and Research Underway.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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EXECUTIVE SUMMARY

Continuously reinforced concrete (CRC) pavement is portland cement concrete (PCC) pavement with continuous longitudinal steel reinforcement with no intermediate transverse expansion or contraction joints. The continuous joint-free length of CRC pavements can extend to several thousand meters (ft) with breaks provided only at structures. Terminal anchorage is provided at the ends of the CRC pavement to restrain length changes due to temperature variations and drying shrinkage of concrete. The CRC pavements develop a random cracking pattern with cracks generally spaced at about 0.9 to 2.4 m (3 to 8 ft). The cracking pattern is governed by the environment conditions at the time of construction, the amount of steel, and concrete strength. The steel reinforcement restrains the opening of the cracks. Also, the higher the amount of steel reinforcement, the more closely spaced the cracks will be. Most of the cracks form shortly after construction but additional cracking may develop over the next few years as a result of continued drying shrinkage of concrete, temperature variations, and traffic loading.

Although CRC pavement can be traced back to the late 1930's, the extensive use of CRC pavements began in the early 1960's during the hey-days of the U.S. Interstate System construction program. Currently, there are over 45 000 lane km (28,000 lane mi) of CRC pavements in the United States with pavements constructed in at least 35 States. CRC pavements can be one of the few truly "zero-maintenance" pavements if they are designed and constructed properly. Many older CRC pavements are considered to have been under-designed leading to premature failures when subjected to ever increasingly heavy truck traffic.

A major concern with CRC pavement is punchout distress. Punchout distress is the area enclosed by two closely spaced (usually less than 0.6 m (2 ft) transverse cracks, a short longitudinal crack and the edge of the pavement or a longitudinal joint. It also includes "Y" cracks that exhibit spalling, breakup, and faulting. Other distresses associated with punchouts include spalling along transverse cracks and faulting. Other leading causes of CRC pavement failure are wide (and spalled) transverse cracks due to steel rupture and spalling of concrete due to steel corrosion in the presence of heavy deicing salt applications in the northern States. The punchout distress is related to crack spacing, pavement thickness, poor foundation support, and heavy truck loadings. The repair of punchout distress typically consists of full-depth patches. With time, as the number of full-depth patches increase, the pavement may be resurfaced with asphalt concrete or portland cement concrete or it may be reconstructed.

Over the years, many State agencies have conducted research studies to develop better understanding of the effects of various design and construction features on the performance of CRC pavements. A large number of these studies have focused on pavement thickness, concrete aggregate type, amount of steel reinforcement, and base/subbase type. Studies have also been conducted to address the benefits of using epoxy-coated reinforcement and the effectiveness of permeable treated base layers under CRC pavements.

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Volume VI - Synthesis of Recommended Practice

This report is volume I in the series and contains a comprehensive annotated bibliography on CRC pavements and a summary of current practice. The summary of practice provides brief details on the extent and practice of CRC pavement usage in the United States and other countries.

PART I - SUMMARY OF PRACTICE

INTRODUCTION

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Several State agencies were surveyed to determine the status of CRC pavement usage in their jurisdiction. This section provides a summary of practice based on data collected through a questionnaire, technical reports, and conversations with agency staff and generally reflect the

conditions as of 1991. In addition, a brief summary of CRC pavement practice in several other countries is presented.

This volume is divided into two sections. The first section is a State by State summary of the States that have constructed CRC pavements. The information for the States was collected through technical reports, conversations with transportation officials, and a questionnaire. The second section is a summary of the international practices that are used in the construction of CRC pavements. Many countries, from Japan to France, have built and continue to build CRC pavements.

STATE BY STATE SUMMARY

Alabama

Projects

Alabama has constructed eight CRC pavement projects. The eight projects are located on four Interstates, 1-20, 1-59, I-65, and 1-459. The total length of these eight projects is approximately 68 km (42 mi). The oldest section was built in 1969 and the youngest in 1980. The estimated equivalent single axle loads (ESAL's) per day for 1988 range from a low of 4,016 to a high of 6,632.

Design

The typical design used for the eight projects was a 203- to 229-mm (8- to 9-in) CRC pavement over a 152-mm (6-in) base on top of a 152- to 254-mm (6- to 12-in) treated modified subgrade. The subgrade was often lime treated to help improve the subgrade characteristics. The shoulder design is either an asphaltic concrete 51 to 102 mm (2 to 4 in) thick over 152 mm (6 in) of selected soil subbase or a concrete shoulder 203 mm (8 in) thick constructed on top of a selected soil subbase. Drainage has been provided for most of the sections with longitudinal edge drains. For the design of the younger CRC pavement sections Alabama used the 1986 AASHTO Guide for Design of Pavement Structures modified by the FHWA.

Maintenance and Rehabilitation

The most common maintenance and rehabilitation that has been performed on the CRC pavements is full-depth repairs for edge punchouts. Edge punchouts are the most predominate distress in Alabama. A rubblization and overlay project has recently been done on a section of an older CRC pavement.

Performance and Evaluation

The overall performance of the CRC pavements in Alabama has been reported to be fair. Some of the CRC pavements have performed well while other sections have not performed as well. Alabama's pavement condition is evaluated by a surface distress survey

every 2 years. The information collected by the survey is primarily used at the network level. The surface ride condition evaluation done prior to 1990 was done with a BPR roughometer. Since 1990, a South Dakota style non-contact profilometer is being used. The surface ride condition information is being used at both the project and network level in Alabama.

Arizona

Projects

Arizona has just recently, within the past decade, constructed four new CRC pavement projects. The oldest project was opened to traffic in 1983 and the youngest in 1991. The four projects are on two highways, SR 101L and SR 360 and have a total length of 17.7 km (11 mi). The traffic estimated for these sections in 1988, ranged from 251,000 to 496,000 ESAL's. Two 3.2-km (2-mi) sections of SR 101L were built as experimental sections according to Arizona Department of Transportation (ADOT).

Design

The design used for all the sections is the same. The CRC pavement is 229 to 254 mm (9 to 10 in) thick on top of a asphaltic concrete base, The thickness of the base has not been reported. Drainage has been provided. Two of the sections have a tied concrete shoulder. Arizona uses the AASHTO Guide for the design of their CRC pavements.

Maintenance and Rehabilitation

No maintenance or rehabilitation has taken place on any of the projects yet.

Performance and Evaluation

No performance data were available on the four CRC pavement projects.

California

Projects

California has constructed two experimental CRC pavements. The two sections are located on I-5 and I-80. The I-80 section was opened to traffic in 1949 and the I-5 section in 1971. The estimated ESAL's for 1989 were 785,000 one way for I-5 and 519,000 for I-80. Combined, these two sections measure approximately 5.1 km (3.2 mi) long. The I-80 section used both 0.5 percent and 0.62 percent steel. The I-5 section had three different types of reinforcement used; mesh, transverse and longitudinal steel and just longitudinal reinforcement.

Design

The design for both CRC projects consists of a 203-mm (8-in) CRC slab constructed on top of a 102- to 127-mm (4- to 5-in) cement treated base and an aggregate subbase over a silty clay. Both sections have asphaltic concrete shoulders over an aggregate base. Drainage was not provided.

Maintenance and Rehabilitation

Little to no maintenance work has been performed on these CRC pavement projects and there has been no major distresses affecting these projects other than minor spalling of the cracks.

Performance and Evaluation

No overall performance level has been reported but since there has been no M&R activity, it can be assumed performance has been good.

Connecticut

Projects

Connecticut has built five CRC pavements, three of which have been overlaid with asphaltic concrete. All five sections have been built on the same Interstate, I-84. The oldest pavement was opened to traffic in 1963, the youngest in 1981. The total length of these five sections is approximately 45 km (28 mi). Connecticut has constructed three experimental test sections along I-84. The first two experimental sections were built in 1976 and 1980 and were used to establish average performance life-cycle curves. The third section is an LTPP/GPS-5 study section. The amount of traffic on these sections range from 2,350,000 ESAL's to 2,920,000 ESAL's for 1987.

Design

The typical design for the five sections is a 152- to 203-mm (6- to 8-in) CRC pavement over a 152- to 610-mm (6- to 24-in) base material. Some CRC sections were placed over an existing concrete pavement. The subgrade was a coarse-grain material. For the overlaid sections, the AC overlay constructed was usually a 19-mm (¾-in) bituminous concrete, Class 14, over a 102- to 152-mm (4- to 6-in) bituminous concrete, Class 1. The shoulder design was a 229-mm (9-in) bituminous concrete on a gravel subbase. Drainage was not provided for any of the five sections. Connecticut is currently not designing any new CRC pavements.

Maintenance and Rehabilitation

The most common distresses that have affected CRC pavements in Connecticut are edge punchouts, blow-ups and partial delamination due to high steel. The maintenance and

rehabilitation that Connecticut is using is the Illinois full-depth patch method that is used to re-establish the steel continuity in any failed areas. Connecticut is also overlaying its CRC pavements with bituminous concrete when it is a viable alternative to patching.

Performance and Evaluation

The performance of the five sections has been mixed. Certain sections have deteriorated rapidly in the last 2 years (as of 1992). The overall ride quality is good but with the increasing patches that are being placed each year the overall condition is fair. The recent rapid deterioration has been attributed to the fact that the CRC pavements have handled 2 to 3 times more ESAL's than designed for and there is poor drainage.

Connecticut has used numerous evaluation procedures for its pavements. The first procedure is the photolog equipment. The surface ride condition is also obtained during the filming process by a Techwest System Class 3 roughness device but may also be collected by a South Dakota profiler. The information collected by this procedure is used at the network level. The CRC pavement condition is rated annually by Connecticut's pavement rating system which is used at the network level. A pavement evaluation and a ground penetrating radar survey has also been used. This information is used at both the project and network level.

Georgia

Projects

Georgia has built approximately 143 km (89 mi) of CRC pavements throughout its Interstate system. There are 10 CRC pavement projects in the State with 1 being an experimental section. They have been built on four separate Interstates, I-20, I-75, I-85 and I-95. The oldest section was opened to traffic in 1971, the youngest in 1973. The average annual daily traffic (AADT) for 1990 ranges from 30,000 to 65,000. The experimental CRC section was a CRC overlay of a jointed concrete pavement which was overlaid with 76, 114, and 152 mm (3, 4½, and 6 in) CRC pavement. The 76 mm (3 in) overlay has been removed since the end of the experiment.

Design

Georgia only designs new CRC pavements as part of a widening program when the existing pavement is CRC and must be retained. The typical design for the 10 pavements was a 118- to 229-mm (7- to 9-in) CRC pavement on top of a 152-mm (6-in) cement treated base over a subgrade of fine sand. The shoulder design was most often a 38-mm (1½-in) asphalt layer over a soil cement base. In half of the projects, drainage was provided and was either edge drains or an asphalt concrete (AC) drainage course.

Maintenance and Rehabilitation

The most common distresses affecting Georgia's CRC pavements are punchouts, longitudinal cracking and poor construction joints. Some older pavements have begun to require maintenance of their punchouts but overall Georgia has not needed to rehabilitate any of its CRC pavements except for correction of settlement in marshy areas by asphaltic overlays.

Performance and Evaluation

The overall performance of the States CRC pavements has been good. The CRC pavements have served well for almost 20 years with few maintenance needs on most projects.

The evaluation of the pavements is done with two methods. The first is the surface ride condition which is done with the Mays Meter. The time frame of when it is done was not reported. The information collected from the Mays Meter is used at both the network and project level. The second method is the evaluation of the pavements structural condition. This is done by visual distress surveys noting cracking patterns, punchouts and other distresses. This information is used at the network level. Deflection testing and coring is also used for the investigation of the structural condition but are used at the project level.

Illinois

Projects

Illinois has constructed over 1,600 km (1,000 mi) of CRC pavements. They have been constructed throughout the State highway system. Most of this construction was done between 1957 and 1980. However, new CRC pavement continue to be constructed on the Interstate and other primary roadways. The mean yearly ESAL application rate averages of all pavements has increased from 300,000 to 1,200,000 over this time period.

Some of the first experimental sections of CRC pavements were built in Illinois and since 1971 Illinois has built 13 experimental sections. The different experimental sections have ranged from different CRC thicknesses with PCC shoulders to CRC overlays of CRC pavement.

Design

The design of the CRC pavements range from a CRC surface thickness of 203 to 254 mm (8 to 10 in). The most common thickness is 229 mm (9 in). The steel reinforcing was either deformed bars or deformed welded wire fabric of approximately 0.58 to 0.72 percent. The base thicknesses are most often 102 mm (4 in). The base materials that have been used are, a bituminous aggregate mixture (BAM), roller compacted concrete (CAM), econocrete (CAM II), and a granular material. The most common materials used are CAM and BAM. The subgrades were generally fine grained silts and clays. Drainage is provided for most of

the sections and when the drainage type was known its was usually a crushed stone drainage layer or longitudinal edge drains. The type of shoulders that were used are not known and are project specific according to design. On recent projects, a permeable CTB has been used as a base/drainage layer.

Maintenance and Rehabilitation

The predominate distresses in Illinois CRC pavements are D-cracking, punchouts, steel rupture, and terminal end section problems. The most common maintenance and rehabilitation has been full-depth or partial-depth patching and AC overlays. The maintenance and rehabilitation methods are project specific.

Performance and Evaluation

The CRC pavements have performed remarkably well in terms of traffic actually carried compared to design traffic. Based on the long-term cost-effective performance of CRC pavements in the State, Illinois continues to rely on CRC pavement as the pavement of choice for heavy truck traffic highways.

Iowa

Projects

Iowa has constructed approximately 475 km (295 mi) of CRC pavements. The oldest section was built in 1965 and the youngest in 1975. The cumulative ESAL's as of 1990 have ranged from a high of 18 million to a low of 1 million.

Design

The most common design is a 203-mm (8-in) CRC pavement over a 102-mm (4-in) granular base or asphalt treated base. The shoulder design is an asphalt concrete usually 203 to 279 mm (8 to 11 in) thick. All the CRC pavements are drained with a 102 mm (4 in) shoulder subdrain 1,219 mm (48 in) deep.

Maintenance and Rehabilitation

Many CRC pavements have been overlaid with both AC and PCC. The AC overlay thickness ranges from 76 to 127 mm (3 to 5 in) while the PCC overlay thickness ranges from 127 to 152 mm (5 to 6 in) thick.

Performance and Evaluation

No information pertaining to Iowa's performance and evaluation was available.

Kentucky

Projects

Kentucky has built only three CRC pavements throughout the State. These sections are located on two Interstates, I-71 and I-275. The total length of the sections are approximately 18 km (11 mi). Of the three projects one has already been overlaid with 118 mm (7 in) of AC, another is to be rubblized and overlaid with PCC and the third is scheduled to be replaced (as of 1991). The oldest pavement was built in 1968 and the youngest in 1973.

Design

The design used was a 203- to 229-mm (8- to 9-in) CRC pavement over a 152-mm (6-in) densely graded aggregate over the insitu material.

Maintenance and Rehabilitation

The maintenance strategies for the CRC sections was not reported but there rehabilitation strategies seems to be to replace or overlay the existing CRC pavements with either AC or PCC. The most common distresses in the Kentucky pavements were cracking and spalling.

Performance and Evaluation

The overall performance of the CRC sections was reported to be fair because the CRC sections deteriorated earlier than other PCC pavements nearby. The sections are evaluated by a rideability index and condition points. The procedure is used on all Interstates pavements every year. Routine structural analysis from deflection testing is not done on PCC pavements.

Maryland

Projects

Maryland has constructed seven CRC pavements throughout the State. These pavements are located on seven different Interstates. The total mileage of all the sections is approximately 158 km (98 mi). The oldest pavement was opened to traffic in 1951 and the youngest is still being constructed (as of 1991). The heaviest traffic is on 1-95 with 6.4 million ESAL in 1989, the lowest is 0.17 million ESAL in 1985 on I-195.

Design

The thickness design for the seven CRC sections ranges from 203 to 330 mm (8 to 13 in). The base is either cement treated or a stone aggregate usually 152 or 178 mm (6 or 7 in) thick. The subbase is usually a select fill 305 mm (12 in) thick. The subgrade ranges from a sand to a silt or clay. CRC pavements have also been used as an overlay of jointed reinforced

concrete pavement (JRCP). The design method Maryland uses is the 1986 modified AASHTO design procedure.

Maintenance and Rehabilitation

The distresses that most commonly effect Maryland's CRC pavements are punchouts, spalling, and some pumping. Some of the older CRC pavements have been rehabilitated with a 76 to 152 mm (3 to 6 in) AC overlay.

Performance and Evaluation

The overall performance of the CRC sections has been fair to good, based upon the distress surveys taken by the State.

The CRC sections are evaluated with a number of processes. Road roughness surveys are taken with a K.J. Law Model 8300 Roughness surveyor. This information is used at the network level. A surface friction or skid survey is taken using the K.J. Law-ASTM E-274 trailer and the information is used at the network level. A distress survey is performed (window survey) and is also used at the network level. Intensive condition surveys using cores, profilograph, falling weight deflectometer (FWD), and others are used to collect information at the project level. The lime period at which these surveys are taken was not reported.

A recently constructed CRC pavement along a section of U.S. 50 has exhibited premature occurrence of punchouts - within 3 years of construction. The punchouts are related to longer crack spacings resulting from the use of low amount (0.50 percent) of steel reinforcement.

Michigan

Projects

Seven separate highways contain CRC pavements. The oldest one was built in 1958 and the youngest in 1978.

Design

The most common design used was a CRC thickness of 203 or 229 mm (8 or 9 in). CRC sections with less than one thousand ESAL's per day are 203-mm (8-in) thick while those sections with more than one thousand ESAL's are 229 mm (9 in) thick. The base and subbase for all CRC sections was a 102-mm (4-in) dense-graded aggregate over 254 mm (10 in) of granular material. On depressed pavements drainage is provided with the use of 152 mm (6 in) underdrains.

The steel percentage used between 1958 and 1962 was 0.6 percent. Since 1962, the pavements were designed with 0.7-percent steel. Transverse steel was required in all CRC pavements until 1973 when it was omitted from two and three-lane pavements.

The end treatment design prior to 1958 was a 3.1-m (10-ft) expansion relief section. Anchor lugs were used from 1962 through 1969. Wide flange beam joints have been used since 1969. In mid-1978 the wide flange beam joints were discontinued in specified areas where there was clay and sand subgrades, and were replaced with anchor lugs.

Michigan has not constructed any new CRC pavement sections since 1978.

Maintenance and Rehabilitation

The most common distresses affecting the CRC pavements are base support failure, longitudinal cracking and delamination at the reinforcement level. Michigan has done very little rehabilitation of its CRC sections. In general, they have either recycled them or constructed an AC overlay.

Performance and Evaluation

The overall performance of the CRC sections in Michigan has been fair to poor due to the distresses that are common to the pavement. They have evaluated their CRC pavements with limited coring and delamination investigations for structural evaluation. They also conduct an International Roughness Index study and PMS survey periodically.

Minnesota

Projects

Minnesota has constructed 29 CRC pavements. The 29 projects are located on 5 highways, the major highway being I-35. The oldest section was built in 1964 the youngest in 1973. The largest AADT that one section carries is 109,123 and the smallest is 4,903. Minnesota has constructed three experimental sections throughout the State. Two of the sections, located on I-94 and I-35, have a bonded overlay and are currently being monitored. The third section was constructed in 1982 with cathodic protection.

Design

The most common design of Minnesota's CRC pavements has been a 203- to 254-mm (8- to 10-in) CRC pavement over a 76- to 152-mm (3- to 6-in) base. The base is usually constructed of an uncrushed gravel or a crushed stone. The subgrade in most of the sections is classified as an A-4 material or poor. Minnesota is no longer building CRC pavements.

Maintenance and Rehabilitation

The distresses that are predominate in Minnesota are delamination of concrete at the top layer of steel and tension failures (steel rupture). The maintenance and rehabilitation has consisted of full-depth patching, asphalt overlays and reconstruction of the CRC sections.

Performance and Evaluation

The overall performance of the CRC has been generally fair to poor with some projects performing well.

The ride is monitored at least every third year (with a Mays Meter until 1989, when a South Dakota Profiler replaced the Mays Meter). They also monitor the surface distresses. The monitored distresses are patch deterioration, localized distress, D-cracking and transverse cracking. All this information is used at the network level.

Mississippi

Projects

Eighty-nine CRC pavements have been built in Mississippi. This corresponds to 1 652 center-lane km (1,027 center-lane mi). The oldest section was built in 1960 and the youngest in 1982. A large majority though, were built before 1975. The CRC sections are located on 14 separate highways and interstates.

Design

The most common design is a 203- mm (8-in) CRC pavement over a 152-mm (6-in) cement treated base on top of clay or silt. One experimental section has been built in Mississippi. This section is a CRC overlay of an existing CRC pavement and was constructed in 1981 on I-9. CRC pavements are no longer being built in the State.

Maintenance and Rehabilitation

The most common distresses in Mississippi are edge punchouts. The maintenance that has been done to the CRC sections is the repair of punchouts with the use of full-depth patching. According to specifications which are similar to the Illinois full depth patching method, the steel is connected to ensure continuity.

Performance and Evaluation

The overall performance on the CRC pavement has been good. Mississippi uses three methods to evaluate its pavements. A dynaflect is used to monitor the structural condition. A windshield distress survey is used to evaluate the functional condition and a South Dakota

Road Profiler is used for the surface ride condition. All three evaluation processes are used at the project level at the present time.

Missouri

Project

Missouri has constructed only one CRC pavement section. This 8.2-km (5.1-mi) section was built in 1971. It is an experimental section and is included in the LTPP program.

Design

Missouri does not, presently, use CRC design. This one section has been the only section designed and built in the State.

Maintenance and Rehabilitation

The most common distress of the CRC pavements reported has been "extensive" transverse cracking. There has only been one punchout repair in the pavement since its opening. The punchout was repaired with a 3.1-m (10-ft) long full-depth patch.

Performance and Evaluation

The ride and general appearance of the CRC pavement remains in good condition in relation with the other pavements.

Nebraska

Projects

Only one CRC pavement has been constructed in Nebraska. The pavement was built in 1968. In 1986 the estimated AADT for the project was 31,400.

Design

The design of the project was a 203-mm (8-in) CRC slab over a 76-mm (3-in) base of cement treated sand on top of silty clay. The shoulder design was asphaltic concrete. There was no drainage provided.

Maintenance and Rehabilitation

No maintenance and rehabilitation of the pavement has been reported.

Performance and Evaluation

The overall performance of this section has been excellent. It has provided a good ride and is in excellent condition.

Nebraska uses a distress evaluation of twelve 30.5-m (100-ft) long segments to obtain a condition index. They measure surface ride by using a South Dakota Profilometer or Mays Ride Meter and skid data is obtained using K.J. Law equipment. This data is used at both the project and network level for evaluation.

New Jersey

Projects

New Jersey constructed two CRC pavements in 1947. These pavements were experimental sections. The two pavements were built with different CRC and base thicknesses.

Design

The two designs were a CRC thickness of 203 and 229 mm (8 and 10 in) over a subbase of a densely graded base 356 and 305 mm (14 and 12 in) thick, respectively.

Maintenance and Rehabilitation

The most common distresses have been cracking and spalling. The sections have been overlaid with asphaltic concrete.

Performance and Evaluation

The overall performance of the two pavements has been fair. The surface ride is evaluated by ARAN and the information is used at the network level. The functional condition is also evaluated with ARAN and used at the network level.

Ohio

Projects

Ohio has constructed 27 CRC pavements throughout the Sate. The total mileage is approximately 146 center-lane km (91 center-lane mi). The oldest section was opened in 1964 the youngest in 1988. The heaviest traffic is along 1-270 with AADT of 63,320 in 1986 the lightest traffic is along US-62 with 3,860 AADT in 1988. The CRC sections are spread out among 14 Interstates, US routes, and State roads. One CRC section was built experimentally. The purpose of the experiment was to study D-cracking within CRC pavements.

Design

The most common design used in Ohio is a CRC thickness of 203 mm (8 in) over a 76- to 152-mm (3- to 6-in) base coarse. The base material can be an asphalt treated base, cement treated base or a dense graded aggregate. The subgrade is most often an A-4 material or poorer. The shoulder design was most commonly asphaltic concrete. The thickness of the shoulder ranged from 76- to 279-mm (3- to 11-in). Drainage was provided in almost all the CRC sections by a 152-mm (6-in) pipe underdrain The pipe was either run longitudinally along the pavement or was placed deep within the pavement structure.

Maintenance and Rehabilitation

The most common problems with the CRC sections have been short transverse crack spacing, punchouts, pumping and occasionally D-cracking. Maintenance and rehabilitation methods range from full-depth patching to overlaying with AC or JRCP. Overlay design is based on the "Manual of Operation and Use of Dynaflect for Pavement Evaluation." This manual was produced especially for the Ohio Department of Transportation.

Performance and Evaluation

The overall performance of the CRC in Ohio has been reported to be fair. The CRC sections did not perform as well as JRCP pavements constructed during the same time period.

At the network level, four lane and Interstate pavements are ranked for rehabilitation based on a combined index which includes, PSI, skid and Pavement Condition Rating (PCR). At the project level, the pavement is rated by the designer, pavement cores are taken and deflection data is taken with a Dynaflect. The deflection data is used to determine the required overlay thickness.

Oklahoma

Projects

Thirty-six CRC pavements have been built in Oklahoma. All the sections have been built after 1970 and the youngest section was built in 1991. The pavements have been built on 12 different highways ranging from 6-lane Interstates to 2-lane US highways. The heaviest trafficked CRC section is not reported. Five sections are experimental. Three sections located on US-69, US-412 and US-75/SB are LTPP GPS-5 test sections. US-75/NB is a LTPP GPS-9 test section. The other experimental section has had the wide flange beam terminal joint design replaced with a three slab expansion joint design.

Design

The most common design for the CRC sections is a 229- to 254-mm (9- to 10-in) CRC slab over a 76- to 127-mm (3- to 5-in) base on top of a subbase. The base material varies.

Oklahoma uses a 76- to 127-mm (3- to 5-in) AC type A or B, econocrete, asphalt treated bases, open graded bituminous base, and a fly ash stabilized base. The subbase, when it is used, can be a fly ash or lime modified material, select fill, aggregate, or a stabilized aggregate. The steel percentages in the different pavements range from a low of 0.50 percent to a high of 0.61 percent.

Drainage is not provided in most of the pavements, when it is, the drains are longitudinal edge drains. The shoulder design is most often PCC with the thicknesses corresponding to the thickness of the CRC pavement. Some shoulders on the older pavements are 38 mm (1.5 in) of asphaltic concrete.

Maintenance and Rehabilitation

No maintenance and rehabilitation methods have been reported. Only one section of CRC has been rehabilitated.

Performance and Evaluation

The overall performance of the CRC pavements in Oklahoma has been good. Only 1 of the 10 CRC projects from 1969 to 1972 (180 lane km (113 lane mi)) has been rehabilitated. The remaining CRC pavements, constructed from 1984 to 1990, have only 1 of 26 projects showing early deterioration. However, some of the projects with 0.5 percent steel content exhibit much longer crack spacing.

Oregon

Projects

Oregon began construction of CRC pavements in the 1960's. They have constructed approximately 1 287 center-lane km (800 center-lane mi) of CRC pavements. The oldest section was built in 1963 and the most recent one in 1987. The heaviest traffic is 117,900 AADT on Interstate 2 and the lightest traffic is 4,400 AADT on Interstate 6.

Design

The most common design for CRC pavements is a 203-mm (8-in) slab over a 102-mm (4-in) cement treated base or a 178-mm (7-in) aggregate base. However, thicker CRC pavement pavements have also been built. The subbase is either an aggregate or lime treated. The subbase thicknesses range from 102 to 432 mm (4 to 17 in). The CRC slab thicknesses range from 178 to 330 mm (7 to 13 in). Some CRC sections have been designed as overlays for asphalt pavements, "white topping." The shoulder and drainage types used, if at all, were not reported. The older CRC sections were designed with 0.6 percent steel while the younger ones were designed with 0.7 percent steel. Some of the CRC pavements incorporate lane widening for the outside lane.

Maintenance and Rehabilitation

The most common distress affecting CRC pavements in Oregon are construction related distresses (i.e. construction joint failure, poor quality concrete and random longitudinal cracking) rutting and polished aggregate. The rutting and polishing is caused by studded tires. The most common rehabilitation has been full-depth patching.

Performance and Evaluation

The performances of the CRC sections have been very good. Many of the older pavements have carried more than their design traffic and have lasted longer than their design lives with very little maintenance, if any.

Pennsylvania

Projects

Some of the oldest CRC section in Pennsylvania were built in 1927 and 1929 and the youngest ones were built in 1989. CRC pavements have been built throughout the State on many different State highways and roads.

Design

The most common design is a 203- to 229-mm (8- to 9-in) CRC pavement constructed on top of a open graded soil or an aggregate soil. The subbase thickness ranges from 76 mm (3 in) for the oldest pavements to 330 mm (13 in) for the younger pavements. The CRC pavement thickness ranges from 102 mm (4 in) for a 1927 design to 305 mm (12 in) for a 1989 design. CRC pavement have also been used as overlays for JRCP and CRC pavements. Shoulders are either concrete or AC and edge drainage is used on the newer section as part of the design. As for the older sections, which have been overlaid, edge drains have been installed.

Maintenance and Rehabilitation

Some of the CRC sections have been overlaid with JRCP and AC. The other maintenance that has been used is full-depth patching.

Performance and Evaluation

Roughness is measured with the use of an ultrasound profilometer, which are a modified South Dakota profilometer. The ultrasound is mounted on a Mays Meter van. Data from both the ultrasound and Mays Meter is used. The performance for the CRC pavements has been reported to be mixed.

South Carolina

Projects

Fourteen CRC sections have been built in South Carolina. The oldest section was built in 1970, and the most recent one was built in 1983. The total length for these sections is approximately 515 km (320 mi). The sections were constructed on three Interstates, I-20, I-77, and I-95. The heaviest traffic is 38,900 AADT on I-95 and the lightest is 6,350 AADT on I-77 in 1990.

Design

The most common design for the CRC sections is a 203- to 229-mm (8- to 9-in) CRC pavement over a 127- to 152-mm (5- to 6-in) base on top of a 152- to 457-mm (6- to 18-in) subbase. The base material was either a 152-mm (6-in) econocrete or a 127-mm (5-in) cement-treated material. The subbase is either a 152-mm (6-in) cement-treated subgrade or 457 mm (18 in) of selected fill, A4 or better. The shoulder design is asphaltic concrete. There is no drainage provided in any of the sections.

Maintenance and Rehabilitation

The most common distress affecting the CRC sections is punchouts. The pavement has been rehabilitated with an overlay and a rubblization.

Performance and Evaluation

Of the 14 sections, 2 projects performed poorly, 3 projects performed fairly and 8 of the projects have performed well.

South Dakota

Projects

South Dakota has built 10 CRC sections. All these sections have been built on Route 1-90 and 1-90 East. The heaviest traffic was 3,438 AADT and the lightest was 1,745 AADT in 1989. The oldest section was built in 1968 the youngest in 1974. One 0.8-km (½-mi) long experimental section has been built in South Dakota and is a LTPP GPS site.

Design

The most common design is a 203-mm (8-in) thick CRC pavement over a 51- to 305-mm (2- to 12-in) base and often a subbase. The base material can be either a 76-mm (3-in) lime treated base material, a 51-mm (2-in) asphaltic concrete, or an aggregate base 102 to 305 mm (4 to 12 in) thick. The subbase material is either an aggregate or a cement-treated

subgrade. At the present time South Dakota does not build CRC pavements, but there are plans to start building them in the next couple of years.

Maintenance and Rehabilitation

The most predominant problem with the CRC sections in South Dakota has been alkali-silica reaction. No maintenance and rehabilitation techniques were reported.

Performance and Evaluation

The overall performance of the CRC sections has been good, The CRC has provided smoother, lower maintenance highways than have other concrete pavements. The inspections of the pavements have been mostly visual and informal. Longitudinal profile measurements have been made since 1983. Dynaflect deflection surveys and skid resistance tests have been taken since the mid-1970's. A Pavement Condition Index (PCI) survey was taken as recently as 1990 of all the concrete pavements throughout the State.

Texas

Projects

During the 1950's and 1960's the Texas Department of Transportation constructed thousands of kilometers (miles) of CRC pavements on the Interstate System. The design usually consisted of 203-mm (8-in) thick pavement with AC shoulders that typically consisted of a thin wearing surface over a granular base. The longitudinal steel percentage was either 0.5 or 0.6 percent. A majority of CRC pavement construction utilized deformed bars while others used welded wire fabric (WWF). However, the CRC pavements that contained WWF typically did not perform well which resulted in the discontinuation of use of WWF. Performance surveys of these pavements indicated that transverse cracks tended to open too wide, letting water and incompressible materials within the cracks which eventually contributed to punchout distress.

CRC pavements are the most extensively used concrete pavement in Texas. This high level of use has resulted primarily because of very good overall performance of CRC pavements in Texas. In addition, the asphalt concrete overlays of CRC pavements have been reported to provide relatively in good performance in Texas.

The longitudinal steel reinforcement used has been about 0.6 percent in past designs of CRC pavements. Currently, the longitudinal steel percent is increased with pavement thickness. It has been reported that under the old 0.6 percent longitudinal steel design, the pavements with siliceous river gravel aggregate developed closer and less desirable crack spacing than CRC pavements using limestone aggregate.

CRC pavement standards in Texas require additional steel at transverse construction joints. The CRC pavement standards also require that two layers of longitudinal steel and

transverse steel should be used for the pavements that are 330 mm (13 in) or greater in thickness. It was found that the longitudinal steel spacing should not be less than 152 mm (6 in), or difficulties with concrete vibration and consolidation could occur. The Texas standards also require the staggering of longitudinal steel splices (i.e., only one third of the splices can be at one location). The longitudinal and transverse steel for CRC pavement is typically supported by chairs.

CRC Pavement Performance In Texas

The performance of CRC pavement in Texas can be illustrated by a comparison of the performance of CRC pavement overlays and new construction for three projects: I-35-2(45)175, located in Guadalupe County; I-35-4(13)317, located in Falls and McLennan Counties; and I-35-5(44)401, located in Johnson County. These above mentioned projects were constructed by the Texas Department of Transportation several years ago but some benefit may be gained from initial comparisons since each project included overlay and new construction built side by side.

Guadalupe County

This project extends along IH-35 in a northeasterly direction for a distance of 5.18 km 3.22 mi). The original 229-mm - 152-mm - 229-mm (9-in - 6-in - 9-in) jointed-concrete pavement (JCP) was built over 152 mm (6 in) of selected base course material in 1934 to a width of 6.1 m (20 ft). This pavement structure also included a 38-mm (1.5-in) overlay of asphalt concrete (AC). In 1954, the surface profile was restored with another layer of AC. In 1965, a 152-mm (6-in) overlay of CRC pavement was constructed in the southbound lanes. A new CRC pavement was constructed between the sections of the overlaid pavement. The pavement width was increased to 7.3 m (24 ft).

It was concluded from a statistical comparison of present serviceability rating (PSR) values that there was no measurable difference between the performance of the CRC pavement overlay and new CRC pavement. Statistical comparison showed a significant difference in crack spacings between the overlay and new CRC pavement sections. Thirteen percent of the cracks in the overlay sections and 35 percent of the cracks in the new CRC pavement sections have spacings between 1.5 and 2.4 m (5 and 8 ft) which is desirable in CRC pavements. Thus, the new CRC pavement sections were performing better with respect to crack spacings.

From the statistical comparison of severe transverse cracks, minor localized cracks, and minor spalling, it was concluded that no significant difference existed between the performance of the overlay and new CRC pavements. Since the average PSR values for both the CRC pavement overlay and the new CRC pavement sections are in the range of 3.8 to 3.9, it can be concluded that both pavements were performing well and were relatively similar in performance.

Falls and McLennan Counties

The Falls-McLennan County project extended along IH 35 in a northerly direction, covering a distance of 4.0 km (4.38 mi). The original 229-mm - 152-mm - 229-mm (9-in - 6-in - 9-in) JCP was built over a 203-mm (8-in) gravel base course in 1934; to a width of 6.1 m (20 ft). In 1952, the original JCP was overlaid with 90 mm (3.5 in) of AC and the width of the pavement was increased to 7.3 m (24 ft). In 1959 the northbound lanes were overlaid with 178 mm (7 in) of CRC pavement, with a portion of the project constructed as new CRC pavement.

From a statistical comparison of PSR values, it is concluded, that there were no significant differences between the performances of the CRC pavement overlay and the new CRC pavements. The mean crack spacing for the overlay section was 1.7 m (5.42 ft) and for the new CRC pavement sections the mean crack spacing was 2.4 m (7.93 ft). The desirable crack spacing for CRC pavement is in the range of 1.5 m to 2.4 m (5 to 8 ft). Thirty percent of the cracks in the overlay sections and 25 percent of the cracks in the new sections have spacings between 1.5 m and 2.4 m (5 and 8 ft).

Johnson County

This project extended along IH-35 in a southerly direction at a distance of 14.4 km (8.93 mi). The original 229-mm - 152-mm - 229-mm (9-in - 6-in - 9-in) JCP was built over select base course material in 1937 to a width of 6.1 m (20 ft). In 1947, the southbound lanes were overlaid with 51-mm (2-in) of AC and, in 1957, with 38 mm (1.5 in) of AC. In 1965, a new 203-mm (8-in) CRC pavement was constructed over a 152-mm (6-in) lime-treated subgrade. While other portions of the project were overlaid with 152 mm (6 in) of CRC pavement. The north bound lanes were constructed of a new 203-mm (8-in) CRC pavement over a 152-mm (6-in) lime-treated subgrade throughout the entire project length. The width was also increased to 7.3 m (24 ft) in 1965.

The mean PSR values for the new CRC pavement sections and the CRC overlay sections obtained by the condition survey were 3.77 and 3.89, respectively. The statistical analysis of these results showed that the overlay sections and the new construction sections were performing relatively the same. In summary, each the pavements noted above performed well at the time of the pavement survey.

Harris County (Houston)

An experimental 305-m (1,000-ft) of thin-bonded concrete overlay (TBCO) was placed on Interstate 610 (Loop 610), which encircles downtown Houston and was built 14 years ago. The original pavement was a continuously reinforced concrete pavement with a thickness of 203 mm (8 in) and with 0.5 percent longitudinal steel. The CRC pavement was placed on top of a 152-mm (6-in) thick cement-treated subbase. The subgrade is a silty clay. Although, certain areas of the original pavement required heavy maintenance, the original CRC pavement performed very well before the construction of the overlay. At this site, spalled transverse

cracks, longitudinal cracks, and patches were detected. While these were not seen as an immediate threat to the load carrying capacity to the pavement structure, they required increasing amount of maintenance with increasing traffic control requirements.

Typically, overlays for CRC pavements in Texas vary in thickness from 25 to 152 mm (1 to 6 in) and are either asphalt or concrete. For this pavement a thin bonded concrete overlay was used for the following reasons:

1. Restoring ride quality.
2. Improving skid resistance of original pavement.
3. Curtailing maintenance requirement.
4. To correct minor grade problems.

In this design, several factors were considered that were thought to have an impact on performance. At the same time efforts were made to reduce problem areas such as temperature strain differentials due to coarse aggregate type. The same type and source of coarse aggregate was specified for the project. Coarse aggregate type is known to have significant impact on concrete strength and also on concrete coefficient of thermal expansion, and thus on concrete movement and CRC pavement performance. Therefore, the probability of differential movement between original pavement and overlay was decreased along with potential debonding due to interface shear.

The main factors considered in the experimental design were material type and thickness. The following test sections were constructed:

1. 51-mm (2-in) thick plain concrete overlay.
2. 51-mm (2-in) thick steel-reinforced (welded wire fabric) concrete overlay.
3. 76-mm (3-in) thick steel-reinforced (welded wire fabric) concrete overlay.
4. 76-mm (3-in) thick steel fiber-reinforced concrete overlay.
5. 51-mm (2-in) thick steel fiber-reinforced concrete overlay.

It was decided before the overlaying of the pavement that the pavement placement temperature should not exceed 29.4 °C (85 °F), the concrete overlay should be cured above 4.4 °C (40 °F) for a period of 4 days, and minimum flexural strength of concrete at 7 days should be 4.8 MPa (700 lbf/in^2).

The pavement surface was scarified to a depth of 3.2 mm (0.125 in). An additional 25-mm (1-in) minimum depth of scarification was applied at each end of concrete overlay. After scarification, the concrete surface was sandblasted and then airblasted just before the grouting-paving operation. Cement grout consisted of 1 bag of portland cement and 26 liters (7 gallons) of water and contained a water-reducing plasticizer. The water cement ratio was approximately 0.62 by weight or 26 liters (7 gallons) of water per cement sack. The concrete was batched at a central plant and hauled in ready-mix trucks to the construction site. The concrete was dumped on to the grouted surface and spread manually. A transverse concrete finisher guided by rails was used to consolidate and finish the concrete to grade.

Following surface texturing, a white pigmented impervious curing compound was spread uniformly onto the overly surface from a second working bridge. Within 24 hours of placement, the pavement edge and centerline longitudinal joints were saw cut. The center line longitudinal joints were cut to a nominal 25 mm (1 in) depth and sealed with a hot-poured asphaltic sealant. Membrane curing was placed at the rate of 2.9 m^2/l (120 ft^2/gal).

Visual condition surveys were conducted before and after overlay construction. Cracks were mapped and spalls were counted and classified as minor or severe. A mechanical strain gauge was used to measure the crack width. It is concluded that the 76-mm (3-in) thick fiber reinforced overlay was best for longitudinal cracking. The spall survey was conducted 9 months after the construction of the overlay. No spalls were reported at that time. This survey also showed that a 60 percent reduction in cracking was achieved. It was concluded that a 76-mm (3-in) steel-reinforced design was most effective in reducing Dynaflect surface deflections and the fiber sections were most effective in reducing cracking. A portion of the overlaid pavement section (approximately 30.5 m (100 ft)) was removed and replaced due to excessive debonding.

La Porte Test Sections

Test sections on SH 225 in La Porte, Texas, paved on November 11, 1991 and opened to the traffic on December 12, 1991, consisted of new CRC pavement placed 330 mm (13 in) thick with two layers of steel reinforcement. The total length of the test pavement was 777 m (2,550 ft) and was sub-divided into nine test sub-sections (with a buffer section at each end). Each sub-section was 762 m (250 ft) long 3.7 m (12 ft) wide and each buffer section, was 45.7 m (150 ft) long. Paving started at the west end of the test pavement at 8:00 a.m. and ended at the east end of the test pavement at 8:30 p.m. The paving direction was identical with the traffic direction. Although the concrete mix design was the same for each sub-section pavement of the test, different orientations of the transverse steel reinforcing, different curing methods and different cracking control methods were applied. The purpose of the field investigation was to detect the factors that affect the cracking behavior of the CRC pavement. Many different variables were measured and cracks were surveyed at pavement ages ranging from 3 days to 125 days. A preliminary summary of data is given below:

Steel Reinforcement and Curing Methods

The concrete used for the pavement contained river gravel as the coarse aggregate. The pavement section had two layers of reinforced steel with #5 steel as the longitudinal rebars and #6 steel as the transverse rebars. The transverse rebar in the top layer was placed at the mid-depth location and the transverse rebar in the bottom layer was 64 mm (2.5 in) above the surface of the subgrade. In all the sub-sections except Sub-Section 2, the transverse bars were perpendicular to the longitudinal reinforcement with the interval between adjacent longitudinal bars at 203 mm (8 in) while adjacent transverse bars were placed at 0.9 m (3 ft) on center. Accordingly, the percentage of the longitudinal steel was 0.590. The transverse reinforcement was placed in an alternating pattern between the top and bottom layers of longitudinal steel.

Transverse steel bars were skewed in Sub-Section 2 to form an angle of 60° with the pavement edge. These bars were also placed 0.9 m (3 ft) on center.

Four different curing methods were employed. These curing methods are as follows:

1. Membrane curing compound is referred to as the standard curing method, noted as "Standard Cure."

2. Membrane curing compound using Procrete - a proprietary product, noted as "Procrete."

3. Cotton mat curing plus membrane curing, noted as "Cotton Mat."

4. Polyethylene film curing plus membrane curing, noted as "Polyethylene."

The buffer sections were cured with the standard curing methods.

Sawcut for Crack Control

The longitudinal joint in the test sections was cut by using early-age saw cutting techniques. This technique is different from conventional sawcut methods which uses external sources of water to cool the blade during cutting operations. This method does allow the concrete to be sawcut at an early age with minimal or no raveling which is typically much earlier than what is possible using conventional sawcut methods. The notch placed by the early-age method was approximately 25 mm (1 in) in depth.

The early-age technique was used to place transverse sawcuts at specified intervals in Sub-Sections 6 and 9. A series of transverse sawcut 53.3 m (175 ft) in length was placed in Sub-Section 6. Within the series, the spacing of the transverse sawcuts was 0.9 m (3 ft) for a length of 17.4 m (57 ft), and in the remaining portion, the spacing of the transverse sawcuts was 1.5 m (5 ft). The transverse sawcut operations started at 9:00 p.m. on November 11, or about 7 hours after placement of the concrete in Sub-Section 6. Four sawcut machines were used simultaneously in order to meet the pavement cutting schedule. Sawcutting operations for Sub-Section 6 ended at 9:00 a.m., November 12. No apparent raveling of the sawcut joints was noted. Twenty-five feet (7.6 m) of Sub-Section 9 was sawcut transversely.

Measurement of Pavement Temperature and Relative Humidity

Temperature and relative humidity are two important variables for concrete. Changes in either of these conditions can induce stresses in the pavement as well as affect the rate of the strength gain of the concrete. The influence of the parameters is very apparent during the early ages of the concrete. Both temperature and relative humidity in the test sub-sections were measured with two different digital systems. One was a product of Vaisala, in which the sensor is a capacitor. It monitors the change in capacitance of a thin polymer film as it absorbs

water vapor. The other, manufactured by General Eastern, measures the change in electric resistance of a bulk polymer sensor with the moisture the sensor absorbs.

For each sub-section, temperature and relative humidity measurements were taken at approximately 38 mm (1.5 in) below the pavement top surface. These measurements were made automatically by a portable data recording system. In this way, continuous recording were achieved. At some locations, three channels in the data logger (with one probe per channel) were used to record the temperature and relative humidity at three different depths in the pavement at 25, 51, and 102 mm (1, 2, and 4 in). For security reasons, the logger system had to be dismantled during off hours, which meant that data during these periods of time were not recorded.

It is speculated that the cotton mat protected the pavement surface from solar radiation and as a result the temperature in Sub-Section 3 was lower than in other sections. The polyethylene film covering the pavement (Sub-Section 5) caused a "green house" effect, which made the temperature in Sub-Section 5 higher than that in sub-sections where other curing methods were used. However, change in temperature of pavement was caused by complicated environmental conditions as well as properties of concrete mix. On the other hand, the relative humidity in Sub-Section 5 was the highest, since the polyethylene film isolated the pavement top surface from the atmosphere and kept the moisture in the pavement from evaporating. Between the two membrane curing methods, the standard method resulted in a lower temperature and higher relative humidity in the pavement than the proprietary product.

Crack Surveys

The development of the crack pattern in each of the pavement test sections were surveyed. Sub-Section 6, which was transversely sawcut after paving, was surveyed on November 14 (3 days after paving), November 15 (4 days after paving), November 19 (8 days after paving), November 22 (11 days after paving), and November 26 (15 days after paving) in 1991. It was surveyed again on March 16, 1992 (125 days after paving). Other sub-sections were surveyed at 3, 15, and 125 days after paving. All the sections were opened to the traffic on December 12, 1992.

All the surface cracks observed were either from the sawcuts or were at the locations of the transverse steel bars. All the surface cracks were initiated from weak points in the pavement, the pavement sawcuts or interfaces between rebars and mortar. In other words, no random surface cracks were observed in the sawcut part of Sub-Section 6.

From the change in the average crack spacing for all the sections except Sub-Section 6, it was observed that the number of the surface cracks increased rapidly within the first 3 days and the rate of the increase in number of surface cracks decreased with time. Many sections did not have new surface cracks between the 3rd day and the 125th day.

Among four different curing methods, the Cotton Mat and the polyethylene reduced daily temperature variation in the pavement and slowed down the concrete drying process. As

a result, increase in the number of surface cracks in Sub-Sections 3, 5 and 8 was suppressed in the first 3 days but more surface cracks were formed between the 3rd day and 15th day (Cotton Mat and Polyethylene were removed 7 days after paving). It appears that the formation of these surface cracks was delayed by the effect of these two curing methods.

Coring of SH-225 Test Section in La Porte

It was of interest to determine the effect of early aged sawcutting on the formation of horizontal planes of delamination that eventually lead to spalling distress, particularly in CRC pavement constructed with river gravel coarse aggregates. The main objectives of the coring operation were to see if there are any delaminations being developed in the pavement, and to see if the early sawcutting of the pavement (within a matter of a few hours) achieve the desired effects on the pavement. Coring was performed on September 24, 1992. The pavement was a little over 10 months old and had been in use for more than 9 months. Previous investigations of spalling in BW-8 in Houston had indicated that there were pronounced delaminations and spalling in pavements as early as 3 years after construction.

The coring study indeed indicated that at randomly occurring transverse cracks there were delaminations present in the slab. Even though these delaminations were not as pronounced as those in much older pavements, there was no doubt about their presence. This adds credence to earlier assertions that the process of delamination indeed starts at a very early age. In all cores, transverse cracks were clearly visible down to level of the bottom rebar layer (102 mm (4 in) from the bottom).

Important Observations

1. There were delaminations present near random transverse cracks.

2. In the cores taken, there were no indications of delaminations in the saw cut section.

3. The delaminations at random transverse cracks have occurred during the first 10 months of the life of the pavement.

4. Slight spalling was observed mostly along wheel paths.

5. In the saw cut section (Sub-Section 6), a longitudinal crack runs through at a distance varying from 0 to 0.9 m (0 to 3 ft) from the longitudinal saw cut. This may be an indication that the crack had already initiated when saw cutting was done.

6. Similarly, where cracks were not observed starting from saw cuts, there were transverse cracks away from saw cuts nearby. This again may be an indication of a delay in saw cutting.

Findings and Conclusions

1. A 777-m (2,550-ft) long CRC pavement test section was placed in La Porte, Texas for experimental studies in crack control. Different curing methods and crack-control methods were applied to different sections of the pavement to compare their influences on performance of the pavement. Temperature and relative humidity in these sections were monitored. Differences made by these different methods were obvious, which made it clear that such field tests are useful in helping understand effects of these curing methods and crack-control methods.

2. In comparison with the membrane curing method (using white pigments or Procrete), cotton mat and polyethylene film reduced daily temperature variation and slowed down the drying process in pavement concrete. Accordingly, the number of surface cracks, cracks that went transversely through the top surface of the pavement, in test sections cured with cotton mat or polyethylene film was lower than in test sections cured with membrane in the first 3 days after paving. After the mat or the film was removed, the number of surface cracks increased in the sections that were initially covered by the mat or film.

3. The crack density (number of surface cracks per unit length of pavement) was affected by the restraints inherent within by the pavement system (longitudinal steel rebars, subbase friction, etc.). Its distribution with respect to the distance from the pavement end (over a 1-day placement) may be expressed in terms of a half-sine function. Regression was made for the crack-density distribution on the 15th day and on the 125th day. On the 125th day, or 4 months after paving, crack density in sections cured by polyethylene film was lower than the regression curve based on the data from membrane-cured sections, while crack density in the section cured by cotton mat was very close to the regression curve.

4. A 53.3-m (175-ft) long test section cured by the standard membrane curing method was transversely cut with the early-age sawcut technique at an interval of 0.9 and 1.5 m (3 and 5 ft). Different from the conventional sawcut method, no water-cooling was used and the depth of the cut was about 25 mm (1 in) which is much less than D/4 or D/3, as used for conventional sawcutting of joints in jointed concrete pavement. The average crack spacing in the sawcut part was ultimately larger than that in the non-sawcut sections.

   The sawcut reduced the number of cracks and also controlled the location of the crack. In the sawcut portion, most of cracks were initiated from the sawcut and the rest of cracks were initiated from the transverse steel positions.

5. No significant raveling occurred although the sawcutting operation started relatively early, which indicates an improved sawcut efficiency with this type of

an approach. Data analysis shows that early-aged sawcutting can occur without raveling when the pulse velocity reaches 1524 m/sec (5,000 ft/sec) and verifies the same conclusions drawn in the previous field tests.

6. A large percentage of the transverse steel rebars initiated cracks, part of which developed as surface cracks. This means that these surface cracks are not random cracks, but actually were initiated from the transverse steel. Good design practice may suggest that cracking at the rebar interface should be avoided to improve the utility of the reinforcement. It is apparent, however, that the transverse steel can be used to control cracking which occurs randomly between rebars.

7. Some cracks may have been initiated on the lateral edge surface of the pavement from the rebar interface. It may be because temperature varies more and drying proceeds faster along the edge surface than elsewhere in the pavement. Even in the cotton mat and polyethylene film curing methods, the edge surface was not covered by the mat or film, but exposed to the air. More moisture can evaporate from the surface so that, at the same depth, moisture content could be lower near the edge than at greater distances from the edge.

8. The digital system, General Eastern, for temperature and relative humidity measurement in pavement provided significant data to show the effects of different curing methods. This system may serve well for quality control purposes. To detect the two-dimensional effect described previously, distributions of temperature and relative humidity along the edge surface and in the depth from the edge surface should be considered in future tests.

9. Since skewed transverse steel rebars constituted weak bonding not perpendicular to the direction of the maximum tensile stress, the number of surface cracks in the skewed rebar reinforced pavement section was lower than the half-sine regression curve on the 125th day after paving. It appears that the skewed steel minimized the incidence of transverse cracking occurring at the transverse steel location.

Virginia

Projects

Virginia has built 60 CRC pavements since the mid-1960's. CRC pavements have been built on 11 different highways throughout the State. The heaviest traffic is 37,445 AADT while the lightest is 3,900 AADT in 1988. The total mileage of all these sections is roughly 306 km (190 mi). The oldest pavement was built in 1968 the youngest in 1991.

Design

The most common design is a 203-mm (8-in) CRC pavement over a 127- to 178-mm (5- to 7-in) cement treated base. Aggregate has also been used as a base material. The subbase is often a cement treated/modified subgrade material. The subgrade material is a fine soil. All of the CRC pavements contain 0.6 percent longitudinal steel.

Maintenance and Rehabilitation

The predominant distresses in Virginia's CRC pavements were construction joint failures but are now punchouts and alkali-silica reaction.

Performance and Evaluation

The overall performance of the CRC projects has been good. The performance has been generally acceptable and would be considered excellent if the alkali-silica reaction had not surfaced in recent years. Some pavements are approaching 25 years of service and are still performing well.

Structural condition of the pavements are occasionally evaluated with a falling weight deflectometer (FWD). The FWD information is backcalculated to find the concrete moduli values. This information is used at the project level. Functionally, the procedures developed in the COPES project are used. The Mays Meter, the K.J. Law 8300 Roughness Surveyor, and the South Dakota Road Profiler are used for roughness evaluations. Both the functional and ride information is used at the network level.

Wisconsin

Projects

Over 2252 lane km (1,400 lane mi) of CRC pavement have been built in Wisconsin by the beginning of 1988. The oldest pavement was built in 1961 and the youngest in 1976.

Design

From 1961 to 1968, the standard design thickness was a 203-mm (8-in) thick CRC pavement. By 1984, the thickness was changed to 254 mm (10 in) due to the increase in traffic volumes and increased maximum weight limits. As of 1987, thicknesses up to 305 mm (12 in) have been constructed on individual projects. The base course for the CRC section is most often a granular or an asphalt treated base. The percent steel ranges from a low of 0.61 to a high of 0.81 percent.

For the earliest CRC pavements in Wisconsin, from 1961 to 1964, longitudinal reinforcement was placed on chairs and transverse steel was utilized. Then from 1969 to 1981, transverse reinforcement and chairs were eliminated. The longitudinal reinforcement was tube

fed into place. By 1984 it was found that tube feeding resulted in poor control of the depth of reinforcement and contributed to premature pavement failure. The use of chairs and transverse reinforcement was reinstated to maintain more positive control of depth of the longitudinal reinforcement.

Maintenance and Rehabilitation

The most common distress affecting the CRC sections in Wisconsin has been corrosion of the reinforcing steel. The corrosion of steel often leads to other distresses such as punchouts, spalling, wide transverse cracks, and delamination. Wisconsin has tried tree types of rehabilitation techniques. These three techniques are thin bonded PCC overlays, structural hot mix asphalt overlay and PCC patching. The patching has been both full-depth and partial depth patching of CRC distresses.

Performance and Evaluation

CRC pavements in Wisconsin are evaluated annual and biannually. An annual condition index has been performed on all CRC pavements since 1975. The type of data that is obtained from these surveys include crack spacing of selected test sections and pavement distresses and patching of the overall projects. A PDI, pavement distress survey, is done annually on all the CRC sections. The PDI is used for programming purposes at the network level.

INTERNATIONAL PRACTICE

Introduction

Many countries other than the United States have constructed and are currently constructing CRC pavements. Some countries may be as close as Canada others are on the other side of the world such as Australia and Japan. Much of the CRC pavement construction, internationally, has been constructed in Europe in countries such as France, Belgium, Netherlands and the United Kingdom. This section describes the types of design, construction process and performance of the CRC pavements in other countries.

Canadian Experience

A limited amount of CRC pavement has been constructed in Canada. In 1958, CRC pavement test sections of various designs involving different thicknesses and variable reinforcing were constructed on the Trans-Canada Highway near Calgary, Alberta. The CRC pavement sections were 7.3 m (24 ft) wide and about 2.9 km (1.8 mi) long. Two sections of the CRC pavement were 178 mm (7 in) thick with 0.71 and 0.78 percent longitudinal steel and two other sections were 152 mm (6 in) thick with 0.72 and 0.82 percent longitudinal steel. A graded 102 mm (4 in) crushed-gravel subbase separated the slabs from a compacted subgrade consisting of inorganic clays and silty clays of low to medium frost susceptibility. Pavements in this area of Canada are typically subjected to a large range of climatic conditions with

highest recorded July temperature of 36 °C (97 °F) and lowest January temperature of -43 °C (-46 °F).

Pavement construction occurred during the fall with temperatures ranging from a high of 21 °C (70 °F) to a low of -1 °C (30 °F). After the first 3 years, 10 to 22 cracks had developed per 30.5 m (100 ft). The resulting crack spacing ranged from 1.3 to 3.1 m (4.3 to 10 ft).

In 1968 two blowups occurred in the CRC pavement test sections. Both of the blowups in the CRC pavement were in the 152-mm (6-in) thick section with 0.72 percent longitudinal steel. The first occurred at a construction joint location where yielding of the steel had been observed during the first winter, and the second occurred at a location where the cracking frequency was extremely high, on the order of 0.9 m (3 ft) spacings. There appeared to be no single specific reason for the occurrence of these blowups after 10 years of construction.

French Experience

Projects

Concrete pavements have been built in France since 1939, but it was not until the 1960's that CRC pavement began to be used widely. The first CRC pavement in France was a reconstruction project on the A6 southeast of Paris. France has over 550 lane km (342 lane mi) and more than 20 projects. Over 100 lane km (62 lane mi) of CRC pavements have been used as overlays of concrete truck-lanes and asphalt highways. CRC pavements have become very popular in certain areas of France.

Design

The thickness for CRC pavements varies according to the current truck traffic and subgrade soil modulus. The types of bases used are either a 152-mm (6-in) lean concrete base or a 51-mm (2-in) asphalt concrete layer used directly beneath the CRC pavement. A subbase is often used consisting of a thick layer of select granular material or cement- stabilized soil. Some CRC pavements are constructed with a trapezoidal cross-sections having varying thicknesses across two lanes with the thicker section being the truck lane. Some design examples observed by the U.S. Tour were:

- Freeway Trapezoidal design - 191 to 254 mm (7.5 to 10 in).
- Lane Widening - 318 mm (12.5 in).
- CRC overlay of JPCP - 178 mm (7 in).
- CRC overlay of AC - 165 mm (6.5 in) (minimum).

Two shoulder designs are used in France. The first is a tied concrete shoulder which sometimes may be lean concrete. The second is an AC shoulder with a pervious aggregate base, porous concrete base or a tied lean concrete placed on a non-woven geotextile drainage

layer of 5 mm (0.2 in) thick. Longitudinal drainage is provided along the edge of the concrete slab.

The CRC pavement reinforcement consists of deformed longitudinal bars at a typical steel percentage of 0.67. The steel is placed at a depth of 76 mm (3 in), approximately one third the slab thickness. Transverse bars with diameters from 10 to 13 mm (0.4 to 0.5 in) are placed every 1 m (3.3 ft) to tie the lanes together. A steel reinforcement of 0.72 percent was used along a section of the A6 Freeway constructed during 1982. This section is providing excellent performance (as of 1992).

The French use several end treatments for CRC pavements at bridges. Their end treatment designs are to provide expansion joints, roughen the surface of the subbase to promote high bonding, or if the bridge has been designed for the extra dead load, placement of the CRC pavement over the bridge deck.

Development of FLEXARM

In the mid-1980's, the French began working on solutions to some of the problems they were encountering with CRC pavement construction projects. The result of one of these efforts was the development of FLEXARM steel reinforcing in 1985. With this technique, a reinforcing steel was available which shortened the effective work zone, eliminated the need for frequent lap joints, and allowed a reduction in work site labor.

FLEXARM was made as a pavement reinforcing steel, produced in a flat ribbon, 2 mm (0.08 in) thick by 40 mm (1.57 in) wide, and is sometimes referred to as "slotted steel strips." The yield stress for this steel is over 690,000 kPa (100,000 lbf/in^2). The top and bottom surfaces of the steel strips are deformed in a regular pattern of alternating bumps and dimples with both surfaces being heat galvanized. The sides of the each strip are not galvanized because of galvanization takes place while the steel is still in large rolls.

FLEXARM is manufactured in 44-mm (1.73-in) wide strips, 2.2 mm (0.085 in) thick with a yield stress of 793,000 kPa (115,000 lbf/in^2). It is supplied in long rolls or spools, ranging in length from 20 to 402 m (80 to 1,320 ft). Because of its high strength, the steel can be stored in coils.

Design of CRC Pavement with FLEXARM

The design procedures for pavements with FLEXARM are empirical, based on the limited construction of experimental pavements and observation of the subsequent performance of the inservice pavements. Test sections were constructed in France with 0.2, 0.3, and 0.4 percent FLEXARM steel, and through observations indicated that a value between 0.3 and 0.4 percent steel produced the generally recommended crack spacing and width.

Performance

The FLEXARM percent of 0.3 has not worked as well as those with 0.37 percent so the current design in France is to use 0.37 percent FLEXARM. In general, the CRC pavements of France, have performed very well whether the design is with FLEXARM, trapezoidal, or deformed reinforcement. This applies to CRC pavements being constructed as new construction, widening projects, or overlays. France has had generally good experience with CRC pavements.

Belgium Experience

Belgium has constructed concrete pavements since 1923. The first experimental section of CRC pavement was constructed in 1950 which was followed by other experimental roads until in 1970 a large program of construction was initiated. Four hundred of 1,023 mi (650 of 1,650 km) of freeway have been constructed of concrete pavement most of which are CRC pavements. The Belgian government favors CRC pavements due to its low maintenance requirements and is now an accepted form of construction for heavily trafficked roads in Belgium. The concrete used throughout Belgium is very similar in all parts of the country and therefore standard designs are used for CRC pavements.

Design

Belgium has used two different CRC pavement designs since 1970. The older design was used between 1970 and 1979 and the newer design has been used since 1979. In the older design, the percentage of reinforcement was 0.85 percent, the steel was placed at a depth of ⅓ of the slab thickness, and a 64-mm (2.5-in) bituminous interlayer was used between the CRC pavement and the lean concrete layer. This design resulted in short crack spacing. Because of the short crack spacing, the designs after 1979 used 0.67 percent steel. Also, the steel was placed at mid-depth and the CRC pavement was placed directly over the lean concrete base. It should be noted that sections with 0.85 percent steel (close crack spacing) have continued to perform well under very heavy axle loadings indicating that closely spaced cracks are not detrimental if a good support is provided under the concrete pavement.

The type of concrete used in Belgium differs widely from that used in the United States. High strength and density are characteristic of Belgian pavement concrete. The quality of concrete is high and great care is taken to ensure full compaction. There is a stringent requirement for minimum density which if not attained involves removal of the concrete. The transverse steel may be placed at either right angles to the longitudinal steel or at an angle to limit the frequency of transverse cracks occurring at the position of the transverse steel.

Performance

The performance of the CRC pavements can be divided between the old and current designs which have been used.

Old Design (0.85 percent Steel) - over 100 km (62 mi) of the original CRC pavement design were built. It has performed exceptionally well with no punchouts occurring over the past 20 years. However in 1978, the pavement exhibited very tight and closely spaced cracks commonly less than 0.6 m (2 ft) and the design was changed to the current design because of the concern the pavement would develop punchouts. This design has, however, performed very well.

Current Design - the performance of the current design sections have generally been good. However, some sections have had larger crack spacings, wider cracks, erosion of lean concrete base and some punchouts.

A corrosion study was conducted on both pavement designs in which cores where taken on top of the most severe cracks found and were examined. Only minimal corrosion was observed particularly for the old design sections. The loss in cross section area of reinforcing bars does not exceed 5 percent for either deign.

"The performance of concrete pavements in Belgium has been described as exceptionally good especially the original CRC pavement."

British Experience

Experience in the United Kingdom with CRC pavements is not considered to be extensive. However, some concrete road base construction in the 1930's contained continuous reinforcement. Also CRC pavement has been used in some airfield construction, however, the percent of steel reinforcement was 0.3 percent or less. The use of CRC pavement in the United Kingdom is somewhat limited because of pavement type selection emphasis is on first cost considerations. CRC pavement construction has only been possible where no alternative designs are available.

Spanish Experience

CRC pavements have been constructed in Northern Spain since 1975. Several test sections have carried very heavy traffic, ADTT exceeding 5,000. The typical design is a 14-mm (8.5-in) thick pavement constructed on top of a 160 mm (6.3 in) base and a 220 mm (8.7 in) granular subbase. The amount of steel is 0.85 percent and is placed on chairs. One test section had a 0.73 percent steel with no change in the crack pattern. The performance of the CRC pavement has been excellent and has required very little maintenance work. The design of the new CRC pavements allow a section thickness reduction of 40 mm (1.6 in) from JRCP design, which is 254 to 305 mm (10 to 12 in) for heavy trafficked roads and 229 to 279 mm (9 to 11 in) for lightly trafficked roads.

Japanese Experience

The information on CRC pavement used in Japan is limited as CRC pavements have been used on a very limited basis.

References

The information summarized above has been developed based on a review of publications presented in Part II - Annotated Bibliography and based on information provided by State highway agencies.

PART II - FACTORS AFFECTING CRACKING AND PERFORMANCE OF CRC PAVEMENTS

ANNOTATED BIBLIOGRAPHY

Each entry listed is summarized and rated according to the usefulness of the document to meet the objectives of this research (which is "to update guidance related to the design, construction, maintenance, and rehabilitation of CRC pavement"). Therefore, the rating should not be construed as an evaluation of the quality of the research but only as an evaluation within the context of this study.

ANNOTATED BIBLIOGRAPHY FOR 1932

1. **TITLE:** Stresses in Reinforced Concrete Due to Volume Changes

   AUTHORS/AGENCY/COUNTRY: Vetter, C.P./American Society of Civil Engineers/United States

   SOURCE: American Society of Civil Engineers

   NUMBER OF PAGES: pp 1039-1089

   APPLICABLE CATEGORY: Design

   SUMMARY: This paper presented a rational analysis of the stresses occurring in a continuous reinforced concrete structure which are due to variations in moisture content and in temperature. Formulas and diagrams are given whereby the required reinforcement may be determined for any combination of the various factors which produce volume changes. Although cracks in structures of this kind cannot be entirely avoided if is possible, through suitable reinforcement, to make the individual cracks exceedingly small. It is shown however, that the ratio of steel to concrete required for this purpose is relatively high and, in many cases, it will be considered prohibitive.

ANNOTATED BIBLIOGRAPHY FOR 1947

1. **TITLE:** Continuously Reinforced Concrete Pavements Without Joints

   AUTHORS/AGENCY/COUNTRY: Wooley, W.R./Public Roads Administration/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Proceedings 1947 Vol. 27/1947

   NUMBER OF PAGES: pp 28-33

   APPLICABLE CATEGORY: Design

SUMMARY: It is suggested that continuously reinforced concrete pavements having heavier than normal reinforcement and no joints would be subject to few, if any, of the weaknesses now inherent in jointed concrete pavement: pumping, high joints, faulted joints, faulty load transfer devices, corner breaks, and blowups. Available information indicates that longitudinal steel in the amount of 0.5 percent of the cross-sectional area of the pavement may be sufficient to prevent open transverse cracks. Transverse steel extending across two lanes of pavement should allow elimination of the longitudinal joint and prevent longitudinal cracking.

2. **TITLE:** An Experimental Continuously Reinforced Concrete Pavement in Illinois

AUTHORS/AGENCY/COUNTRY: Russell, H.W.; Lindsay, J.D./Illinois Division of Highways/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Proceedings Vol. 27/1947

NUMBER OF PAGES: pp 42-52

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: Eight test sections, four each uniformly 178 and 203 mm (7 and 8 in) thick, were constructed. One section of each thickness was reinforced longitudinally with 0.3, 0.5, 0.7, and 1.0 percent steel, using round deformed rail-steel bars. Transverse reinforcement consisted of 9.5 mm (⅜ in) round deformed, intermediate grade, billet steel bars at 305 and 457 mm (12 and 18 in) centers. Horizontal and vertical movements and transverse crack widths were measured at various locations along the pavement. Unit strains in longitudinal reinforcing bars were also measured by SR-4 strain gauges, and concrete and subgrade temperatures, with thermocouples. The development of fine transverse cracks were noted and unit tensile stresses of almost 276 MPa (40,000 lbf/in^2) were measured in the longitudinal reinforcement in the 178-mm (7-in) section with 0.7 percent steel.

3. **TITLE:** Preliminary Report on Current Experiment with Continuous Reinforcement in New Jersey

AUTHORS/AGENCY/COUNTRY: Van, Breemen, V./New Jersey State Highway Department/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Proceedings Vol. 27/1947

NUMBER OF PAGES: pp 33-42

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: Two sections of continuously reinforced concrete pavements were constructed on a length of highway which carries a considerable volume of heavy truck traffic (in 1947). Reference lines were established to determine the magnitude of subsequent longitudinal movements of the ends and interior portions of the continuously reinforced pavement. Gauge points were installed to determine the width of cracks, changes in section length, changes in widths of all transverse joints, and the amount of opening of the longitudinal joints. Data pertaining to pavement behavior during construction and early pavement life is included. This report also refers to details of the original design (using two-layers of steel), materials employed and construction procedures.

ANNOTATED BIBLIOGRAPHY FOR 1950

1. **TITLE:** Report on Experiment with Continuous Reinforcement in Concrete Pavement - New Jersey

   AUTHORS/AGENCY/COUNTRY: Van, Breemen W./New Jersey State Highway Department/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Proceedings Vol. 30/1950

   NUMBER OF PAGES: pp 61-80

   APPLICABLE CATEGORY: Performance Evaluation

   SUMMARY: The observed behavior and performance of two sections of continuously reinforced concrete pavement constructed in New Jersey in 1947 were reported. The pavement sections, each approximately 1.61 km (1 mi) long, carried a relatively heavy amount of truck traffic at the time of this report. Most of the pavement was in good condition, but there was developing an excessive amount of spalling and ravelling at a number of the cracks in the outside lanes which was attributed to the concentration of heavy traffic on those lanes.

2. **TITLE:** Three-Year Performance Report on Experimental Continuously Reinforced Concrete Pavement in Illinois

   AUTHORS/AGENCY/COUNTRY: Russell, H.W.; Lindsay, J.D./Illinois Division of Highways/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Proceedings Vol. 30/1950

   NUMBER OF PAGES: pp 45-61

   APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The performance of the experimental continuously reinforced concrete pavement in Illinois during the period since its construction in 1947-48 was presented. The performance of all the test sections was satisfactory at the time of this report. The average interval between transverse cracks was becoming progressively shorter with age and had an inverse relationship to the amount of longitudinal steel. The average crack interval ranged from 1.8 to 4.9 m (6 to 16 ft). Generally speaking the average crack width was greater when lowering the percentage of longitudinal steel. Average crack width ranged from 0.18 to 0.53 mm (0.007 to 0.021 in). All the test sections became progressively longer with age. The permanent growth ranged from about 51 to 91 mm (2 to 3.6 in). Some spalling has occurred at both longitudinal and transverse cracks but not to a serious extent. Spalling appeared to be a function of the crack width, with more spalling at the wider cracks.

ANNOTATED BIBLIOGRAPHY FOR 1954

1. **TITLE:** Frictional Resistance Under Concrete Pavements and Restraint Stresses in Long Reinforced Slabs

AUTHORS/AGENCY/COUNTRY: Friberg, B.F./Consulting Engineer/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Proceedings Vol. 33/1954

NUMBER OF PAGES: pp 167-184

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Temperature contraction of short pavement slabs was not greatly diminished by frictional-tension stress. But long pavement slabs, as used in continuously reinforced concrete pavements, actively contract and expand only for some hundreds of feet near each end. The friction coefficient before sliding on the subgrade is not constant; in tests, large movements of long slabs have been observed without sliding at frictional resistance proportionate to the root of the movement. The overall modulus of elasticity of the reinforced pavement is much decreased below that for concrete alone due to closely spaced open cracks. Observed behavior of continuously reinforced pavements agrees well with that computed for frictional resistance increasing at a relatively low rate with movement. Fully restrained central parts of continuously reinforced cracked pavements are subject to temperature restraint stresses in accordance with stress formula which take into consideration the mechanics of concrete-steel bond. Cyclic crack widening was only partially prevented by the steel, but for typical close crack spacing, the opening at each crack is small. Restraint stresses increase at a much lower rate than temperature drop. The average frictional resistance indicated under continuously reinforced pavements was much lower than the value commonly proposed for design of distributed reinforcement in conventional-length slabs.

ANNOTATED BIBLIOGRAPHY FOR 1958

1. **TITLE:** Design of Continuously Reinforced Concrete Pavement

   AUTHORS/AGENCY/COUNTRY: Wooley, W.R./Trusan Steel Division/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Board Bulletin No. 181/1958

   NUMBER OF PAGES: pp 1-4

   APPLICABLE CATEGORY: Design

   SUMMARY: Experience gained from existing continuously reinforced concrete pavements is now adequate to suggest certain design principles. Transverse cracks at frequent intervals are caused by drying shrinkage, warping, wheel loads, and falling temperature. It is believed that the stress in the steel would be independent of the temperature drop if the tensile strength of the concrete remained constant. There is evidence that the strength of the concrete increases considerably as the temperature falls and this increased concrete strength causes an increase in steel stress.

2. **TITLE:** Preliminary Report on Continuously Reinforced Concrete Pavement Research in Pennsylvania

   AUTHORS/AGENCY/COUNTRY: Schiffmann, R.L.; Taylor, I.J.; Eney, W.J./Fritz Engineering Laboratory, Lehigh University/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Board Bulletin No. 181/1958

   NUMBER OF PAGES: pp 5-20

   APPLICABLE CATEGORY: Construction, Performance Evaluation

   SUMMARY: In the fall of 1956, the Pennsylvania Department of Highways constructed the first of two experimental continuously reinforced concrete pavements. The first of these projects is on Route 111, near York. In this project, measurements are being made of the strain in the bar-mat reinforcing steel in a uniform 229 mm (9 in) pavements. Studies are also being conducted on the crack frequency, the crack width, and the slab temperature. The second project will be on US 22, near Hamburg. The pavement thickness will be varied to include sections of 178 and 229 mm (7 and 9 in) thickness. The reinforcing will be bar-mat, with the exception of 305 m (1,000 ft) of welded wire fabric. In addition to strain measurements, studies of temperature distribution, pavement warping, longitudinal movement, crack width, and crack frequency will be made.

ANNOTATED BIBLIOGRAPHY FOR 1959

1. **TITLE:** Discussion of Observations on the Behavior of Continuously Reinforced Concrete Pavements in Pennsylvania

   AUTHORS/AGENCY/COUNTRY: Friberg, E.A./Consulting Engineering/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Board Bulletin 238/1959

   NUMBER OF PAGES: pp 33-36

   APPLICABLE CATEGORY: Design, Performance Evaluation

   SUMMARY: This report summarizes the results of a 3-year sponsored research project 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. The pavement was built during early October and cold weather with seasonal temperatures decreasing further between 1 and 4 months. Crack widening during the first seasonal temperature drop was only slightly less than what would be the unrestrained crack widening for 7 cracks per 30.5 m (100 ft). Most, if not all, of the 7 cracks per 30.5 (100 ft) observed at 6 months probably did occur during the early part of the first winter. The paper contains no data on the instrumented test panels in the 178, 203, and 229 mm (7, 8, and 9 in) bar reinforced and the 229 mm (9 in) mesh reinforced pavements of the project on US 22 near Hamburg, PA, which were part of the research. Progressive destruction of bond near cracks appears to be a factor of equal or greater concern than yield strength in determining restrain stresses which can be induced by the steel. Design recommendations in the paper disregard the important influence of bond upon the steel stresses which alone are stated to induce close crack spacing and assure narrow cracks.

2. **TITLE:** Analysis of Special Problems in Continuously Reinforced Concrete Pavements

   AUTHORS/AGENCY/COUNTRY: Zuk, W./Virginia Council of Highway Investigation and Research/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Board Bulletin No. 214/1959

   NUMBER OF PAGES: pp 1-21

   APPLICABLE CATEGORY: Design, Performance Evaluation

   SUMMARY: In order to fill gaps in the fundamental understanding of the behavior of continuously reinforced concrete pavements, a number of studies on various topics

were presented in this report. Most are presented from a theoretical analytical viewpoint. Some, which are not readily adaptable to analysis were presented from an experimental viewpoint. Some of the topics studied were pavement thickness, differences in behavior of deformed bars and plain wire mesh, buckling tendencies, horizontal and vertical alignment changes, end anchorage, crack behavior under repeated loading, and reduced slab rigidity due to cracks.

3. **TITLE:** Continuously Reinforced Concrete Pavement in California After Eight Years Service

AUTHORS/AGENCY/COUNTRY: Tremper, B./California Division of Highways/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 214/1959

NUMBER OF PAGES: pp 76-79

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: An experimental continuously reinforced concrete pavement 1.6 km (1 mi) in length was constructed in California in 1949. After 8 years of heavy traffic, it remains in good condition. Adjacent sections of non-reinforced jointed pavement constructed at the same time are also in relatively good condition, with the exception of a moderate amount of faulting at a few joints.

4. **TITLE:** First Year Performance Report on Continuously Reinforced Concrete Pavements in Pennsylvania

AUTHORS/AGENCY/COUNTRY: Taylor, I.J.; Eney, W.J./Fritz Engineering Laboratory, Lehigh University/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 214/1959

NUMBER OF PAGES: pp 98-113

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Extensive mechanical and electrical instrumentation has been utilized to measure and evaluate the performance of two continuously reinforced concrete highways in eastern Pennsylvania. The first of these pavements was constructed on US 111 near York in the fall of 1956. This highway remained closed to traffic throughout a complete year of temperature cycling in extreme weather conditions, allowing observation of its performance without the influence of heavy wheel loads. The second pavement, on US 22 near Hamburg, was constructed in the spring of 1957. The pavement thickness and type of reinforcement were varied, but the cross-sectional area

of steel was kept constant. This report describes the instrumentation used and presents the information obtained during a year of observations. An effort is made to evaluate this information and explain some of the changes that occur during the early life of a continuously reinforced concrete pavement.

5. **TITLE:** Ten Year Report on Experimental Continuously Reinforced Concrete Pavement in New Jersey

AUTHORS/AGENCY/COUNTRY: Van Breemen, W./New Jersey State Highway Department/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 214/1959

NUMBER OF PAGES: pp 41-75

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: The behavior and performance of two experimental sections of continuously reinforced concrete pavement constructed in New Jersey in 1947 were discussed. These sections, each approximately 1.61 km (1 mi) long, have been subjected to relatively heavy truck traffic. The northerly section is of 203 mm (8 in) uniform thickness, and contains 0.72 percent of longitudinal reinforcing steel. The southerly section is of 254 mm (10 in) uniform thickness, and contains 0.72 percent of longitudinal steel. The paper includes data relative to the recorded changes in length, crack pattern, crack width, behavior of the terminal joints, and the effect of these sections on the adjacent concrete pavement. It also described the defects which have developed, and compared the performance and cost of these sections with that of the standard design of reinforced concrete pavement constructed on the same routine.

6. **TITLE:** A Ten Year Report on the Illinois Continuously Reinforced Pavement

AUTHORS/AGENCY/COUNTRY: Lindsay, J.D./Illinois Division of Highways/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 214/1959

NUMBER OF PAGES: pp 22-40

APPLICABLE CATEGORY: Design

SUMMARY: In the fall of 1947 and the spring of 1948, the Illinois Division of Highways constructed on US 40 an experimental continuously reinforced pavement consisting of eight test sections ranging in length from 1067 to 1289 m (3,500 to 4,230 ft). Four sections were uniform 178-mm (7-in) pavement and four were 203-mm (8-in)

pavement. The pavement was constructed directly on natural subgrade, 90 percent of which was composed of soils classified as potentially pumping types. Longitudinal steel amounting to 0.3, 0.5, 0.7, and 1.0 percent of the gross cross-sectional area of the pavement was used with each pavement thickness. The longitudinal reinforcement consists of round deformed rail-steel bars. This report describes the behavior and performance of the pavement during the 10-year period. The behavior of the pavement, particularly of the more lightly reinforced sections, has been beyond expectations. All of the test sections have given good performance. The pavement is noticeably smooth riding, which is further indicated by a recent roughometer test that gave an average reading of less than 1138 mm/km (72 in/mi). There has been a progressive increase in the length of all test sections, resulting in full closure of the 102 mm (4 in) expansion joints. At several of these joints high localized compressive stresses, probably caused by irregular interfaces, have resulted in rather large surface spalls that have required some maintenance. These repairs, limited amounts of undersealing to reduce pumping at expansion joints and construction joints, and repairs of a few local structural failures account for the only slab maintenance performed during the 10-year period.

7. **TITLE:** Continuously Reinforced Concrete Pavement in Pennsylvania

AUTHORS/AGENCY/COUNTRY: Witkoski, F.C.; Shaffer, R.K./Pennsylvania Department of Highways/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 214/1959

NUMBER OF PAGES: pp 80-97

APPLICABLE CATEGORY: Design, Performance Evaluation, Current Research

SUMMARY: This paper refers to an experimental continuously reinforced concrete pavement was constructed in Pennsylvania to: (1) study the effect of pavement thickness on service performance, (2) study the effect of subbase thickness on service performance, (3) determine the maximum stresses in the reinforcing steel at a crack, considering varying thicknesses of pavement, (4) determine the effect of traffic upon stresses in the reinforcing steel, (5) determine the thermal effects on the steel and concrete stresses in the pavements, (6) determine the warping effects on the pavements, (7) determine the magnitude of longitudinal movements of the pavements, and (8) determine the ultimate slab length. Tabular and graphical results were presented on these tests.

ANNOTATED BIBLIOGRAPHY FOR 1960

1. **TITLE:** An Experimental Continuously Reinforced Concrete Pavement in Maryland

AUTHORS/AGENCY/COUNTRY: Lee, A.; Looney, C.T.; Lepper, H.A./United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Abstracts Vol. 30, No. 3/March 1960

NUMBER OF PAGES: pp 39-40

APPLICABLE CATEGORY: Design

SUMMARY: An experimental pavement on the Baltimore-Harrisburg expressway, Interstate Route 83, included varying the amount of steel used in reinforcement. A supplementary study involved determining the effects of covering methods as a possible means of minimizing transverse cracks that occur in a small area immediately following a construction joint.

2. **TITLE:** LTS Design of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Ledbetter, W.B./Highway Division/ United States

SOURCE: American Society of Civil Engineers

REPORT NUMBER/DATE: Proceedings Vol. 86, No. HW4/December 1960

NUMBER OF PAGES: 25 p

APPLICABLE CATEGORY: Design

SUMMARY: With the advent of the CRC pavement, without joints, the highway engineers has been forced to discard existing design theories and rely largely on experimentation and judgement to attempt to properly design the new type of pavement. This report presented a rational and uncomplicated approach to the approximate design of continuously reinforced concrete pavement, considering all of the factors and variables. The two major factors that were considered include, internal forces developed from restrained pavement volume changes and external forces developed from the traffic loads, were examined, and methods were given where by each can be evaluated in arriving at economically safe design. The load-temperature-shrinkage design approach is predicted on the assumption that the concrete should be designed to withstand the external forces developed from traffic loads, and the reinforcing steel should be designed to withstand the internal forces developed from restrained pavement volume changes. It is shown that a pavement thickness of 178 mm (7.0 in), with 0.5 percent interior longitudinal hard grade steel over a subgrade whose modulus of subgrade reaction is 27 MPa/M (100 lbf/in^2/in), will be sufficient to carry a 71.17-kN (16,000-lb) design wheel load. Past experiences are cited to indicate that this design approach is adequate.

3. **TITLE:** Stresses and Deflections in Concrete Pavements Continuously Reinforced with Welded Wire Fabric

AUTHORS/AGENCY/COUNTRY: M.J. Gutzwiller; J.L. Waling/Purdue University/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 238/1960

NUMBER OF PAGES: pp 48-63

APPLICABLE CATEGORY: Design

SUMMARY: Some of the conclusions reached as a result of this research, subject to the limitations imposed by the range of variables studied are: (1) Inadequately-reinforced continuous pavements, temperature decreases of more than about 16.7 °C (30 °F) below casting temperature tend to increase the deflections due to vertical (wheel) loads. Temperature decreases less than 16.7 °C (30 °F) tend toward a slight decrease in deflections. (2) The percentage of mid-depth reinforcement has an influence on maximum deflections due to vertical loads; the maximum deflections vary somewhat inversely with the percentage of reinforcement. (3) Upper surface crack widths vary somewhat linearly with temperature decreases in slab reinforced with inadequate amounts of welded wire fabric but with adequate splice laps. Pavements with adequate amounts of reinforcement from new cracks during sizable temperature decreases and old cracks do not continue to widen in direct proportion to temperature drop. (4) Maximum active crack widths at the upper and lower surfaces of the slab can be equalized and minimized by proper placement of the steel reinforcement. (5) An increase in the average steel stress at a crack accompanies increased temperature drops; furthermore, the stresses vary somewhat inversely with percentage of longitudinal reinforcement and mid-depth. (6) Vertical loads contribute significantly to stresses in the reinforcement. (7) Reinforcement placed 25 to 38 mm (1 to 1½ in) above mid-depth must resist stresses considerably greater than the sam amount of reinforcement placed at mid-depth or below.

4. **TITLE:** An Experimental Continuously Reinforced Concrete Pavement in Michigan

AUTHORS/AGENCY/COUNTRY: Cudney, G.R./Michigan State Highway Department/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 274/1960

NUMBER OF PAGES: pp 30-56

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: This project includes two 7.3 m (24 ft) roadways each containing two 3.7-m (12-ft) lanes. Two types of reinforcing steel, deformed bar mat and welded wire mesh, each providing a steel ratio of approximately 0.6 percent, were used in the continuously reinforced, 203-mm (8-in) uniform pavement sections. The eastbound roadway is composed of a 3.2 km (2 mi) section of continuously wire mesh, 1.1 km (0.7 mi) of standard 229 mm (9 in) uniform pavement with contraction joints spaced at 30.2 m (99 ft) intervals, and a 3.2-km (2-mi) section of continuous bar mat. The westbound

roadway contains approximately 6.4 km (4 mi) of continuously reinforced pavement, 3.2 km (2 mi) each of bar mat and wire mesh. Construction methods and equipment are described, including construction joints in the continuously reinforced sections. Various characteristics associated with the construction phase of the project were discussed including subgrade soil classification, concrete and air temperatures, concrete strength, and a record of construction progress. Studies involved in comparing the performance of various project sections include longitudinal displacements of the ends, end regions, and center of the continuously reinforced sections, relative displacements of joints and selected cracks, crack patterns and formation, surface roughness, effects of traffic, performance of relief sections and load deflection behavior.

5. **TITLE:** Continuously Reinforced Concrete Pavements in Pennsylvania

AUTHORS/AGENCY/COUNTRY: Witkoski, F.C.; Shaffer, R.K./Pennsylvania Department of Highways/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 238/1960

NUMBER OF PAGES: pp 1-22

APPLICABLE CATEGORY: Performance Evaluation Maintenance and Rehabilitation

SUMMARY: This report described the general condition of each project and presented the combined results of a comprehensive crack frequency and width survey on pavements. A study is made of the different crack patterns evolved as a result of paving in opposite seasons of the year. Further analysis is made of the effect of various pavement thickness upon service performance of the Hamburg roadway and 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 was described, together with an account of the subsequent repair of these damaged areas.

6. **TITLE:** Experience in Texas with Continuously Reinforced Concrete

AUTHORS/AGENCY/COUNTRY: Shelby, M.D.; McCullough, B.F./Texas Highway Department/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 274/1960

NUMBER OF PAGES pp 1-29

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: The reasons for trying continuously reinforce concrete pavement were presented. Data and conclusions based on physical measurements and observations of new and old projects were reviewed, and the possible reasons for variations of the crack patterns were discussed. With the above data and observations, and reported experience in other States as a background, the current policies and practices followed by the Texas highway department in the design and construction of continuously reinforced concrete pavements were numerated. In addition, a short summary of projects constructed and proposed for construction was reported.

7. **TITLE:** Mechanics of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Miller, M.M.; Gutzwiller, M.J./Purdue University/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 238/1960

NUMBER OF PAGES pp 94-104

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This investigation was primarily concerned with the deflections and the resulting stresses in a continuously reinforced concrete pavement, loaded simultaneously with longitudinal and transverse loads. The main assumptions in the first class are: (1) the deflection at a point some distance from the transverse load is zero and (2) the subgrade modules constant throughout the full range of deflection. The assumptions peculiar to this problem are: (1) the cracks formed by volume changes in the pavement are evenly spaced, (2) the segments between cracks are assumed to be straight, and (3) the moment at a crack is some function of the angle change.

8. **TITLE:** Observations on the Behavior of Continuously Reinforced Concrete Pavements in Pennsylvania

AUTHORS/AGENCY/COUNTRY: Taylor, I.J.; Eney, W.J./Fritz Engineering Laboratory of Lehigh University/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Bulletin No. 238/1960

NUMBER OF PAGES: pp 23-38

APPLICABLE CATEGORY: Performance Evaluation, Design, Construction

SUMMARY: The results of 3 years of research on continuously reinforced concrete pavements were summarized. Test data and conclusions based on pavement projects were reviewed, and a general pattern of behavior for continuous pavements was

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

ANNOTATED BIBLIOGRAPHY FOR 1961

1. **TITLE:** Maryland Continuously Reinforced Concrete Test Pavement

   AUTHORS/AGENCY/COUNTRY: Lee, A.; Lepper, H.A.; Garber, D.L./Bureau of Research; Maryland State Roads/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Proceedings Vol. 40/1961

   NUMBER OF PAGES: pp 235-281

   APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

   SUMMARY: The Maryland continuously reinforced concrete pavement project was part of a regional investigation of this type of pavement. The pavement and subbase thickness are constant while the steel percentage and bar size are varied. The project location materials, design, and construction, the applied traffic exposure, and observations and test results during the early life of the pavements were described.

ANNOTATED BIBLIOGRAPHY FOR 1962

1. **TITLE:** Laboratory Studies of Progressive Bond Failure in Continuously Reinforced Concrete Slabs

   AUTHORS/AGENCY/COUNTRY: Moore, J.H.; Lewis, A.D./Pennsylvania State University and Purdue University/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Board Bulletin No. 332/1962

   NUMBER OF PAGES: pp 1-15

   APPLICABLE CATEGORY: Design, Performance Evaluation

   SUMMARY: This paper reported the results of research initiated to determine a method of measuring bond failure, to evaluate the effect of repetitive vertical loads in producing progressive bond failure form crack to crack in continuously reinforced concrete pavements and determined the magnitude and distribution of bond stresses in the vicinity of cracks. To evaluate bond stresses near cracks and to study their change under repetitive loads, a plastic gauge used in conjunction with an air flow meter provides a simple and practical means of determining the differential movement of steel

bars with respect to the concrete without destroying any of the deformation on the bars, (2) bond stress at points within a region of slip may greatly exceed the average bond stress over this region, (3) heavy repetitive vertical bond stresses were not increased in the same proportion, (4) seven million repetitions of heavy wheel loads resulted in slip of less than 0.051 mm (0.002 in) at a distance of 152 mm (6 in) from a crack, 305 mm (12 in) from a crack the slip was zero, (5) when cracks are spaced more than 0.6 m (2 ft) apart, the possibility of 40.03 kN (9,000 lb) truck wheel loads producing progressive bond failure in continuously reinforced pavements on medium plastic subgrades is practically nonexistent.

ANNOTATED BIBLIOGRAPHY FOR 1963

1. **TITLE:** Determining and Evaluating Stresses of an In-Service Continuously Reinforced Concrete Pavement

   AUTHORS/AGENCY/COUNTRY: Shelby, M.D.; McCullough, B.F./Texas Highway Department/United States

   SOURCE: Highway Research Record

   REPORT NUMBER/DATE: Highway Research Board No. 5/1963

   NUMBER OF PAGES: pp 1-49

   APPLICABLE CATEGORY: Design, Performance Evaluation

   SUMMARY: The determination of an optimum percentage of longitudinal steel in a continuously reinforced concrete pavement, for a given region, is a pressing problem facing highway engineers. To arrive at a satisfactory solution, in place performance tests are required to check theoretical formula used to design these pavements. In Walker County, Texas, an area of moderate climate, the Texas highway department constructed an experimental continuous pavement to compare the relative performance of 0.5 and 0.6 percent longitudinal steel/yield stress of 345 MPa (50,000 lbf/in^2). To date both steel percentages 0.5 and 0.6 percent have performed satisfactorily on this project. Other factors such as cement type, time of placement, concrete properties and the average crack spacing were found to influence steel and concrete stresses more than the steel percentage as long as slab continuity is maintained. The magnitude of effect for each of these factors is presented in the report.

2. **TITLE:** End Anchors For Continuously Reinforced Concrete Pavements

   AUTHORS/AGENCY/COUNTRY: Mitchell, R.A./Virginia Council of Highway Investigation and Research/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Record No. 5/1963

NUMBER OF PAGES: pp 50-82

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Unrestrained end sections of continuously reinforced concrete pavements have been observed to move several mm (in) longitudinally due to thermal, shrinkage, or swelling strains. During the last few years a number of continuous slabs have been provided with subgrade anchors of various configurations to prevent these large end movements. This paper reported and experimental and theoretical study to develop guidelines for selecting and designing a suitable end anchor system. A full-scale experimental investigation of two different end anchor configurations a cylindrical theoretical analysis has been developed for the elastic and plastic range of end anchor response. The more complex theoretical solutions have been presented in the form of curves for use in design.

3. **TITLE:** Maryland's Two Continuously Reinforced Concrete Pavements - A Progress Report

AUTHORS/AGENCY/COUNTRY: Lee, A./Maryland State Road Commission/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board

NUMBER OF PAGES: pp 99-119

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: Two highways projects using continuously reinforced concrete paving have been constructed by the Maryland State roads commission. Nine sections of continuously reinforced pavement are included in the project. The pavement is 203 mm (8 in) thick, founded on a granular-type subbase of 152 mm (6 in) minimum thickness. Two lengths of conventional jointed pavement are included as control sections. They are 229 mm (9 in) thick, jointed at 12.2-m (40-ft) centers, and founded on a granular subbase of the same thickness. Traffic data tables provide an annual report of axle loads of various magnitudes using the facility. Analysis was made of crack patterns, crack widths, failures and possible causes, end movements of continuously reinforced slabs, end anchorages, and road roughness measurements. The performance and cost of continuously reinforced concrete pavement was compared with conventional pavements. The following improvements were suggested from this study (1) it is important and to vibrate both lifts of a continuously reinforced pavement and to use two pavers when two lift construction procedure is followed, (2) replacing the steel in a very long lengths and completely randomizing splice locations would be a preferred type of construction, (3) the length of the lap should be lengthened (4) the simplest type of terminal joint should be used and (5) end anchorages, if used must be massive.

4. **TITLE:** An Experimental Self-Stressing Pavement, Rt. 2, Glatonbury, Final Report

AUTHORS/AGENCY/COUNTRY: Bowers, D.G./Connecticut Department of Transportation/United States

SOURCE: Transportation Bureau of Highways

REPORT NUMBER/DATE: 1963

NUMBER OF PAGES:

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: In 1963, three slabs 7.3 m (24 ft) by 152.4 m (500 ft) by 152 mm (6 in) thick were placed on Route 2 in Glatonbury, Connecticut. Longitudinal steel consisted of 546 mm (21.5 in) 7-wire strands on 356-mm (14-in) centers and transverse steel consisted of #7 rebars on 0.6-m (2-ft) centers. The concrete contained calcium sulfo-aluminate adhydrite which expanded on hydration and stretched the steel to create a self-stressing prestressed pavement. Growth of each slab was about 0.3 m (1 ft) which was only ⅓ of that needed. Hence, the pavement cracked and behaved similarly to a continuously reinforced concrete pavement. Sleeper slabs special terminal joints and a bond-breaking medium were used in the construction. Strains in the steel, length changes of the slabs, crack intervals, crack openings, traffic, and surface condition were all observed for 8 years and the results are discussed. The adjacent jointed pavement has encroached the expansion space of the slabs and the surface condition is poor. Resurfacing may soon be necessary.

5. **TITLE:** Continuously Reinforced Concrete Pavements in Pennsylvania A Six-Year Progress Report

AUTHORS/AGENCY/COUNTRY: Shaffer, R.K.; Jensen. C.D./Pennsylvania Department of Highways/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 5/1963

NUMBER OF PAGES: pp 83-98

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: After 5 and 6 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. The background history of the two projects were reviewed briefly and the design variables of each pavement were described. Significantly different data were obtained from these variables particularly from the season of paving. Included are data on crack frequency, crack width, traffic count, and roughness surveys. Annual end movement and performance of the terminal joints are described. Shortly after completion for 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 178-mm (7-in) pavement had to be replaced, essentially because of foundation failure and poor subbase densification. The relative performance of both pavements is discussed and a suggested design for continuously reinforced pavements is offered.

ANNOTATED BIBLIOGRAPHY FOR 1964

1. **TITLE:** Test of Reinforcement Splices for Continuously Reinforced Concrete Pavement

   AUTHORS/AGENCY/COUNTRY: Lepper, H.A.; Kim, J.B./University of Maryland/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Record No. 60/1964

   NUMBER OF PAGES: pp 116-139

   APPLICABLE CATEGORY: Design

   SUMMARY: Lap splices in reinforcement for continuously reinforced concrete pavements were tested under longitudinally-applied static axial tensile loading to failure. Twenty-eight specimens, 203 mm (8 in) thick, 330 mm (13 in) wide, by 6.1 m (20 ft) long were reinforced with two hard grade No. 5 deformed bars (average yield strength 441 MPa (64,000 lbf/in^2)) and 24 specimens of similar size were reinforced with a strip of welded-wire fabric having 5/0 longitudinal wires (average yield strength 558 MPa (81,000 lbf/in^2)). Observations were made for the openings of the preformed crack under load, together with the openings of the occurrence and opening of additional cracks and the mode of failure. Results were evaluated in terms of several criteria that are significant to the function of reinforcement in the continuously reinforced pavement.

2. **TITLE:** Construction of a Continuously Reinforced Concrete Pavement in South Dakota

   AUTHORS/AGENCY/COUNTRY: Crawford, R.A.; Anderson, D.W./United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Record No. 60/1964

   NUMBER OF PAGES pp 154-168

   APPLICABLE CATEGORY: Construction

   SUMMARY: Two demonstration sections of continuously reinforced concrete pavement were constructed in South Dakota in 1963. The purpose of these sections was to (a) demonstrate the feasibility of continuously reinforced concrete pavement in South Dakota, (b) compare the relative merits of fixed depths of longitudinal steel within the

pavement. This paper discussed the environment, design, construction and testing of the continuously reinforced pavement sections and their control sections. A program of testing of indefinite duration is to continue, including present serviceability index studies, pavement movement surveys, and crack width measurements.

3. **TITLE:** Behavior of Experimental Continuously Reinforced Concrete Pavements In Mississippi

AUTHORS/AGENCY/COUNTRY: Spigolon, S.J./Mississippi State Highway Department/ United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 60/1964

NUMBER OF PAGES: pp 140-153

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This paper described the performance of the first two continuously reinforced concrete pavements constructed by the Mississippi State highway department. These pavements contain several design features which were relatively new in this type of construction. A brief description of the design features and the construction methods used for both pavements was presented. Longitudinal movements of the pavement have been measured periodically as have crack width changes. Crack surveys were performed, particularly in the early weeks after construction. Data on end movements, crack widths, and crack frequency and methods used for obtaining the data are also presented and discussed.

ANNOTATED BIBLIOGRAPHY FOR 1966

1. **TITLE:** Maryland Investigation of Continuously Reinforced Concrete Pavement 1959 - 1964 Strain Observations

AUTHORS/AGENCY/COUNTRY: Nixdorf, R.H.; Lepper, H.A./University of Maryland/ United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 112/1966

NUMBER OF PAGES: pp 82-105

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: The Maryland experimental continuously reinforced concrete highway pavement was constructed on the Baltimore-Harrisburg expressway, Interstate 83, during the summer of 1959. The pavement and subbase thickness are constant. Steel percentages

of 0.5, 0.6, and 0.7 percent and bar size Nos. 4, 5, and 6 are the variables. Observations of steel strains, crack openings, and pavement temperatures have been made over a 4½-year period. Reinforcement strains and crack openings vary with the daily range in pavement temperatures. The highest steel strains at the crack and the largest crack openings occurred in the sections containing the smallest amount of reinforcing 0.5 percent. The magnitude of the reinforcing strain is not appreciably affected by the bar size and is controlled primarily by the percentage of reinforcement. The width of the crack opening, however, is governed by both the percentage of steel and bar diameter. Construction conditions also have an apparent influence on pavement stresses. The crack openings have shown a slight increase and the maximum steel strains the crack have decreased as the pavement aged.

2. **TITLE:** Determining the Relationship of Variables in Deflection of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Treybig, H.J./University of Texas/ United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 131/1966

NUMBER OF PAGES: pp 65-86

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: A comprehensive study of deflection in continuously reinforced concrete pavements was conducted in Texas using AASHO road test studies as guidelines for the design of the experiments. Load and temperature differential, transverse crack width and spacing, and varying conditions of subbase and subgrade types were studied in terms of deflection and radius of curvature. An empirical equation for all these variables was formulated. The deflection of continuously reinforced concrete pavements is a function of the load applied, crack width, crack spacing, temperature, pavement thickness and the supporting characteristics of the subbase and subgrade.

3. **TITLE:** Preliminary Report on Continuously Reinforced Concrete Pavement in Oregon

AUTHORS/AGENCY/COUNTRY: Morgan, F.D./Oregon State Highway Department/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 112/1966

NUMBER OF PAGES: pp 106-119

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The experience in Oregon with continuously reinforced pavements has been rather encouraging, based on present evidence. Of the two pavements of this type constructed during 1962-1963, one has not been subject to traffic and the other has been open to traffic for only 3 months at the time of writing. Two pavement failures have occurred in the major project, but they are apparently unrelated to the type of pavement. Although these pavements have been somewhat more expensive on the base of first costs, the knowledge gained in Oregon is as yet insufficient to warrant any conclusions about the long term economics of this type of pavement as compared to conventional types.

ANNOTATED BIBLIOGRAPHY FOR 1967

1. **TITLE:** Aggregate Interlock at Joints in Concrete Pavements

   AUTHORS/AGENCY/COUNTRY: Colley, B.E.; Humphrey, H.A./Portland Cement Association/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Paper presented at the 46th Annual Meeting/1967

   NUMBER OF PAGES: 18 p

   APPLICABLE CATEGORY: Performance Evaluation

   SUMMARY: Load transfer across joints in concrete pavements through shear developed by interlocking aggregate was investigated in the laboratory by simulating the repetitive motion of tandem truck wheels across a joint. Effectiveness of load transfer was found to depend on load magnitude, number of repetitions, slab thickness, joint opening, subgrade bearing value and aggregate angularity. A summary statistic called "endurance index" is used to relate the significant variables to test performance.

ANNOTATED BIBLIOGRAPHY FOR 1968

1. **TITLE:** Shrinkage and Thermal Cracking in a Reinforced Concrete Retaining Wall

   AUTHORS/AGENCY/COUNTRY: Evans, E.P.; Hughes, B.P./Civil Engineering Department, University of Birmingham/United Kingdom

   SOURCE: Institution of Civil Engineers (London)

   REPORT NUMBER/DATE: Proceedings, Volume 39/1968

   NUMBER OF PAGES: pp 111-125

   APPLICABLE CATEGORY: Design

SUMMARY: Strain readings have been taken with a demec gauge of 0.9 m (3 ft) gauge length for 2 years on a reinforced concrete conterfort type retaining wall. Attempts were made to isolate thermal strains from shrinkage strains by taking measurements on specially cast control blocks suitably sealed against loss of moisture. The results indicated that the thermal movements in the wall, which were far greater than the shrinkage movements were the primary cause of cracking. The cracks nearly always occurred at all vertical construction joints. It is evident that thermal effects have a far greater influence on the cracking behavior of reinforced concrete structures that has generally been recognized in the past. A general theory for the cracking behavior of lightly reinforced and lightly loaded reinforced concrete members has been developed. This theory explains the erratic behavior which is often experienced in practice, and can be used to design to the limit state for maximum desirable crack width.

2. **TITLE:** Mississippi's Experience with Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Guy, V.W.; Teng, T.C./United States

SOURCE: Southeast Association State Highway Officials

REPORT NUMBER/DATE: October 1968

NUMBER OF PAGES: pp 101-103

APPLICABLE CATEGORY: Maintenance/Rehabilitation

SUMMARY: Mississippi's experience in the maintenance and repair of continuously reinforced concrete pavements is described in detail. Among the topics treated are removal of pavement, alternative methods of repair and types and causes of cracking and failure.

3. **TITLE:** A Statewide Deflection Study of Continuously Reinforced Concrete Pavement in Texas

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Harvey, K.J./University of Texas/ United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Record No. 239/1968

NUMBER OF PAGES: pp 150-174

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This report summarized the performance study of continuously reinforced concrete pavement in terms of load deflection studies. In this study the following factors affecting pavement performance were considered: subgrade support, subbase type, concrete modules of rupture, pavement thickness, season of the year, and soil

moisture condition. The effect of each of the factors on the deflection and stress made in the design and development of continuously reinforced concrete pavements for Texas conditions.

4. **TITLE:** A Twenty-Year Report on the Illinois Continuously Reinforced Pavement

AUTHORS/AGENCY/COUNTRY: Burke, J.E.; Dhamrait, J.S./United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 239/1968

NUMBER OF PAGES: pp 197-211

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: An experimental study was conducted to obtain more information on the relationships between performance and slab dimensions and steel amounts of continuously reinforced concrete pavements. Comparison of the experimental pavement behavior with and adjacent conventional control pavement indicates the following: (1) transverse cracks begin to develop at closely spaced intervals in continuously reinforced concrete pavements soon after construction with the number of cracks increasing with age and decreasing with the amount of longitudinal steel, (2) no strong difference occurred between the behavior of the 178- and 203-mm (7- and 8-in) thick pavements, (3) crack widths is an important factor in the behavior of continuously reinforced pavements since arrow cracks are essential to the maintenance of structural integrity and crack width is a function of steel content with the width increasing slowly with age, (4) slight spall begins to occur in at transverse cracks soon after construction increasing with age, (5) meandering longitudinal cracks will occur in a continuously reinforced pavement constructed wider than one lane without a center joint, (6) construction joints are potential sources of weakness at longitudinal steel contents of less than 0.7 percent, (7) when longitudinal movement is unrestrained, seasonal movements of continuously reinforced pavements can be expected, and also permanent increases in length with age, (8) continuously reinforced pavements can be designed and constructed to serve at least as effectively as conventional pavements, and have the potential of overcoming the basic weakness that occurs at transverse joints of conventional pavements, (9) continuously reinforced pavements can be built, and can retain for long periods of time, a high standard of surface smoothness, and (10) while pumping has not been a major cause of failure of the experimental pavement, it is not a positive protection against pumping. Design recommendations are made for experimental continuously reinforced pavement.

ANNOTATED BIBLIOGRAPHY FOR 1969

1. **TITLE:** Design, Construction and Performance of Continuously Reinforced Pavement

AUTHORS/AGENCY/COUNTRY: Lindsay, J.D./United States

SOURCE:

REPORT NUMBER/DATE: Ohio Highway Engineering Conference Proceedings/April 1969

NUMBER OF PAGES: pp 125-137

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: Expansion and contraction joints are eliminated by the use of additional reinforcing steel in continuously reinforced concrete (CRC) pavement. Cracks in a properly designed and constructed CRC pavement are held tightly closed by the steel and remain so provided the steel percentage is adequate for the prevailing climatic conditions. It has been shown empirically by performance of experimental CRC pavements that for equal load carrying capacity a CRC pavement need not be as thick as a jointed pavement. For equal load carrying capacity, the thickness of a CRC pavement need be only about 75 percent of that of a jointed pavement. Extensive load deflection tests by the Texas Highway Department have shown that cracks in the CRC pavement are virtually 100 percent effective in transferring load. Failures can be avoided in CRC pavement by: (1) recognizing that adequate consolidation of the concrete is essential in the construction of any type of concrete pavement, (2) extreme care must be taken to avoid honeycombed concrete and poor bond with the steel, (3) adequate lapping of the steel must be provided, and (4) weak subgrades and subbases can cause failures as they do in jointed pavement. Some failures have occurred but the causes can be avoided and better pavements built.

2. **TITLE:** Continuous Reinforcement in Airport Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Antonelli, F.A./United States

SOURCE:

REPORT NUMBER/DATE: Civil Engineering (NY) Vol. 39 No. 12/December 1969

NUMBER OF PAGES: pp 62-65

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: Portions of new runways and taxiways at Chicago's O'Hare Airport were constructed with continuously reinforced pavement (CRC pavement). CRC pavement has no transverse joints except at construction joints. Small transverse cracks are so narrow they do not require sealing. Expansion at pavement ends is handled either by a wide-flange steel beam cast in a reinforced concrete tie slab, or by use of lug anchors cast into trenches.

3. **TITLE:** Consolidation Practices in Concrete Pavement Construction

AUTHORS/AGENCY/COUNTRY: Ledbetter, T.B.; Treybig, H./Texas Transportation Institute/United States

SOURCE: Texas Transportation Institute

REPORT NUMBER/DATE: TTI Research Report 128-1/August 1969

NUMBER OF PAGES: 18 p

APPLICABLE CATEGORY: Construction, Maintenance/Rehabilitation

SUMMARY: This investigation involved and examination of current technology on concrete consolidation, current continuously reinforced pavement (CRC pavement) consolidation practices in Texas, and selected current concrete pavement problems through field examination and laboratory investigation. While the vast majority of concrete pavements were in excellent condition, inadequate concrete consolidation has been found in many areas of Texas, the most prevalent locations occurring adjacent to transverse construction joints in CRC pavement. With proper construction control, rigorously enforced, these isolated consolidation problems can be minimized. Selected changes in current practices were introduced.

4. **TITLE:** Continuously Reinforced Concrete Pavements with Elastic Joints Elastically Articulated Pavements (See also Reference 1972(3))

AUTHORS/AGENCY/COUNTRY: Persson, B.O.E./Cement Och. Betong/Sweden

SOURCE: Nordisk Betong

REPORT NUMBER/DATE: v. 13 n. 2/1969

NUMBER OF PAGES: pp 107-138

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This report describes continuously reinforced pavement with plain round bars located at mid-depth of cross section, in which the pavement transverse joints are formed with strips of asphalt-impregnated fiberboard, 3 mm (0.1 in) thick. Slab panels between joints are fitted with additional crack-controlling reinforcement in form of welded wire fabric. After concrete has hardened, V-shaped groove is sawn over each strip. Continuous plain round bars under joints are coated with asphalt for bond prevention along portion which corresponds to elastic extension of steel at maximum joint opening.

5. **TITLE:** Performance of continuously Reinforced Concrete Pavement in Texas

AUTHORS/AGENCY/COUNTRY: Treybig, H.J./Highway Design Division, Texas Highway Department/United States

SOURCE: Natural Academic of Sciences/National Research Council

REPORT NUMBER/DATE: Highway Research Record No. 291/1969

NUMBER OF PAGES: pp 32-47

APPLICABLE CATEGORY: Performance Evaluation, Design

SUMMARY: The performance of pavement test sections with varying subbase, subgrade, and slab thickness characteristics is evaluated in terms of steel strain, deflection, crack pattern, pumping, and traffic. Empirical equations developed by using regression technique are modified for use. Pavement type, pavement thickness, subbase type, and subgrade were all found to affect deflection.

6. **TITLE:** Use of Linear-Elastic Layered Theory For the Design of CRC pavement Overlays

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Boedecker, K.J./University of Texas/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 291/1969

NUMBER OF PAGES: pp 1-13

APPLICABLE CATEGORY: Design, Overlays

SUMMARY: The design of overlay pavements for upgrading existing pavements, especially rigid pavements, has presented a formidable task for engineers in the past due to the lack of a rational design procedure. This paper justifies the use of linear-elastic layered theory for the design of continuously reinforced concrete pavements (CRC pavement) overlays of existing pavements. The background rationale for selecting layered theory instead of conventional concrete pavement design procedures form plate theory is presented. A comparison is made of the mechanical state of stress, strain, and deflection derived from layered theory and the Westergaard interior equation with field measurements of pavement deflection and strain. This comparison indicates that layered theory is an acceptable model for the design of overlays. Techniques such as increasing the subgrade stiffness with depth beneath a pavement structure are presented for developing a reasonable correlation between predicted and measured deflection. Also discussed are the effects on design of an intermediate asphalt concrete stress-relieving layer between concrete pavement.

ANNOTATED BIBLIOGRAPHY FOR 1970

1. **TITLE:** High Strength Steels in Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Dechamps, Y.; Van Ael, P.; Hofmans, M.; Doyen, A./ United States

SOURCE:

REPORT NUMBER/DATE: CNRM No. 23/June 1970

NUMBER OF PAGES: pp 11-21

APPLICABLE CATEGORY: Design

SUMMARY: Such a pavement is characterized by the use of continuous longitudinal reinforcements which are interrupted only at the approaches of certain bridges. The thickness of this pavement may be reduced by 20 to 30 percent as compared with a noncontinuously reinforced pavement. The reinforcements required are either longitudinal or transverse, and the reinforcement grid, made of tied or welded wires, rests on metallic supports. A correctly designed and built continuously reinforced concrete pavement may be in service for many years without need of repair.

2. **TITLE:** A Field Investigation of Concrete Pavement in Texas (See also Reference 1969(3))

AUTHORS/AGENCY/COUNTRY: Ledbetter, W.B.; Meyer, A.H.; Treybig, H.J./Texas Transportation Institute; Austin Research Engineers, Inc./United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Special Report No. 116/1970

NUMBER OF PAGES: pp 167-173

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: The investigation involved an examination of current technology on concrete consolidation, current continuously reinforced concrete pavement consolidation practices in Texas, and selected current concrete pavement problems through field examination and laboratory investigation. Principal conclusions reached are as follows: (1) although the vast majority of concrete pavements are in excellent condition, inadequate concrete consolidation has been found in may areas of Texas, the most prevalent locations occurring adjacent to transverse construction joints in CRC pavement; and (2) with proper construction errors; these errors were discussed. Other topics treated in detail were transverse cracking and anchor systems.

3. **TITLE:** Continuously Reinforced Concrete Pavement Observation Program in Mississippi - A Progress Report

AUTHORS/AGENCY/COUNTRY: Teng, T.C./Mississippi State Highway Department/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 329/1970

NUMBER OF PAGES: pp 34-54

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: This report covered the 5-year observation study of continuously reinforced concrete pavement construction in Mississippi. Their design features, data on end movement, crack width, and crack frequency, were presented and discussed. A preliminary review of the design and construction statistics and the statewide crack survey of all completed projects was made. This review indicates that in Mississippi the pouring temperatures and the design average daily traffic are not the major factors influencing crack spacing. After the early years of service, age of the pavement does not appear to be an important factor in crack spacing. The failure investigations and repair procedures are also reported.

4. **TITLE:** Effect of Transverse Steel in Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Treybig, H.J.; McCullough, B.F.; Hudson, W.R./ University of Texas/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Board Special Report No. 116/1970

NUMBER OF PAGES: pp 138-150

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Continuously reinforced concrete pavements are reinforced in the transverse direction for several reasons based on practice, judgement, and some theory. Since 1966 some pavements of this type have been constructed without transverse reinforcement with an economic advantage. This paper presents an evaluation of transverse steel in continuously reinforced pavements and considers the probability that the pavement will experience longitudinal cracking. The analysis also considers potential monetary saving by omitting transverse steel and the probabilities that pavement will last its design life with an without transverse steel, assuming that it will experience longitudinal cracking.

5. **TITLE:** Evaluation of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Hughes, P.C./Minnesota Department of Highways/United States

SOURCE: Minnesota Department of Highways

REPORT NUMBER/DATE: Inv No. 184/1970

NUMBER OF PAGES: 44 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: The purpose is to evaluate the performance of a continuously reinforced concrete pavement (CRC pavement) under the influence of concrete shrinkage,

temperature change, and traffic at Fairbault, Minnesota. The project design and layout, construction procedures and materials are described. Crack survey results, longitudinal pavement and moments, roughmeter measurements, pavement failures and cost analysis are also presented and described. Based on the findings of this investigation, it is recommended that at least 0.7 percent deformed steel reinforcement be used on all CRC pavement built in Minnesota, and that large expansion joints be used in place on end anchors to account for the longitudinal end movements.

6. **TITLE:** Experimental Studies on PCC and CRC Pavements Made with Expansive Cement Concrete

AUTHORS/AGENCY/COUNTRY: Nagataki, S./Japan

SOURCE: Japan Cement Association

REPORT NUMBER/DATE: 24th General Meeting, Synopsis No. 39/May 1970

NUMBER OF PAGES: pp 124-132

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Two concrete and two continuously reinforced concrete pavements were cast experimentally at Niigata prefecture with and without the expansive cement component (CSA by denka) in order to examine the effects of the use of expansive cement on pavement. It is shown that use of expansive cement concrete in CRC pavements may generate stresses to some degree and these are effective in counteracting stress due to temperature drops and drying shrinkage at the center zone of long span pavements.

7. **TITLE:** A Pavement Overlay Design System Considering Wheel Loads, Temperature Changes, and Performance

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Monismith, C.L./University of Texas; Institute of Transportation and Traffic Engineering, University of California Berkeley/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 237/1970

NUMBER OF PAGES: pp 64-82

APPLICABLE CATEGORY: Design, Overlays

SUMMARY: A review of overlay design procedures revealed that a few bona fide procedures exist and that even the best of the, i.e., those based on deflection, have limitations and inconsistencies. Furthermore, the review emphasized the need for considering volume change stresses. The purpose of this paper, therefore, is to briefly discuss a recently developed overlay design procedure, which has been applied to 17.7 km (11 mi) of

Interstate highway and 2 airports. The design is discussed in terms of wheel load and temperature stresses.

ANNOTATED BIBLIOGRAPHY FOR 1971

1. **TITLE:** Continuously Reinforced Concrete Pavements - The State of the Art

   AUTHORS/AGENCY/COUNTRY: York, G.P./U.S. Air Force/United States

   SOURCE: Air Force Weapons Laboratory

   REPORT NUMBER/DATE: Technical Report No. AFWL-TR-71-102/October 1971

   NUMBER OF PAGES:

   APPLICABLE CATEGORY: Design

   SUMMARY: This report details a design procedure for CRC pavement for airfield applications which reflects the current state-of-the-art available at the time. The design procedure accounts for steel and concrete structure responses typically considered in CRC pavement design. Accompanied with the design procedure are illustrations of various punchout relates distresses which occur in airfield pavement.

2. **TITLE:** Techniques in Slipform Paving and Continuously Reinforced Concrete Pavement Construction

   AUTHORS/AGENCY/COUNTRY: Olateju, O.T./Purdue University; Indiana State Highway Commission/United States

   SOURCE: Highway Research Board

   REPORT NUMBER/DATE: Highway Research Report No. 6/March 1971

   NUMBER OF PAGES: 257 p

   APPLICABLE CATEGORY: Construction, Performance Evaluation

   SUMMARY: Current techniques for slipform paving and for installing reinforcing steel in continuously reinforced concrete pavement constructed steel by slipforming are examined. In performing the study, contracts were made with various highway officials, contractors, equipment manufacturers and private individuals. The information thus obtained included descriptive literature photographs, and time-lapse movies of the construction operations. The report is divided into four major parts. The first of these reviews the developments, acceptance and usage of the slipform paving technique. It also discusses ancillary highway paving activities, other than the construction of the primary traffic supporting pavement, where slipform paving techniques have proved applicable. Procedures for checking the pavement depth and texturing and measuring the surface smoothness of a slipformed pavement are also

discussed. The second part describes the various methods for installing both mesh and rebars for CRC pavements. It includes review of the experience of several States in which these techniques have been used, based on information from a questionnaire and from telephone conversations. The third section of the report describes eight field studies which were made during the summer of 1970 in five different States. These observations were recorded by time-lapse photography. A description of the time lapse technique and the manner in which it was applied to this study is also provided. The fourth part consists of an evaluation of the findings and the conclusions drawn therefrom. This part also includes recommendations for action and for further study.

3. **TITLE:** Proceedings of the 20th Annual Georgia Highway Conference, Atlanta, Georgia, March 15-16, 1971

AUTHORS/AGENCY/COUNTRY: United States

SOURCE: Georgia Institute of Technology

REPORT NUMBER/DATE: Practice No. 60/July 1979

NUMBER OF PAGES: 53 p

APPLICABLE CATEGORY:

SUMMARY: Nine papers by various authors were presented. The topics discussed were continuously reinforced concrete pavement, maintenance problems and practices with portland cement concrete pavement. New developments in testing; construction procedures for achieving modified density in bases; maintenance of asphaltic concrete pavements and problems of mixing and placing asphaltic concrete.

4. **TITLE:** Concrete Pavements, Japan

AUTHORS/AGENCY/COUNTRY: Kamiua, H.; Iwama, S.; Suzuki, M.; Fujii, H./Ministry of Construction/Japan

SOURCE:

REPORT NUMBER/DATE: 1971

NUMBER OF PAGES: 15 p

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: This report covered the performance of jointed concrete pavements in Japan and the design of subbases. Some performance data is presented with respect to LCRC pavement. Excellent performance has been observed with continuously reinforced concrete pavements subjected to heavy traffic for 7 years. Problems of concrete slab construction are identified as those relating to spreading and compacting the 300 mm (11.8 in) thick slabs.

5. **TITLE:** Effect of Transverse Steel in Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Treybig, H.J.; McCullough, B.F.; Hudson, W.R./ University of Texas/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Special Report No. 116/1971

NUMBER OF PAGES: pp 13850

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: The paper presents an evaluation of transverse steel in continuously reinforced pavements and considers the probability that the pavement will experience longitudinal cracking. The analysis also considers potential saving by omitting transverse steel and the probabilities that pavement will last its design life with and without transverse steel assuming that it will experience longitudinal cracking.

6. **TITLE:** Evaluation of Terminal Anchorage Installations on Rigid Pavements

AUTHORS/AGENCY/COUNTRY: McCullough, B.F./University of Texas/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 362/1971

NUMBER OF PAGES: pp 21-29

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: The problem of cyclic movement with continuously reinforced concrete pavement is explored. It was hypothesized that the same type of Anchorage system used on jointed pavements could be used on continuous pavements, thus solving the expansion problem. The anchor lugs were placed in the ground transversely across the pavement and were attached to an anchor slab. Long-term observations and measurements were performed on 186 existing terminal Anchorage systems on continuous concrete pavements. After several years of observation, it was found that no adverse movement or pavement growth took place. The terminal movement was found to be directly related to pavement length of up to 305 m (1,000 ft) and temperature change and indirectly related to pavement grade, subbase coefficient, and number of lugs. An empirical equation expressing movement terms of these variables is derived in this study.

7. **TITLE:** Performance Study of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Majidzadeh, K.; Talbert, L.O./Ohio Department of Highways/United States

SOURCE: Ohio Department of Highways

REPORT NUMBER/DATE: 1971

NUMBER OF PAGES:

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The major construction, design and materials variables which affect the performance of continuously reinforced concrete (CRC) pavements are discussed and an overall treatments is provided of the performance of this type of pavement in Ohio. Unstable support conditions accompanied by the lack of sufficient subsurface drainage were the main contributors to the observed pavement failures. The spacing, pattern and width of transverse cracks are significant performance parameters. Practically all of the failures have occurred in the outside lane of the CRC pavements where the frequency of occurrence of heavy traffic load is significantly greater.

8. **TITLE:** Effect of Welding on Fatigue Life of High Strength Reinforcing Steel Used in Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Pasko, T.J./United States

SOURCE:

REPORT NUMBER/DATE: November 1971

NUMBER OF PAGES: 30 p

APPLICABLE CATEGORY: Performance Evaluation, Current Research

SUMMARY: The literature and laboratory experimentation were used in an attempt to determine the effects of welding on ASTM A 615, grade 60 steel that is used to fabricate welded bar mats for reinforcement in continuously reinforced concrete pavements (CRC pavement), It was concluded that the formulation of a generalized stress spectrum for steel in CRC pavement is unrealistic. On the basis of field experience with this product in Michigan it was concluded that welded bar mats are satisfactory for use in CRC pavement. It was also concluded that some definitive research is needed to improve the design procedures for CRC pavement.

ANNOTATED BIBLIOGRAPHY FOR 1972

1. **TITLE:** A Design Procedure for Continuously Reinforced Concrete Pavements for Highways

AUTHORS/AGENCY/COUNTRY: American Concrete Institute/United States

SOURCE: American Concrete Institute

REPORT NUMBER/DATE: June 1972

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: Design methods, including the load-temperature-shrinkage design method, the Texas design, the Illinois design method, and the CRSI design method were reviewed. These thickness design methods have generally been based on used, but the variables of climate subgrade type and support, and drainage conditions complicated the extension of the AASHO road test results to other geographical locations. Theories, modified by performance experience, are presented to compute the required pavement thickness and amount of longitudinal steel, and also to design the end Anchorage or the jointing means at the end of pavement selections.

2. **TITLE:** Analysis of Bending Stiffness variation at Cracks in Continuous Pavements

AUTHORS/AGENCY/COUNTRY: Abou-Ayyash, A.; Hudson, W.R./University of Texas/ United States

SOURCE: Texas Center for Highway Research

REPORT NUMBER/DATE: No. 56-22/1972

NUMBER OF PAGES: 143 p

APPLICABLE CATEGORY: Design

SUMMARY: This study reports an analytical look at the effect of transverse cracks on the behavior of continuously reinforced concrete pavements. Results show that the percent reduction in bending stiffness at crack locations range between 80 and 90 percent of the original uncracked value. By simulating this effect on the discrete-element model, a sensitivity study was performed on the parameters considered in the design of continuously reinforced concrete pavements. These covered the practical range of each of the following variables; slab bending stiffness, modulus of subgrade reaction, and crack spacing. The influence of the width of the crack on the behavior and performance of continuously reinforced concrete pavements is highly significant. Slab deflections increase, while no significant change in principal moments is encountered.

3. **TITLE:** Concrete Pavement With Continuous Reinforcement and Elastic Joints-Test Roads, Joint Inserts and Design

AUTHORS/AGENCY/COUNTRY: Persson, B./Cement Och, Betong/Sweden

SOURCE: Cement Och. Betong

REPORT NUMBER/DATE: Vol. 47/1972

NUMBER OF PAGES: pp 509-523

APPLICABLE CATEGORY: Design, Construction

SUMMARY: A new type of pavement is suggested: a continuously reinforced concrete pavement with elastic joints. The pavement is centrally reinforced with continuous round bars using fiber board strips as crack initiators at suitable intervals. At the joints, the continuous plain round bars are debonded with cutback bitumen, over such a length that when a movement occurs the tensile yield point is not exceeded and the joint openings restrained.

4. **TITLE:** Design Procedure for Continuously Reinforced Concrete Pavements for Highways

AUTHORS/AGENCY/COUNTRY: ACI Committee 325/United States

SOURCE: American Concrete Institute

REPORT NUMBER/DATE: American Concrete Institute c 69 No. 6/June 1972

NUMBER OF PAGES: pp 309-319

APPLICABLE CATEGORY: Design

SUMMARY: ACI Committee 325, Subcommittee VII. Report presents and interim design method based on current practices for determining the pavement thickness and amount of reinforcing steel for continuously reinforced concrete pavement. Recommendations are presented on end anchorage systems.

5. **TITLE:** Mechanical Methods of Steel Placement for Slip-Form Construction of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Shcoler, C.F.; Olattju, O.T./Purdue University/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 389/1972

NUMBER OF PAGES: pp 1-4

APPLICABLE CATEGORY: Construction

SUMMARY: The extent of the use of mechanical steel placers in this country was evaluated through questionnaires directed to selected highway officials, correspondence and interviews with contractors and other highway officials and observations of actual jobs. The procedures followed on elected jobs were recorded on film with the aid of a time-lapse camera, and the photographs were later used in the analyses of the placement methods and techniques. Several types of mesh depressors and bar placers are

described. From the observation and subsequent analyses, the following summary comments are made: (1) the number of States that have turned to the use of continuously reinforced concrete pavements is rapidly increasing; (2) machines are now available that can place steel faster, at less expense, and with less labor than the manual operations formerly employed. These machines have been used to the general satisfaction of the State highway officials; (3) several states have modified their specifications so as to accommodate placement tolerances that are compatible with the mechanical methods; (4) many States have eliminated the use of transverse bars in construction of continuously reinforced concrete pavements; (5) through adequate planning and the use of mechanical methods for steel placement, contractors have demonstrated that they can improve the efficiency of their steel laying operations; (6) currently available mechanical devices for depressing steel are not yet fully perfected, but additional improvements can be expected in the future; and (7) the savings that can currently be realized from the use of mechanical steel placers cannot be specifically identified because of limited experience. However, the potential savings can be sufficiently attractive to warrant the interest of highway officials.

6. **TITLE:** Report on Performance of CRC pavement in Indiana

AUTHORS/AGENCY/COUNTRY: McCullough, B.F./Austin Research Engineers/United States

SOURCE: Austin Research Engineers

REPORT NUMBER/DATE: Report CR-8/1972

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This report describes pavement survey results and types of pavement distresses which occur in Indiana CRC pavements. A detailed description is given for each noted distress and the associated failure mechanism.

7. **TITLE:** Effect of Cracks on Bending Stiffness in Continuous Pavements

AUTHORS/AGENCY/COUNTRY: Abou-Ayyash, A.; Hudson, W.R.; Treybig, H.J./ University of Texas/United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 407/1972

NUMBER OF PAGES: pp 10-21

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: An analytical look at the problem of transverse cracking in continuously reinforced concrete pavements was presented. The influence of the cracks on the longitudinal bending rigidity was studied by using basic moment curvature relations. A relation was developed that expresses the average moment of inertia due to the effect of crack as a function of material properties and slab geometric characteristics. A discrete-element method of slab analysis.

8. **TITLE:** Long Term Performance of an Experimental Composite Pavement

AUTHORS/AGENCY/COUNTRY: Ryell, J./Canada

SOURCE: Ontario Ministry of Transportation & Communications

REPORT NUMBER/DATE: Rr 184/December 1972

NUMBER OF PAGES: 17 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The report presents an evaluation of an experimental pavement constructed on Highway 401 near Milton in 1959. The experiment consisted of seven sections of composite pavement and a section of continuously reinforced concrete pavement. The control section is normal reinforced concrete pavement (1959 design). Data on transverse and longitudinal cracking, road rideability and skid resistance are presented, and each pavement section is rated on present performance and economic aspects. It is concluded that the most satisfactory pavement section in the experiment consists of a 83 mm (3¼ in) bituminous overlay on an 203 mm (8 in) unreinforced concrete base and that mesh reinforcement in the concrete base has no beneficial effect on the overall performance of the composite pavement. It is also concluded that the best composite pavement is rigid and flexible pavements, approximately the same age and subjected to a similar traffic volume, elsewhere on Highway 401.

9. **TITLE:** Studies on Continuously Reinforced Concrete and Prestressed Concrete Pavements Made with Expansive Cement Concrete

AUTHORS/AGENCY/COUNTRY: Nagataki, S.; Yoneyama, K./Tokyo Institute of Technology/Japan

SOURCE: Tokyo Institute of Technology

REPORT NUMBER/DATE: Klein Symp on Expansive Cement Concrete; American Concrete Institute Fall Convention/November 1972

NUMBER OF PAGES: pp 131-163

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: The expansive cement concrete could be effective not only in compensating drying shrinkage of concrete pavements but also in inducing a self-stress due to the restraint of expansion by subgrade friction and reinforcement. Laboratory and field testing results indicate that the value of self stress in the central zone of pavement can be expected to reach up to 2.07 MPa (300 lbf/in^2) during early curing period, and about 1.04 MPa (150 lbf/in^2) of residual self-stress even after longer period; continuously reinforced concrete pavement can be made without causing any cracks in it when expansive cement concrete is used.

10. TITLE: Recent Trends in Concrete Surfacings

AUTHORS/AGENCY/COUNTRY: Lazaro, F./Association Espanola de la Csrretera Serrano/Spain

SOURCE: Association Espanola de la Cerretera Serand

REPORT NUMBER/DATE: May 1972

NUMBER OF PAGES: pp 109-122

APPLICABLE CATEGORY: Overlays

SUMMARY: This report reviewed the stages of development of concrete surfacings from the traditional design (with shrinkage and expansion joints) to the most recent trends (continuously reinforced concrete (Illinois), or concrete surfacings with sawed joints and short slabs without reinforcement (California). Details are given if the different types of surfacings, and mention is made of the present trend to follow the Californian method because of its economy and simplicity.

ANNOTATED BIBLIOGRAPHY FOR 1973

1. TITLE: Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: NCHRP/United States

SOURCE: Highway Research Board/National Research Council

REPORT NUMBER/DATE: NCHRP Report No. Synthesis 16/1973

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design, Performance Evaluation, Construction, Maintenance/ Rehabilitation

SUMMARY: CRC pavement is portland cement concrete pavement with continuous longitudinal steel reinforcement and no intermediate transverse expansion or contraction joints. Natural cracking develops a few days after construction and stabilizes within the first few years. Percentage of steel, bond area of steel, depth of

reinforcement, friction between concrete and base, concrete strength, season of construction, and curing temperature influence the crack spacing.

At the time, design methods were based on long-term pavement observations. Nonerodible bases provided better support and lower deflections. Smooth wire fabric was not used because it was linked to unsatisfactory performance. Steel percentages of 0.5 to 0.7 were used. Steel was placed at slab mid-depth. Anchors and expansion systems were used at the ends.

- The potential for CRC overlays was recognized in the report.
- Proper splicing of reinforcement and consolidation especially around construction joints, are important for good performance.

2. **TITLE:** Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Anonymous/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: NCHRP, Synthesis of Highway Practice No. 16/1973

NUMBER OF PAGES: 32 p

APPLICABLE CATEGORY: Design, Construction

SUMMARY: This report reviewed the literature on the guidelines for design and construction of portland cement concrete pavement with continuous longitudinal steel reinforcement and no intermediate transverse expansion or contraction joints presented.

3. **TITLE:** Recent Experimental PCC Pavements in California

AUTHORS/AGENCY/COUNTRY: Spellman, D.L.; Woodstrom, J.H.; Neal, B.F.; Mason, P.E./United States

SOURCE: California Department of Transportation

REPORT NUMBER/DATE: June 1973

NUMBER OF PAGES: 56 p

APPLICABLE CATEGORY: Design, Construction

SUMMARY: The construction of experimental PCC pavement sections is described. The predominant experimental feature was continuously reinforced concrete pavement with three different types of reinforcement. Also included were unreinforced sections with (1) weakened plane joints at about one-half the normal intervals, (2) higher cement content, (3) over designed thickness, and (4) use of a lean concrete (4-sack) base.

Design and construction details are presented along with a comparison of the construction costs of the various sections.

4. **TITLE:** Amsterdam is First in Constructing a Continuously Reinforced Concrete Pavement with a Slip-Form Paver

AUTHORS/AGENCY/COUNTRY: Hille, G.J.A.; Vries, D.J.A.; Luitwieler, J.A./Verenging Het Nederlansche Wegencongres/Netherlands

SOURCE: Legen, Netherlands

REPORT NUMBER/DATE: Wegen/December 1973

NUMBER OF PAGES: pp 371-381

APPLICABLE CATEGORY: Construction

SUMMARY: A continuously reinforced concrete pavement, total area 21,000 m^2, (226,000 ft^2) thickness 180 mm (7.1 in), was constructed on a section of dual-carriageway road. The width of each carriageway is 7.5 m (24.6 ft). On a roadbase of sand cement, thickness 200 mm (7.9 in), a 50-mm (2.0-in) base course or gravel-sand asphalt was laid in order to improve the evenness of the base and to obtain a uniform thickness of the concrete layer. The reinforcement, composed of B50 steel bars, diameter 16 mm (0.6 in), was assembled on the site. The transverse bars were placed at an angle of 60° with the alignment. The percentage of reinforcement is 0.75. The concrete was laid by means of a slip-form paver. Details of the construction method are described and some related aspects of concrete technology are discussed. It is concluded that the experimental use of a slip form paver for this purpose has been successful.

5. **TITLE:** Condition of Longitudinal Steel in Illinois Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Dhamrait, J.S.; Jacobsen, F.K.; Schwartz, D.R./Illinois State Department of Transportation/United States

SOURCE: Illinois State Department of Transportation

REPORT NUMBER/DATE: No. 43/March 1973

NUMBER OF PAGES: 47 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: An investigation was made of several CRC pavements constructed within Illinois to determine the extent of corrosion occurring on the longitudinal reinforcement at transverse cracks. The effects of crack width, crack spacing, depth of reinforcement, slab thickness, and type of reinforcement were studied to determine their influence on the progression of corrosion. An analysis was made of 151 cores throughout the State

for an intensive study on the behavior of a variety of CRC pavement designs. Of the cores removed from the experimental pavements, 49 percent showed no evidence of active steel corrosion, 50 percent indicated slight pitting to moderate pitting and less than 1 percent showed advanced rusting with a marked reduction in cross-sectional area of the reinforcing steel. The findings indicate that corrosion of the steel reinforcement in adequately designed CRC pavements is relatively minor, and that corrosion of the steel does not appear to be a potential problem with pavements designed in accordance with the present criteria. Of the parameters investigated, crack width appeared to be the only significant factor influencing the progression of corrosion. The entrance or ejection of water through transverse cracks was evident in all cores. Some discoloration was noted at all cracks.

6. **TITLE:** Field Study of Performance of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Majidzadeh, K./Ohio Department of Transportation/ United States

SOURCE: Ohio Department of Transportation

REPORT NUMBER/DATE: Ohio-DOT-09-74/1973

NUMBER OF PAGES:

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: In this report the results of field observations on CRC pavements constructed in the State of Ohio are presented. The field performance parameters such as deflection, moduli variability, support conditions, crack spacing, and pattern and drainage conditions are evaluated and related to pavement structural conditions. The results of pavement core strength data are utilized to develop interrelations between material properties and life expectancy of the CRC pavement structure. The concept of concrete maturity and the strength-maturity relations are used as a basis for a proposed design scheme. The results of field curing conditions and the effects of curing methods on the crack spacing and patterns were also investigated. This field study has shown that the crack spacing and pattern is independent of curing conditions and is mostly affected by the climatic condition prevailing during construction. It is also shown that in CRC pavements constructed using soil-cement or lime-flyash mixture, the transverse cracks in the pavements structure have, in all instances, penetrated into the base course. The drainage conditions in these pavements have been shown to be of critical significance. Similarly, this study has demonstrated the extent of variability observed in the construction of these pavements. The field observation of the performance of an overlayed structure on a CRC pavement has indicated that reflection cracking would occur in areas where the continuity of steel reinforcement has been destroyed.

7. **TITLE:** Long Term Performance of an Experimental Composite Pavement

AUTHORS/AGENCY/COUNTRY: Ryell, J.; Corkill, J.T./Ministry of Transportation and Communications/Canada

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 434/1973

NUMBER OF PAGES: pp 1-23

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The report presents an evaluation of an experimental pavement constructed on Highway 401 near Milton, Ontario, in 1959. The experiment consisted of 7 sections of composite pavement and a section of continuously reinforced concrete pavement. The control section is normal reinforced concrete pavement. Data on transverse and longitudinal cracking, road rideability, and skid resistance are presented.

8. **TITLE:** Problems of High-Volume Change Soils in North Dakota

AUTHORS/AGENCY/COUNTRY: Leer, D.K./North Dakota State Highway Department/ United States

SOURCE: North Dakota State Highway Department

REPORT NUMBER/DATE: Workshop Proceedings/June 1973

NUMBER OF PAGES: pp 256-258

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: This report reviewed problems encountered in North Dakota in areas with expansive soils. Expansive soils have no longer been a problem since 1967. This is due to the fact that the continuously reinforced paving concept was employed with new compaction standards, whereby soils are compacted to a lower density and a higher moisture content.

9. **TITLE:** Relative Effects of Structural Variables on Performance of Continuous Pavements

AUTHORS/AGENCY/COUNTRY: Abou-Ayyash, A.; Hudson, W.R./University of Texas/ United States

SOURCE: Highway Research Board

REPORT NUMBER/DATE: Highway Research Record No. 466/1973

NUMBER OF PAGES: pp 38-54

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This paper describes a sensitivity analysis performed to establish the relative importance of structural variables on the performance of continuously reinforced

concrete pavements. The experimental design for the study consisted of three basic variables: slab bending stiffness, subgrade modulus, and crack spacing. The discrete-element method of slab analysis was the mechanistic tool applied to obtain slab responses, i.e., deflections, principle moments, and stresses. For the range of variables studied, the analysis of variance showed that the most significant variables which explained about 90 percent of the variation in deflection and principle moment responses were slab bending stiffness and modulus of subgrade reaction. Although the first variable made of higher contribution to principle moments than to deflections, subgrade modulus had a contrasting effect. As cracks widen to approach the hinge case, slab deflections increase significantly, but no appreciable drop is experienced in the principle moments. Indeed, cracks as narrow as possible are desirable for the successful performance of continuous pavements.

ANNOTATED BIBLIOGRAPHY FOR 1974

1. **TITLE:** Design and Performance of Continuously Reinforced Concrete Pavements

   AUTHORS/AGENCY/COUNTRY: Yoder, E.J.; Faiz, A./Purdue University Indiana State Highway Commission/United States

   SOURCE: Purdue and Indiana State Highway Commission, JHRP

   REPORT NUMBER/DATE: CE 293/July 1974

   NUMBER OF PAGES: 17 p

   APPLICABLE CATEGORY: Design, Performance Evaluation

   SUMMARY: Design concepts are discussed and a statewide condition survey (1972) is described that was designed to evaluate the performance of continuously reinforced concrete (CRC) pavements in Indiana. A sampling procedure was used to design the field survey and statistical methods were used to study on the factors influencing CRC pavement performance was made. Details are outlined of the statistical study in which weighted least squares analysis of variance procedure was used. Conclusions drawn from the study are presented and significant factors affecting performance are listed.

2. **TITLE:** Investigation of Stell Tension Failure in Continuously Reinforced Concrete Pavements

   AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Treybig, H.J./Austin Research Engineers/United States

   SOURCE: Austin Research Engineers

   REPORT NUMBER/DATE: Report Cr-7/2/1974

   NUMBER OF PAGES:

   APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report describes an investigation into the causes of steel reinforcement failures in several CRC pavements located in the Midwestern part of the United States. In many of the sites considered, heavy corrosion of the reinforcement had occurred. Several hypothesis were developed to determine the cause and the mode of failure leading to the tensile breaks. The accepted hypothesis suggested that tensile failure could occur due to fatigue damage accumulating during temperature cycles throughout the year and to the corrosion loss area of the steel.

3. **TITLE:** Mechanistic Behavior of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Abou-Ayyash, A./The University of Texas/United States

SOURCE: Center for Transportation Research, University of Texas

REPORT NUMBER/DATE: Ph.D. Thesis/May 1974

NUMBER OF PAGES: 341 p

APPLICABLE CATEGORY: Design

SUMMARY: This report examined the analysis of CRC pavements, in which an incremental approach was adopted to predict the formation of transverse cracks due to shrinkage and drop in temperature as a function of time. From this predicted crack pattern, theoretical models were developed to compute the crack width. Stresses in the steel and stresses in the concrete at every station along the slab. The method was developed to simulate adequately the mechanistic behavior of the pavement materials, namely portland cement concrete, reinforcing steel and the underlying soil. The method is too complex for hand calculations. A computer program which solves the derived theoretical equations together with the various nonlinearites encountered in the CRC pavement problem has been developed. Different integration techniques are applied for the various nonlinearities. The program is written in FORTRAN computer language for the control data corporation 6600 Digital Computer. The developed method provides a useful tool for the analysis and design of continuous pavements. It has application to a broad variety of problems which cannot be solved by any other existing method. The example problems investigated in this study provided a better understanding of the behavior of continuous pavements. In these example problems, design parameters were divided into material variables and environmental conditions. It was shown that among the material variables that require intensive consideration are the properties of concrete, such as strength, elastic modulus and bond stress. The change in crack spacing and crack width with concrete is highly significant. The theoretical models described herein provide a unique and useful tool for the study of continuous pavements. The development of the method opens the door for determination of values which previously could only be estimated crudely. Applications of this method are discussed in this section of the report together with recommendations for further research.

4. **TITLE:** Continuously Reinforced Concrete Pavements: A Report of the Study Group

AUTHORS/AGENCY/COUNTRY: Gregory, J.M.; Burks, A.E.; Pink, V.A./Transport and Road Research Laboratory/England

SOURCE: Transport and Road Research Laboratory Environmental Effects Division

REPORT NUMBER/DATE: TRRL Report LR612/1974

NUMBER OF PAGES: 58 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: Continuously reinforced concrete pavements are widely used in the USA and also in Belgium. A study group of British engineers has visited this type of pavement. The study group concluded that for heavily trafficked roads the slab thickness for a continuously reinforced concrete pavement may be 30 mm (1.2 in) less than that required for a jointed concrete pavement; this was associated with a steel percentage of 0.6 and the initial cost of a continuously reinforced concrete pavement is likely to be greater than that of a jointed concrete pavement for the same trafficked urban roads along with associated delay costs. Economic advantages in the use of continuously reinforced concrete pavements are pointed out here.

5. **TITLE:** Stress in Continuously Reinforced Concrete Pavements in Service

AUTHORS/AGENCY/COUNTRY: Birmann, D./United States

SOURCE: Beton, Herstellung

REPORT NUMBER/DATE: Verwendung v. 24 n. 3/March 1974

NUMBER OF PAGES: pp 92-93

APPLICABLE CATEGORY: Design

SUMMARY: This report describes the design of continuously reinforced concrete pavements with particular regard to the formation of cracks, a simplified analysis of stresses occurring at low temperatures is carried out. Concrete and reinforcing steel tensile stresses are given in a diagram. Two examples of a test pavement strip reinforced longitudinally with reinforcing steel bars and steel fabric mats, respectively are calculated.

6. **TITLE:** A Performance Survey of Continuously Reinforced Concrete Pavements in Texas

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Strauss, P.J./University of Texas/ United States

SOURCE: Center for Highway Research

REPORT NUMBER/DATE: RR 21-1F/1974

NUMBER OF PAGES: 131 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The structural performance of continuously reinforced concrete pavements in the State of Texas has become a matter of great importance to administrators since about 4800 km (3,000 mi) of 7.3-m (24-ft) wide pavement of this type have been built in the last 16 years. This report concerns itself with the condition survey and the analysis of the data in the wide field of possible strategies. Research into the relative importance of each type of distress is started on in the report. This will assist in compiling the distress index as well as in the assessment of important distress manifestations in the pavement from maintenance point of view since an early prevention of distress may recent subsequent failures. It is concluded that the survey form serves a useful purpose and that the survey results are useful in design, maintenance, and research.

7. **TITLE:** Continuously Reinforced Concrete Pavements in Mississippi

AUTHORS/AGENCY/COUNTRY: Teng, T.C.; Coley, J.O./Mississippi State Highway Department/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 485/1974

NUMBER OF PAGES: pp 25-38

APPLICABLE CATEGORY: Design, Construction

SUMMARY: This report covered a 5 year observation study of continuously reinforced concrete pavement construction in Mississippi. The current design and construction practice for CRC pavement is reviewed, and special items such as splices, transverse reinforcement, terminal treatments, and construction arrangement, vibration of concrete, curing of concrete, and longitudinal center joint are discussed. Field measurements on present serviceability index, crack spacing, and deflection are included and evaluated. Also included is a proposed maintenance procedure for CRC pavement.

8. **TITLE:** Evaluation of Curing Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Shober, S.F./Wisconsin Department of Transportation/ United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 504/1974

NUMBER OF PAGES: pp 51-62

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: A field evaluation of curing continuously reinforced concrete pavement with white-pigmented liquid membrane and white translucent polyethylene (paper) curing agents was made on WI-15 in Walworth and Waukesha Counties, Wisconsin. Physical properties of the concrete were investigated, and it was concluded that the curing method does not significantly affect tensile or compressive strength of the modulus of elasticity. Data show that the temperature drop experienced by the concrete during the first 24 hr was not significantly affected by the curing agent. Strain readings on the reinforcing bars indicate that the steel stress was nearly equal in paper and membrane-cured sections at a temperature of 18 °C (64 °F). Curing methods, as of 1 year of age, appear to be in the realm of transverse cracking, i.e., membrane curing allowed the pavement to crack earlier and to crack more at early ages. Both membrane and paper curing produced acceptable crack-spacing distributions when climatological conditions were favorable, although neither curing agent contributes to acceptable crack-spacing distributions during hot weather paving conditions. No cold weather paving was performed on this project.

9. **TITLE:** Evaluation of Parameters Significantly Influences the Performance of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Faiz, A.; Yoder, E.J./United States

SOURCE: American Concrete Institute

REPORT NUMBER/DATE: Roadways and Airport Pavements SP51-7/1975

NUMBER OF PAGES: pp 93-133

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The results reported in this paper were obtained from a comparative statistical analysis of properties of failed locations with good locations within test sections showing poor performance. The analysis was based on data obtained from 15 test sections showing significant distress as indicated by a breakup or a patch. Test locations in good condition had subbases with higher stability as evaluated by a static penetrometer test. Pavement failures were observed to be correlated with relatively low bulk density and modulus of elasticity of concrete. No significant difference in splitting tensile strength of concrete was indicated between good and failed locations. Relative to uniformity of concrete properties above and below the steel reinforcement, no significant difference was shown in the analysis. Higher pavement deflections, wider crack widths and non-uniform crack patterns were associated with failed pavement condition.

10. **TITLE:** Experience with Continuously Reinforced Concrete Pavements in Virginia

AUTHORS/AGENCY/COUNTRY: McGhee, K.H./Virginia Highway Research Council/ United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 485/1974

NUMBER OF PAGES: pp 14-24

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This paper reports studies of the cracking characteristics of continuously reinforced concrete pavement (CRC pavement) built in Virginia since 1988 and observations concerning the performance of this type of pavement. Early studies involved crack frequency, in slab width determinations, and laboratory examinations of cores. Later studies determined the seasonal movement of cracks and the patterns of crack development with time. It is concluded from the studies that cracking patterns tend to be fully developed in 2 to 3 years and that an early progressive increase in surface crack widths seems to stabilize after a similar period of time. The core studies showed that cracks are discontinuous in the immediate vicinity of the reinforcing steel and grow progressively wider toward the top and bottom surfaces. This finding is taken as evidence that no danger of steel corrosion exists in pavements having normal crack patterns. The performance of the Virginia CRC pavement was considered to be good. However, at least 1 project showed severe drainage related to inadequate consolidation of the paving concrete. The need for a strong effort toward the development of realistic consolidation specifications is pointed out.

11. **TITLE:** Factors Influencing the Performance of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Faiz, A.; Yoder, E.J./Purdue University/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 485/January 1974

NUMBER OF PAGES: pp 1-13

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: A statewide condition survey of continuously reinforced concrete (CRC) pavements was conducted in Indiana in 1972 to evaluate the effects of subbase and subgrade type, the methods of paving, steel placement and steel fabrication, concrete slump, and traffic on CRC pavement performance. The measures of performance were extent of failures, parallel cracks with less that 760 mm (30 in) crack spacing, random cracks, spilled cracks, and edge pumping. The results showed that subbase type, methods of steel placement and steel fabrication, concrete slump, and traffic

significantly influence CRC pavement performance. Gravel subbases showed poorer performance that crushed stone and bituminous stabilized subbases. Better performance was indicated where deformed wire fabric or loose bars were used than where tied bar mats were used. Depressed steel performed better than steel present on chairs. The data showed little difference between performance of pavements that were slip-formed and those that were side-formed. relative to good performance, an optimum range of concrete slump between 50 to 65 mm (2.0 to 2.5 in) was indicated. Distress of CRC pavements is associated with traffic. Most of the pumping was also indicated where bituminous-stabilized or crushed-stone subbasses were used.

12. **TITLE:** Performance Study of Continuously Reinforced Concrete Pavement on I-95

AUTHORS/AGENCY/COUNTRY: Kalb, M.R.; Kinney, F.S./Maryland Department of Transportation/United States

SOURCE: Maryland Department of Transportation

REPORT NUMBER/DATE: 1974

NUMBER OF PAGES:

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The study evaluated the performance of the continuously reinforced concrete pavement on I-95. Pavement observations and measurements were made on 12 construction contracts and included intensive crack surveys, measurements of width of terminal joints and expansion joints, road roughness, present serviceability index (PSI) determinations and skid resistance. This interim report presents the results of observations and measurements made during the first year of the study. Pavement design and construction details for the construction contracts are also presented.

ANNOTATED BIBLIOGRAPHY FOR 1975

1. **TITLE:** Corrosion of Steel in Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Iowa Department of Transportation/United States

SOURCE: Iowa Department of Transportation

REPORT NUMBER/DATE: July 1975

NUMBER OF PAGES 21 p

APPLICABLE CATEGORY: Performance Evaluation, Maintenance

SUMMARY: A survey is reported of the electric potential and chloride content of 14 sections of continuously reinforced concrete pavement (CRC pavement) on Interstate routes in Iowa. The projects were selected on the basis of age and the source of the aggregate

content in the concrete. Five test locations for each project were selected on the basis of age and the source of the aggregate content in the concrete. Five test locations for each project were selected; all locations were to the right of the midpoint of the right hand lane. Details of core drilling electrical potential measurements are briefly described. Concrete samples for chloride determination were obtained at two points on cracks and two points between cracks. The average electrical potential readings, the chloride content and the crack spacing are summarized in tables. The study indicates that electrical potential greater than -0.35 volt provides a high level of assurance that corrosion is active. The results of the Iowa survey do not indicate serious, wide-spread corrosion of the longitudinal reinforcement.

2. **TITLE:** A Sensitivity Analysis of Continuously Reinforced Concrete Pavement Model CRC pavement-1 For Highways

AUTHORS/AGENCY/COUNTRY: Chiang, C.; McCullough, B.F.; Hudson, W.R./Texas University/United States

SOURCE: Center for Highway Research

REPORT NUMBER/DATE: CFHR 3-8-75-177-2/1975

NUMBER OF PAGES: 132 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: The continuously reinforced concrete pavement model-1, designated as CRC pavement-1 is a mathematical model derived from field observations and laboratory observations that may be used as a design and research tool by the Highway Engineer. The theoretical model is formulated into a computer program which analyzes the behavior of continuously reinforced concrete pavements due to drying shrinkage and changes in temperature as a function of time. This report describes a sensitivity analysis performed to determine the relative effects on various design parameters in pavement behavior. In addition, an effort was also made to debug the computer user errors. It is concluded that CRC pavement-1 give generally reasonable solutions although several revisions should be made in the future.

3. **TITLE:** Evaluation of Continuously Reinforced Concrete Pavements in Indiana

AUTHORS/AGENCY/COUNTRY: Faiz, A./Purdue University/United States

SOURCE: Indiana State Highway Commission

REPORT NUMBER/DATE: JHRP-75-17/1975

NUMBER OF PAGES: 50 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The study consisted of the following sequential steps: (1) Pavement condition surveys, (2) Detailed field testing and evaluation, and (3) Laboratory testing program. A statistics analysis of the condition survey data showed that subbase type, methods of steel placement and steel fabrication, concrete slump, and age of pavement since opened to traffic were significant contributors to pavement performance. The results of the detailed field and laboratory studies showed that failures in CRC pavement are a function of a number of interacting variables. Generally higher pavement deflection, decreased pavement stiffness, wider crack widths, and erratic, non-uniform crack patterns were associated with field pavement condition. The support conditions under CRC pavement were of particular significance relative to performance. Well-compacted granular subbases with high stability and good permeability (internal drainage) showed excellent performance. Failures on CRC pavement were found to be correlated with concrete having a relatively low bulk density and modulus of elasticity. It was observed that paving concrete with a relatively higher slump (minimum of 38 mm (1.5 in) was more suited to CRC pavement with respect to good performance. An analysis of CRC pavement design revealed that use of 0.6 percent steel was, at best, marginal. There were further indications that current CRC pavement thickness design may be inadequate to withstand the traffic loads imposed on Interstate Highways. Finally, the report contains a set of construction and design guidelines that should help to improve the performance of CRC pavement in Indiana.

4. **TITLE:** Investigating the Effect of Aggregate and Steel on Cracks in a Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Strauss, P./United States

SOURCE:

REPORT NUMBER/DATE: July 1975

NUMBER OF PAGES: pp 723-730

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: An experimental continuously reinforced concrete pavement was constructed in Houston, Texas, to test various different quantities of longitudinal steel reinforcement and three performed crack spacings were included as variables. An unplanned fourth variable was introduced in the form of a difference in traffic loads on the sections. The performance of the sections is investigated by comparing crack width, crack spacing, and the structural condition of the pavements. The effect of the design variables on these performance parameters are compared.

ANNOTATED BIBLIOGRAPHY FOR 1976

1. **TITLE:** Thermal and Shrinkage Cracking in Reinforced Concrete Slabs

AUTHORS/AGENCY/COUNTRY: Bricknell, A.; Hoadley, P.J./University of Melbourne/ Australia

SOURCE: The Institution of Engineers, Australia

REPORT NUMBER/DATE: "Civil Engineering Transactions," V. CE 18. No. 1/1976

NUMBER OF PAGES: pp 24-28

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Several mechanisms have been proposed for flexural cracking in reinforced concrete. Cracking also results from restrained volume changes in concrete, and the severity and consequences of such cracking should be considered in serviceability provisions of design codes. This paper reviews the mechanisms proposed by others for crack formations (bond slip, no slip) and suggests a 'tapered bond slip' crack to reconcile their differences. A new more general formula for crack width prediction is proposed and the amount of reinforcement required for crack control is compared with the requirements of design codes. An experimental program was conducted to test the validity of the tapered bond slip crack mechanism and good agreement with the crack width prediction equation was achieved. It is concluded that provided a minimum ratio of reinforcement is included in a reinforced concrete member, thermal and shrinkage crack widths are a function of reinforcement ratio, age and strength of concrete, and development length of reinforcement. Cover to reinforcement has relatively little influence on such cracks. This is in contrast to recommendations for flexural crack control given in the current SSA Concrete Structures Code.

2. **TITLE:** Data Collection and Analysis, Runway 4R-22L, O'Hare International Airport

AUTHORS/AGENCY/COUNTRY: Treybig, H.J.; Von Quintus, H.L.; McCullough, B.F./ Austin Research Engineers Incorporated/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: WES-CR-S-76-11/September 1976

NUMBER OF PAGES: 181 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This report documents and discusses data obtained from field studies of continuously reinforced concrete (CRC) airfield pavement. It includes a discussion and analysis of deflection measurements, material properties, traffic distribution, climatological data, and the pavements physical condition, as they pertain to the design of CRC pavements and overlays. A summary of the analysis is presented which includes conclusions concerning components of the design procedure and a list of recommendations for future revisions and additions to the procedure. Every attempt was made to summarize and establish the initial behavior and performance data of Runway 4R-22L, so that it can be used in future performance studies of CRC airfield pavements.

3. **TITLE:** Design and Construction of Several Maintenance Techniques for Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Florence, R.H. Jr.,/Purdue University; Indiana State Highway Commission/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-RD-76-S0552/March 1976

NUMBER OF PAGES: 168 p

APPLICABLE CATEGORY: Design, Construction

SUMMARY: A considerable amount of CRC pavements in Indiana has shown some distress. Past research by Faiz and Yoder have delved into the causes of this distress. Nevertheless, methods to maintain the existing CRC pavements are needed. This research deals with the design and construction of several maintenance techniques for CRC pavements. A section of pavement on I-65 was stratified into "similar" sections of pavement using deflection, cracking, and breakups as the selection criteria. Observations of the construction process were made and detailed descriptions were presented. Specific conclusions cannot be made at this time as to the best type of maintenance to be used. These final conclusions must await a further evaluation period to determine the long term effects of the maintenance.

4. **TITLE:** Design of Continuously Reinforced Concrete Pavements for Highways

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Adou-Ayyash, A.; Hudson, W.R.; Randall, J.P./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: NCHRP Research Results Digest N82/January 1976

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This report summarizes the essential findings of a research study undertaken to develop an improved structural design procedure for continuously reinforced concrete pavement. A three-directional approach consisting of a theoretical study, field surveys, and a laboratory investigation was used in the research effort. The theoretical study produced a design behavioral model that solves for the state of stress and strain in CRC pavement systems resulting from drying shrinkage and temperature drop. A computer program CRC pavement-1 was developed for application of the model in pavement design. Information obtained in field performance surveys at 133 pavement locations in 14 States was used in the development of as series of regression models for use in design as an alternative to, or in conjunction with, CRC pavement-1. Water penetration was also investigated. The full study led to the proposal of a step-by-step

design process that can be given practical application once several limiting criteria that are now missing are established. The field study also produced several observations of performance that may be of assistance to future CRC pavement users.

5. **TITLE:** Design Procedure for CRC pavement Based on Laboratory and Field Observations

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.,/University of Texas/United States

SOURCE: Engineering Societies Library

REPORT NUMBER/DATE: 1976

NUMBER OF PAGES: 7 p

APPLICABLE CATEGORY: Design

SUMMARY: A continuously reinforced concrete pavement design procedure is summarized along with the necessary limiting criteria. The procedure is derived from theoretical and empirical models developed in connection with numerous field and laboratory studies. The first basic concept is to provide adequate longitudinal steel considering the specific conditions of a project to achieve a desirable crack width, crack spacing, and steel stress. These limiting criteria are shown in the report. A check is also made to limit spalling and other distress manifestations from occurring.

6. **TITLE:** A Comprehensive Pavement Evaluation System Applied to Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Yoder, E.J.; Faiz, A.; Shurig, D.G./Purdue University; Indiana State Highway Commission/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: JHRP-76-2/January 1976

NUMBER OF PAGES: pp 109-116

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This paper presents a comprehensive pavement evaluation system. In addition to the purpose of presenting the method, a secondary purpose is to demonstrate the use of the method as it was used to evaluate continuously reinforced concrete pavements (CRCP's) in Indiana. The evaluation system consists of a hierarchy of increasingly detailed pavement survey strategies - reconnaissance surveys, condition surveys, and evaluation surveys. The paper presents a summary of the results obtained at the completion of each stage of CRC pavement evaluation.

7. **TITLE:** Sixteenth Year Progress Report on Experimental Continuously Reinforced Concrete Pavement in Walker County

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Chesney, T.P./University of Texas/ United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: CFHR 3-8-75-177-6/April 1976

NUMBER OF PAGES: 57 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: This report summarizes the findings of a 16 year study on an experimental CRC pavement placed on IH-45 in Walker County, Texas. An examination of data provides numerous guidelines for the design requirements and construction specifications of future projects where CRC pavement will be used. Specifically, substantially, more failures were found with the lower percentage of reinforcing steel and higher curing temperatures. The data show Type 3 Cement gives higher steel stresses and that special attention should be given at all times to concrete consolidation.

8. **TITLE:** Continuously Reinforced Concrete Pavement Overlay of Existing Portland Cement Concrete Overlay

AUTHORS/AGENCY/COUNTRY: Stephenson, E.L./United States

SOURCE:

REPORT NUMBER/DATE: Highway Focus Vol 8 No. 2/April 1976

NUMBER OF PAGES: pp 90-93

APPLICABLE CATEGORY: Overlays

SUMMARY: The upgrading is reported of a two-lane 6.1-m (20-ft) wide (229- by 152- by 229-mm (9- by- 6- by 9-in)) thick portland cement concrete roadway to a four-lane divided section having 7.3-m (24-ft) wide roadways. The continuously reinforced concrete section provided for 35 No. 5 longitudinal bars in the 203-mm (8-in) thick sections. No. 4 transverse bars spaced at 762 mm (30) in c-c were specified. The longitudinal steel was high strength grade. The evaluation of the center of the longitudinal steel is shown as T/2 + ½ form the subgrade with tolerance of + or - 13 mm (½ in). Observations related to cracking and pumping joints are recorded. Observations lead to the opinion that overlay of concrete with continuously reinforced concrete is entirely satisfactory and practical in areas where the use of salt for snow and ice removal is low.

9. **TITLE:** Fibrous Concrete Overlay-Texas Test Section

AUTHORS/AGENCY/COUNTRY: Gay, L.H.; Hawley, J.C.; Lindsay, W.J./United States

SOURCE:

REPORT NUMBER/DATE: Highway Focus Vol 8 No. 2/April 1976

NUMBER OF PAGES: pp 66-68

APPLICABLE CATEGORY: Performance Evaluation, Overlays

SUMMARY: The inspection (in April 1974) is reported of a 6½-month old experimental fibrous concrete overlay on I-10. A set of photographs made during the inspection is presented here. The original CRC pavement which was overlaid by the fibrous concrete was not repaired prior to placing the overlay and no bond breaker was used between the two concretes. The photographs reveal transverse cracking reflected from the damaged CRC pavement underneath. The photographs also show evidence of fiber balls in the surface of the pavement.

10. **TITLE:** Highway Overlay Reinforced with Welded Wire, Steel

AUTHORS/AGENCY/COUNTRY: Better Roads/United States

SOURCE:

REPORT NUMBER/DATE: Better Roads Vol 46 No. 5/May 1976

NUMBER OF PAGES: pp 38, 41

APPLICABLE CATEGORY: Overlays

SUMMARY: A 1.6-km (1-mi) stretch of Interstate 85 near Atlanta, Georgia, was resurfaced recently in an experiment using four different types of concrete overlays, three of them continuously reinforced with steel. The experiment, along with others in various parts of the country, will help provide information on the performance of continuously reinforced concrete pavement (CRC pavement) overlays. Each experimental section of the overlay is 396 m (1,300 ft) long. Included is a section of 76-mm (3-in) thick CRC pavement reinforced with welded deformed wire fabric; 152-mm (6-in) and 114-mm (4.5-in), CRC pavement sections reinforced with bars; and a 152-mm (6-in) section of plain concrete with dowel joints.

11. **TITLE:** Longitudinal Cracking in a Continuously Reinforced Concrete Overlay in Connecticut

AUTHORS/AGENCY/COUNTRY: Bowers, D.G./Connecticut Department of Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-77-S0657/November 1976

NUMBER OF PAGES:

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The cause of longitudinal cracking that develops in the middle lane of a three-lane continuously reinforced concrete pavement was investigated. Soil borings were removed for frost-susceptibility determination. Rebound deflections were taken to ascertain amount of relative resistance to deflection offered by different base courses underlying the CRC pavement. Pavement cores were also removed through the longitudinal joint sawed between the middle and other lanes, which were place simultaneously. the latter proved beyond a doubt that insufficient depth of longitudinal cut was the primary cause for the random longitudinal cracking.

12. **TITLE:** Condition Survey of Continuously Reinforced Concrete Pavements in the North Central United States

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Treybig, H.J./University of Texas/ United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 572/1976

NUMBER OF PAGES: pp 123-137

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This paper summarizes the observations made in a survey of continuously reinforced concrete pavements in the North Central United States. This research was part of a larger effort to determine the condition of such pavements. Numerous forms of distress were observed. Data collected on the pavements include design, construction, and performance information. Their behavior is summarized in terms of crack spacing. This survey provided insight for further investigation of those problems found to be significant in nature and of those encountered more than once. Generally continuously reinforced concrete pavements are performing quite well. Results show that most crack spacings observed are less than desired. The new problem of tensile failure in longitudinal reinforcement was noted along with significant shoulder distress.

ANNOTATED BIBLIOGRAPHY FOR 1977

1. **TITLE:** Analysis of an Operational Rigid-Pavement System for Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Carmichael, R.F.; McCullough, B.F.; Hudson W.R./ Austin Research Engineers; University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 632/1977

NUMBER OF PAGES: pp 1-6

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: A diagnostic study of four, inservice, continuously reinforced concrete pavements in Texas was prepared by using computerized performance models in the rigid pavement design system. The study shows that use of performance models in the rigid-pavement design system reliably predict service life, but that the designs produced by the program, in light of the performance of the four pavement sections, are reasonable for these inservice sections. Information is also presented that begins to establish the correct level of confidence that should be used in the design of Interstate-type continuously reinforced concrete pavements.

2. **TITLE:** Continuously Reinforced Concrete Pavement: Structural Performance and Design/ Construction Variables

AUTHORS/AGENCY/COUNTRY: Strauss, P.J.; McCullough B.F.; Hudson W.R./Texas University/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: CFHR 3-8-75-177-7/May 1977

NUMBER OF PAGES: 170 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: A summarized analysis of design, construction and environmental variables that may have an effect on the structural performance of a CRC pavement is presented in this report. The variables are tied together by theoretical models where possible to allow for extrapolation outside conditions prevailing at the sites investigated. Stress is calculated in the pavement whereupon the number of load applications till failure can be determined. Since several coefficients are unknown for the structural performance of a CRC pavement, a regression analysis is used to derive the values of these equations. The final regression analysis is used to derive the values of these equations. The final equations that can be put together are employed in designing new CRC pavement and in predicting future distress on existing pavements. This study is part of an evaluation study of CRC pavement structural performance of highways in the rural districts of Texas and is based on information from two districts in Texas. A gross analysis concentrates on all the highways surveyed but excludes some of the design and construction variables that can only be obtained from construction records.

3. **TITLE:** Design and Construction of Continuously Reinforced Concrete Airport Pavements

AUTHORS/AGENCY/COUNTRY: Harvey, C.G./Waterways Experiment Station/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FAA-RD-74-37; WES-TR-S-77-11/August 1977

NUMBER OF PAGES: 92 p

APPLICABLE CATEGORY: Design, Construction

SUMMARY: This report provides design procedures for continuously reinforced concrete (CRC) airport pavements. The basic physical-mathematical model and applicable analyses are discussed. Thickness design procedures for both new CRC pavements can CRC overlays are presented for both civil and military aircraft. Methods of designing steel reinforcement, construction joints, and terminal treatment systems are included.

4. **TITLE:** Design of Terminals for Rigid Pavements to Control End Movements State of the Art

AUTHORS/AGENCY/COUNTRY: Transportation Research Board/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Board Special Report No. 173/1977

NUMBER OF PAGES: 19 p

APPLICABLE CATEGORY: Design

SUMMARY: The ends of continuously reinforced and jointed rigid pavements will experience considerable movement; if they are restrained, they will exert considerable force on the restraining mechanism. Structures or pavements that abut these pavements may be damaged unless provisions are made for their protection. There are two approaches to solving the problem. One is to accommodate the movement by providing sufficient space (joints) in which the end of the pavement may move. The other is to partially restrain the ends with some form of anchor system and to provide space to accommodate the reduced movement. Questionnaires revealed that, for CRC pavement, both procedures are used; anchor lugs may be used and are preferred slightly over wide-flange beam joints. This study has revealed no superior method of terminal treatment in terms of performance or total cost. As a consequence it is recommended that the design agencies continue to use the procedure and techniques that have been successful in the past. In addition, it is recommended that a long-term monitoring project be initiated to obtain cost and performance data for the currently used procedures in order to establish an optimum design or designs.

5. **TITLE:** Design Procedure for CRC pavement Based on Laboratory and Field Observations

AUTHORS/AGENCY/COUNTRY: McCullough, B.F./University of Texas/United States

SOURCE: Center for Highway Research

REPORT NUMBER/DATE: 1977

NUMBER OF PAGES: pp 149-156

APPLICABLE CATEGORY: Design

SUMMARY: A continuously reinforced concrete pavement design procedure is summarized along with the necessary limiting criteria. The procedure is derived from theoretical and empirical models developed in connection with numerous field and laboratory studies. The first basic concept is to provide adequate longitudinal steel considering the specific conditions of a project to achieve a desirable crack width, crack spacing, and steel stress. Theses limiting criteria are shown in the report. A check is also made to limit spalling and other distress manifestations from occurring.

6. **TITLE:** Improved Computer Programs for the Analysis of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Ma, J.; McCullough, B.F./University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-TX-78-177-9/August 1977

NUMBER OF PAGES: 174 p

APPLICABLE CATEGORY: Design

SUMMARY: CRC pavement-2 is an extension and revision of the CRC pavement-1 computer solution for the analysis of continuously reinforced concrete pavement (reported in Research Report NCHRP 1-15). It improves the proficiency and extends the capability of the original model. Small errors in CRC pavement-1 for extreme values of variables combinations, such as high-friction value and a high steel percentage, were remedied by extending the original steel stress model to cover situations where development length under the influence of high frictional resistance might exceed half the crack spacing. The stress-strength interaction model in CRC pavement-1 has been revised such that the maximum concrete strength at the time of minimum temperature is compared with the concrete strength at the time of minimum temperature occurrence, thus allowing for additional strength gain in the concrete. Wheel load and wheel-load stress are included in CRC pavement-1 as new design variables for when the combined effect of the bending stress under wheel load and the in-plane stress under environmental load are considered.

7. **TITLE:** Construction Experience with CRC Pavements in Illinois

AUTHORS/AGENCY/COUNTRY: Dhamrait, J.S.; Jacobsen, F.K.; Dierstein, P.G./Illinois Department of Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-PR-55/March 1977

NUMBER OF PAGES: 61 p

APPLICABLE CATEGORY: Construction

SUMMARY: Developing mechanical means for economically setting steel reinforcing in a continuously reinforced concrete (CRC) pavement was one objective of a study Illinois started in 1960. While constructing six experimental pavements between 1963 and 1966, one bar assembly machine and several reinforcement depressors were developed; however, slipform pavers that feed the longitudinal bars, have replaced the use of side forms and now is the most common way of placing CRC pavement in Illinois. Experience indicates that CRC pavement must be built more carefully than conventional jointed pavements; otherwise insufficient lap and gaps in reinforcement as well as unconsolidated concrete around the reinforcing steel, particular at joints, will cause early failures.

8. **TITLE:** Construction Experience with CRC Pavements in Illinois

AUTHORS/AGENCY/COUNTRY: Dhamrait, J.S.; Jacobsen, F.K.; Dierstein, P.G./United States

SOURCE: Illinois Department of Transportation

REPORT NUMBER/DATE: Phys. Res. No. 55

NUMBER OF PAGES: 56 p

APPLICABLE CATEGORY: Construction

SUMMARY: In this report, practices used in the construction of 6 experimental CRC projects in Illinois for 1963 and 1966 are presented. Early failures in these projects were associated with insufficient or no lap of steel reinforcement; unconsolidated concrete around steel reinforcement, particularly at construction joints; and improper steel positioning. Gravel or cracked stone was used in the subbase. A modulus of rupture (centerpoint loading) at 4.48 MPa (650 lbf/in^2) and 14 days was specified for the occurrence. The slump was specified to be between 19 and 38 mm (¾ and 1½ in). Slumps in excess of 38 mm (1½ in) were permitted provided additional cement was added to avoid increasing the water-cement ratio. Concrete was mixed in the paver or in a batch plant.

The reinforcements percentage was 0.6 percent deformed bars or wire fabric. Depressing the reinforcement in concrete by mechanical means or presetting the reinforcement by hand on chassis were the preferred methods used by the contractors. Polyethylene sheets were used for curing. A mist of water was sprayed before placing the sheets on hot and windy days. Membrane curing is allowed when slipform pavers are used. Reinforcement should be increased by at least 33 percent on longitudinal joints by adding 1.8 m (6 ft) bars.

Longitudinal joints were saw cut 3.2 mm (⅛ in) wide and 25 mm (1 in) deep and sealed. In bridge approaches anchor lugs were used to prevent expansive forces from buckling the pavements and damaging the bridge abatements. Three 19-mm (¾-in) performed bituminous fiber, doweled expansion joints spaced on 15.2-m (50-ft) centers were provided between the lug area and other pavement types. Five such joints were provided on bridge approaches.

9. **TITLE:** Detection of Steel Corrosion in Bridge Decks and Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Marks, V.J./Iowa Department of Transportation/ United States

SOURCE: Iowa Department of Transportation

REPORT NUMBER/DATE: Project HR-156/May 1977

NUMBER OF PAGES: 17 p

APPLICABLE CATEGORY: Performance Evaluation, Maintenance

SUMMARY: The Iowa Department of Transportation initiated this research to evaluate the reliability, benefit and application of the corrosion detection device. Through field testing prior to repair projects and inspection at the time of repair, the device was shown to be reliable. The corrosion detection device was established as a means for determining concrete removal for repair. The corrosion detection device has been used to evaluate corrosion of reinforcing steel in continuously reinforced concrete pavement.

10. **TITLE:** Developing Repair Methods for Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Halverson, A.D.; Hagen, M.G./Minnesota Department of Transportation/United States

SOURCE: Minnesota Department of Transportation

REPORT NUMBER/DATE: 1977

NUMBER OF PAGES:

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: Under Phase I, surveys were conducted to determine the amount of deterioration that has occurred on CRC pavements throughout the State. Under Phase II, Various repair and maintenance methods were tried and evaluated. These include: scarification of the upper 13 mm (½ in) and placement of a low slump concrete overlay; cathodic protection; and complete removal and replacement, reports issued: Continuously Reinforced Concrete Pavement Inventory, Phase I, 8209; Experimental Repair Methods for Continuously Reinforced Concrete Pavement, Phase II, 8505.

11. **TITLE:** Analysis of an Operational Rigid-Pavement System for Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Carmichael, R.F.; McCullough, B.F.; Hudson W.R./ Austin Research Engineering Incorporated/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 632/1977

NUMBER OF PAGES: pp 1-6

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: A diagnostic study of four, inservice continuously reinforced concrete pavements in Texas was prepared by using computerized performance models in the rigid-pavement design system. The study shows that use of performance models in the rigid-pavement design system reliably predicts the change in serviceability for continuously reinforced concrete pavements.

12. **TITLE:** Cracking in Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Havens, J.H.; Deen, R.C.; Rahal, A.S.; Azevedo, W.V./Kentucky Department of Transportation/United States

SOURCE: Kentucky Department of Transportation

REPORT NUMBER/DATE: Research Report No. 480/1977

NUMBER OF PAGES: 19 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: The objective of this study was to monitor placement and evaluate performance of continuously reinforced concrete pavement with an emphasis on determining the time of cracking and crack interval. This paper reports on the design and construction practice for CRC pavement in Kentucky. Data on crack frequency and time of cracking is also included in attempt to further explain the cracking pattern associated with CRC pavement.

13. **TITLE:** Development of Photographic Techniques for Performing Condition Surveys

AUTHORS/AGENCY/COUNTRY: Strauss, P.; Long, J.; McCullough, B.F./University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-TX-78-17710/May 1977

NUMBER OF PAGES: 29 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This objective of this study was to develop a technique for surveying heavy trafficked highways that is compatible with a visual condition survey but does not restrict the flow of traffic. Because of the need to be able to conduct a survey at a speed of at least 48 km/h (30 mi/h), the possibility of utilizing photographic techniques was investigated. Previous studies showed that only a few important distress types need to be surveyed and that sections can be selected from a construction project for a condition survey without a sacrifice in the quality of the results. It was found that a camera with a shutter speed of up to 1/2000 second and capable of taking 4 to 5 frames per second mounted on a boom in front of a vehicle so that the line through the camera lens is perpendicular to the road surface, can record a birds-eye view of the distress on film. By adjusting the vehicle speed and equipment, a survey of condition of a CRC pavement is possible. A cost study indicates that a photographic survey is more economical that a visual condition survey. Although the photographic survey is based on only a 6-percent coverage, there are the additional advantages that the mean crack spacing can be easily determined from the photographs and that visual records of the pavement condition can be obtained for future reference.

14. **TITLE:** Laboratory Study of the Effect of Nonuniform Foundation Support on Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Jimenez, E.; McCullough, B.F.; Hudson, W.R./ University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-TX-78-177-4/August 1977

NUMBER OF PAGES: 103 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: The laboratory is one of the principal means the designer has for developing relationships for pavement behavior in the field. A pre-cursory laboratory experiment concerning CSCR pavement performance was performed under NCHRP Research Project 1-15 with full supported slabs. The purpose of the experiment is to compare and observe the behavior of experimental laboratory slabs with voids beneath them of

various dimensions and to compare these slabs with uniformly supported slabs previously tested under NCHRP 1-15. A theoretical approach is included in the experiment in an effort to model all the laboratory inputs and outputs that can give solutions close to the ones obtained through the experimental physical test. At the end, both the theoretical solutions and the laboratory observations are analyzed and their accuracy is defined. Finally, observations, conclusions, and recommendations are presented in an effort to implement the study solutions within the design of CRC pavements.

15. **TITLE:** Observations of Field Performance of Continuously Reinforced Concrete Pavements In Ohio

AUTHORS/AGENCY/COUNTRY: Majidzadeh, K./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-RD-79-S0849/June 1977

NUMBER OF PAGES: 143 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report documents the fact that the Chang-Majidzadeh design criteria can be used to predict crack spacing in CRC pavement structures. The Chang-Majidzadeh model is also found to be in agreement with the NCHRP proposed design criteria. The major points of agreement are as follows: the optimum average cracking spacing in CRC pavements is 1.5 m (5 ft); crack spacings smaller than 1.5 m (5 ft) and greater than 2.4 m (8 ft) are not desirable; crack spacing is more uniform in thicker CRC pavements (229 mm (9 in)) than in the pavements (152 mm (6 in)); and depth of steel reinforcement has a significant influence on crack spacing. The results of the analysis indicate that the location of steel reinforcement below mid-depth results in excessive crack opening. This finding is in agreement with the results of field observations. Temperature variations during early curing periods, and the temperature differential during the service life affect the pavement performance.

16. **TITLE:** Report on an Experiment for Continuously Reinforced Concrete Pavement in Walker County, Texas

AUTHORS/AGENCY/COUNTRY: McCullough, B.F./University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 632/1977

NUMBER OF PAGES: pp 6-15

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report summarizes the findings from a 16-year study on the performance of a continuously reinforced concrete pavement placed on I-45 in Walker County, Texas. An examination of data provides numerous guidelines for design requirements and construction specifications of future projects of CRC pavement. Specifically, there were more failures for the pavement win which a lower percentage of reinforcing steel and higher curing temperatures were used. The data indicate that type 3 cement withstands higher steel stresses, and that special attention should be given to concrete consolidation at all times. The 7-year performance of a short section of an asphalt-concrete overlay with varying thickness indicates that the rate of failure and the deflection can be substantially reduced by increasing overlay thickness.

17. **TITLE:** Terminal Treatments for Illinois Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Dhamrait, J.S.; Taylor, R.K./Illinois Department of Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-PR-72/April 1977

NUMBER OF PAGES: 53 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: As part of an extensive study conducted to determine the significant relationship between the behavior of CRC pavement and various design features, and evaluation was made of several types of anchor lug systems and terminal joints. Movements of the ends of CRC pavements can exert damaging forces against bridge structures and adjacent conventional pavement. To prevent this type of damage some type of terminal treatment is necessary at each free end. A terminal treatment can be designated either to restrain the movement (an anchor system) or to accommodate the movement (a terminal joint system). Because the optimum number and spacing of anchor lugs for various soil conditions and subbase types were not known, the number and spacing of lugs were varied at different locations in the State, and the behavior of the various lug arrangements were compared.

ANNOTATED BIBLIOGRAPHY FOR 1978

1. **TITLE:** Controlling Shrinkage Cracking in Restrained Reinforced Concrete

AUTHORS/AGENCY/COUNTRY: G.D. Base/Department of Civil Engineering, University of Melbourne and M.H. Murray/James Cook University of North Queensland/Australia

SOURCE: Australian Road Research Board

REPORT NUMBER/DATE: Proceedings, 9th Conference of the Australian Road Research Board Volume 9 Part 4/1978

NUMBER OF PAGES: pp 167-173

APPLICABLE CATEGORY: Design

SUMMARY: This paper points out that drying shrinkage occurs in practically all reinforced concrete structures, so called shrinkage cracking is a problem only in lightly reinforced members not subjected to flexural action. The difference between flexural cracking and direct-tension cracking is discussed, the mechanisms of direct-tension cracking examined in detail and crack-prediction equations presented. Experimental comparisons between longitudinal restrained walls containing various types and amounts of conventional reinforcement are briefly presented and predictions made of the (large) reinforcement ratios required to ensure satisfactory control of direct-tension cracking. The concept of "Strategic Reinforcement" is then presented as a logical outcome of the tests with conventional reinforcement and a means of employing relatively small quantities of reinforcement to ensure a predetermined number of ('shrinkage') cracks of predictable width in restrained member such as a road pavement of long retaining wall. Experimental verification of the principle is described. Finally, shrinkage cracking in thick members and the effect of "curing' on shrinkage cracking are discussed.

2. **TITLE:** Deterioration of Continuously Reinforced Concrete Pavement in Minnesota, An Overview

AUTHORS/AGENCY/COUNTRY: Tracy, R.G./Minnesota Department of Transportation/ United States

SOURCE: Minnesota Department of Transportation

REPORT NUMBER/DATE: August 1978

NUMBER OF PAGES: 9 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: Spalling caused by corrosion of rebar mats in continuously reinforced concrete pavements was a serious problem in Minnesota. It progresses from being an isolated, minor condition and has reached a point where massive distress and surface spalling exists on heavily traveled links of Interstate highway in and around Minneapolis and St. Paul. A total of nine sections of pavement (16 mi - 4 and 6 lanes) were inspected. Nearly all sections carry heavy traffic volume. Most range from 55,000 to 115,000 VPD. As such they posed a serious problem to MN/DOT and the traveling public alike. Initial steps were being taken to investigate the problem and developed solutions were being developed to resolve it. This report was written in support of the first step.

3. **TITLE:** Continuously Reinforced Concrete Roadbase Pavements (CRCR) in the United Kingdom

AUTHORS/AGENCY/COUNTRY: Mercer, J./United Kingdom

SOURCE: Concrete Roads

REPORT NUMBER/DATE: 1978

NUMBER OF PAGES: 5 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: CRCR roadways are pavements composed of a bituminous surface course over a CRC pavement. This pavement system has been in use in England for many years. The CRCR is most often used in areas where a high potential exists for differential settlement of the pavement slab. It has also been used in urban areas. Design of CRCR pavements was initially documented in RN29 3rd Edition in which the reduction in thickness of the CRCR roadbase from the Jointed concrete pavement was a constant 25 mm (1 in). Steel bars were plain round mild steel and the bituminous concrete surfacing was a minimum of 90 mm (3.5 in) which was equivalent to 25 mm (1 in) of CRC. The design was modified for the Great Yarmouth and South Docks Road which was based on 15-percent reductions in the CRCR base that of a jointed concrete pavement and was further reduced by 20 mm (0.8 in) to allow for 100 mm (3.9 in) of bituminous concrete. Longitudinal deformed high yield steel bars were used to control crack spacing and minimize crack width. Ground beams were used to restrain thermal movements at the ends of the slab. A more rational design of CRCR pavements has been reported by Garnham in "Continuously Reinforced Concrete Pavements (CRC pavement and CRCR) development of Design Curves," Journal of Highways and Transportation, 1988.

Three new CRCR projects were planned to be constructed at the time of this article. The first is on the A42 Measham-Ashby By-Pass, Leincestershire over coal and open cast mine workings. The two others will be constructed on the M40 Birmingham - London motorway in Warwickshire.

The policy of the Department of Transport is to include a flexible rigid design for each roadway project, The contractor decides what roadway to construct based on the initial cost. CRCR pavements will now be included in these design options because of the improved design, construction and subsequent lower cost.

4. **TITLE:** Analysis of Load, Temperature, and Shrinkage Effect on Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Ma, J.; McCullough, B.F./University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 671/1978

NUMBER OF PAGES: pp 29-39

APPLICABLE CATEGORY: Design

SUMMARY: A computer program -CRC pavement-2- for the analysis of load, temperature, and shrinkage effects on a continuously reinforced concrete pavement is presented. The transverse cracking of continuous pavements is the result of the restraint of the pavement slab to dimensional changes induced by internal and external forces. The CRC pavement-2 computer program combines the stress caused by internal forces and the flexural stress under wheel load. The internal stress is determined by using the one-dimensional axial structural model that simulates the mechanistic behavior of the composite slab. The wheel-load stress can be determined either externally by slab-analysis methods or internally within the program by using the Westergaard equation for interior loading and imputing the magnitude of the wheel load. The wheel base radius, and the modulus of subgrade. A series of problems can be solved by using the CRC pavement-2 computer program. The function of steel reinforcement in continuously reinforced concrete pavement is to control crack spacing; higher steel percentage means higher restraint to the concrete, which causes more cracks to develop. The function of the slab thickness is to resist the tensile stress under wheel load; thicker slab usually means wider crack spacing. It is concluded the inclusion of both wheel load and internal forces makes it possible to predict more realistically and more accurately the actual crack spacing, the crack width and the steel stress in the pavement system and the slab thickness and the steel stress in the pavement system and the slab thickness and the steel percentage must be properly designed to (a) withstand the internal forces developed from restrained-pavement volume changes, (b) keep cracks tightly closed, and (c) avoid excessive cracking.

5. **TITLE:** Finite-Element Analysis of Jointed or Cracked Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Tabatabaie, A.M.; Barenberg, E.J./University of Illinois/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 671/1978

NUMBER OF PAGES: pp 11-19

APPLICABLE CATEGORY: Design

SUMMARY: A finite-element computer program called ILLI-SLAB and written in FORTRAN IV is described. The procedure is based on the classical theory of a medium-thick plate on a Winkler foundation and can be used for the analysis of concrete pavements that have joints or cracks or both. The program includes consideration of various types of load-transfer systems such as dowel bars, reinforcement steel, aggregate interlock, or keyways by treating the dowel bars and reinforcement steel as linear-elastic string elements and the aggregate interlock and keyways as linear-elastic spring elements. The model is also capable of handling the effects of stabilized bases or overlays on the stresses and deflections in concrete pavements and of traffic loadings on concrete shoulders that may or may not have tie bars.

6. **TITLE:** Pavement Design: Prestressed, Steel Fibrous, and Continuously Reinforced Concrete

AUTHORS/AGENCY/COUNTRY: Parker, F. Jr./Transportation Research Board/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Board Special Report No. 175/1978

NUMBER OF PAGES: pp 46-53

APPLICABLE CATEGORY: Design

SUMMARY: Three Federal Aviation Administration reports on the use of prestressed, steel fibrous, and continuously reinforced concrete for airport pavements are summarized. The technical literature describing the construction, testing, and performance of prestressed concrete was reviewed, and the design criteria that have been best validated by experimental evidence selected. A field study of a continuously reinforced concrete pavement at O'Hare International Airport in Chicago was made. This study involved evaluation of existing pavements and overlays, synthesis of data and methods for design of these pavements, formulation of design procedures and construction specification, collections of response and performance data for an actual pavement subjected to actual aircraft loadings, and finally, the development of a design procedure that can be implemented now and is compatible with Federal Aviation Administration procedures for other types of pavement.

7. **TITLE:** Joints in Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Cruickshank, J.W.; Simmons. M.J./Cement & Concrete Association of Australia/Australia

SOURCE: Australian Road Research Board

REPORT NUMBER/DATE: Proceedings from Conference of Australian Road Research Board 9th, University of Queensland/1978

NUMBER OF PAGES: pp 215-224

APPLICABLE CATEGORY: Design, Construction

SUMMARY: The magnitude of movement at joints is analyzed and methods of accommodating this movement are presented. Load transfer across joints is discussed, together with the properties of current joint sealants. Slab reinforced is essentially determined by the jointing system employed, therefore plain, reinforced and continuously reinforced concrete pavements are also considered.

8. **TITLE:** Maintenance Methods for Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Virkler, S.J./Purdue University/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-RD-78-S0776/February 1978

NUMBER OF PAGES: 150 p

APPLICABLE CATEGORY: Performance Evaluation, Maintenance

SUMMARY: In late 1974, test maintenance sections were constructed on a section of I-65 south of Indianapolis, Indiana. The road was stratified into "similar" sections of pavement using deflection cracking, and breakup as selection criteria. In each case the pavement was patched prior to the installation of the maintenance technique. Since its construction, performance surveys have been made each spring and fall using deflection measurements, crack counts and a general condition survey of the test pavements. Soil samples that were obtained during the construction were tested and the soil and subbase characteristics were evaluated. A cost analysis was performed with a time frame of 2 years and an estimated cost for a third year of maintenance of the pavements. The overlay methods exhibited good behavior over the of years of service. The subdrains and concrete shoulder methods produced less than expected performance.

9. **TITLE:** 1978 Continuously Reinforced Concrete Pavement Workshop - A Summary Report

AUTHORS/AGENCY/COUNTRY: Kinchen, R.W./Louisiana Department of Transportation and Development/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-LA-78-127/September 1978

NUMBER OF PAGES: 36 p

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: In 1977, the Federal Highway Administration sponsored a four-state study concerning value engineering analysis of repair of continuously reinforced concrete pavement. The Federal task order which initiated the study was then modified so as to provide a workshop to disseminate findings from the value engineering study and from related HER research studies. This report summarizes discussions from the workshop. The continuously reinforced concrete pavement is a sophisticated one and warrants the most up-to-date methods of design construction, evaluation and repair. The Road Maintenance Engineer can choose one or a combination of several rehabilitation methods for CRC pavement. Subdrains, concrete shoulders, undersealing, epoxy for cracks and punchouts, overlays and combinations of these features represent alternatives to continual patching and should seriously be considered in lieu thereof.

10. **TITLE:** Maintenance Methods for Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Virkler, S.J./Indiana State Highway Commission/United States

SOURCE: Purdue University School of Civil Engineering

REPORT NUMBER/DATE: JHRP-78-1

NUMBER OF PAGES: 150 p

APPLICABLE CATEGORY: Maintenance/Rehabilitation, Performance Evaluation, Overlays

SUMMARY: This report is an interim document for the final report prepared by Yoder. The performance evaluation and construction procedures are defined in greater detail. The report includes a description of performance surveys, results of performance surveys, cost analysis of each maintenance method, and conclusions evaluating each maintenance method. As in the final report, the asphalt overlay was recorded as the best method for prevention of further deterioration within the CRC pavement within the maintenance methods studied. The concrete shoulder and subdrains proved to be the least cost effective maintenance techniques studied.

11. **TITLE:** A Study of CRC pavement Performance: New Construction Vs. Overlay

AUTHORS/AGENCY/COUNTRY: Daniel, J.I.; Hudson, W.R.; McCullough, B.F./ University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: CFHR-3-8-75-177-12; FHWA-TX-177-12/April 1978

NUMBER OF PAGES: 106 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The report documents the performance of several continuously reinforced concrete pavements in Texas. Specifically, it involves a comparison of the performances of CRC pavement overlays and new CRC pavement construction for three projects: 135-2 (45)175, located in Guadalupe, County, 135-4(13)317, located in Falls and McLennan Counties, and 135W-5(44) 401, located in Johnson County. These projects were constructed by the Texas State Department of Highways and Transportation and each includes overlay and new construction built side by side. This study compares observed performances of CRC pavement overlays and new CRC pavement and reports findings and trends.

12. **TITLE:** Development of a System for the Evaluation of Pavements on Indiana

AUTHORS/AGENCY/COUNTRY: Mohan, S./Purdue University/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: JHRP-78-21; FHWA-ISHC-JHRP-78-21/October 1978

NUMBER OF PAGES: 203 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This research was initiated to set up a method of describing pavement performance in terms of measurements using the roadmeter, Dynaflect and skid tester and to set up guidelines for a methodology for an ongoing evaluation of pavement performance. Inservice pavements including flexible, overlay, jointed reinforced concrete and continuously reinforced concrete pavements were evaluated. Ninety-four test sections were evaluated for the pavement serviceability studies. Forty-six test sections were selected for deflection and skid studies. Present serviceability index (PSI) models were developed which relate PSR with roadmeter ratings alone, and other factors related to the pavement. Deflection studies have indicated that edge deflections should be used for overlay design. Various models were developed which permit estimation of spring deflections.

13. **TITLE:** Motorway Experiment with CRC pavement

AUTHORS/AGENCY/COUNTRY: Highways and Public Works/United States

SOURCE:

REPORT NUMBER/DATE: Vol. 46 No. 1823/Oct 1978

NUMBER OF PAGES: pp 7-9

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: Experimental lengths of continuously reinforced concrete pavement have been constructed on the M180 south Humberside Motorway between Sandtoft and River Trent. The depth of the slab and position of reinforcement have been varied in seven single carriageway lengths, each approximately 1.6 km (1 mi) long. It is claimed that CRC pavement gives a better joint-free riding surface and is a more durable form of pavement.

14. **TITLE:** Observations of Field Performance of Continuously Reinforced Concrete Pavements in Ohio

AUTHORS/AGENCY/COUNTRY: Majizadeh, K./Ohio Department of Transportation/ United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-RD-79-S0849/September 1978

NUMBER OF PAGES: 139 p

APPLICABLE CATEGORY: Design

SUMMARY: This report documents the fact that the Chang-Majidzadeh design criteria can be used to predict crack spacing in CRC pavement structures, The Chang-Majidzadeh model is also found to be in agreement with the NCHRP purposed design criteria. The major points of agreement are given

15. **TITLE:** Performance of Continuously Reinforced Concrete Pavement in Illinois

AUTHORS/AGENCY/COUNTRY: LaCourisere, S.A.; Darter, M.I.; Smiley, S.A./ University of Illinois/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: UIUC- Eng-77-2018/December 1978

NUMBER OF PAGES: 149 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: A study of the performance of Continuously Reinforced Concrete Pavement constructed on the Interstate Highway System in Illinois has been conducted. The major purpose is to determine the types, severities, amounts, and causes of distress. Distress found includes edge punchouts, steel ruptures, "D" cracking, blowups, construction joint failures, lug rotation, longitudinal cracking, distress related to construction problems, pumping, and shoulder deterioration. Heavy truck loads, excess free moisture, deicing salts, construction practice and poor aggregate quality in the CRC pavement slab are the major factors causing distress.

16. **TITLE:** Performance Study of Continuously Reinforced Concrete Pavement of I-95

AUTHORS/AGENCY/COUNTRY: Shah, G.N./Maryland Department of Transportation/ United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-MD-R-78-11/June 1978

NUMBER OF PAGES: 145 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The purpose of this study was to evaluate the performance of the CRC pavement on I-95. Pavement observations and measurements were made on all construction contracts and include intensive crack surveys, measurements of the widths of selected cracks, measurements of changes of width of terminal joints and expansion joints, road roughness. Present Serviceability Index (PSI) determinations, and skid resistance. This final report presents the results and observations and measurements made during the entire study. The evaluation of observations and test results has indicated that in general the I-95 pavement structure is sound and it has exhibited satisfactory performance. Also, it has been observed that the width of a crack is greatest and most noticeable at the surface.

17. **TITLE:** Continuously Reinforced Concrete Overlays on Existing Portland Cement Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Dhamrait, J.S.; Schwartz, D.R./Illinois Department of Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-PR-80/May 1978

NUMBER OF PAGES 38 p

APPLICABLE CATEGORY: Design, Construction, Overlays

SUMMARY: Five experimental sections of CRC overlay over an existing resurfaced PCC pavement on Route US 40 were constructed in 1967 as part of Interstate Route 70 construction near Pocahontas, Illinois. Three thicknesses of overlay and two separate amounts of longitudinal reinforcement were used in the experimental sections. Observations and measurements were carried out over a 10 year period to evaluate the behavior of the experimental overlays under I-80 regular mixed traffic. Changes in transverse crack width from summer to winter were small for all sections, and decreased with increasing slab thickness. Recommendations are included for design and construction of overlays relative to minimum overlay thickness, amount of longitudinal steel, use of a bituminous leveling course as a bond breaker, and tolerances for overlay thickness control during construction.

18. **TITLE:** Shift Toward Concrete Seen in Minnesota Overlay Test

AUTHORS/AGENCY/COUNTRY: Anonymous/Minnesota Department of Transportation/ United States

SOURCE: Minnesota Department of Transportation

REPORT NUMBER/DATE: Engineering New-Record V 201 No. 7/August 17, 1978

NUMBER OF PAGES: pp 26-27

APPLICABLE CATEGORY: Overlays

SUMMARY: This paper reports that the Minnesota Department of Transportation has experimented with a bonded concrete overlay on a continuously reinforced concrete pavement. A 1280-m (4,200-ft) length of I-35W, badly spalled and weakened by chloride corrosion that has attacked the steel reinforcing, is being scarified 19 mm to 25 mm (¼ to 1 in) to create a bonding surface for the 2 to 2 on non-reinforced overlay.

ANNOTATED BIBLIOGRAPHY FOR 1979

1. **TITLE:** Limiting Criteria for the Design of CRC pavement

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Ma, J.C.M.; Noble, C.S./Center for Highway Research, University of Texas/United States

SOURCE: University of Texas

REPORT NUMBER/DATE: FHWA/TX-79/21-177-17/August 1979

NUMBER OF PAGES: 79 p

APPLICABLE CATEGORY: Design

SUMMARY: The primary factors to consider in the thickness and reinforcement design for continuously reinforced concrete pavements are the structural variables; crack spacing, crack width, and maximum steel stress. They play an important role in the outcome of the pavement performance, and can be related to the major distresses common to CRC pavements. This report determines the design limiting criteria for these structural responses. Previous investigations of the design criteria were reviewed and the most recently developed analytical models studied. The basic procedures used to establish the design criteria included examination of the major distress such as punchout, spalling, and steel rupture and study of correlations between these distresses and the corresponding structural responses at appropriate levels. The procedure for use of these limiting criteria in CRC pavement design is outlined along with a series of guidelines for the selection of CRC pavement design input values.

2. **TITLE:** Nomographs for the Design of CRC pavement Steel Reinforcement

AUTHORS/AGENCY/COUNTRY: Noble, C.S.; McCullough, B.F.; Ma, J.C.M./Center for Highway Research, University of Texas/United States

SOURCE: Center for Transportation Research

REPORT NUMBER/DATE: Research Report 177-16/August 1979

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: This report presents the results of a fractional factorial study of several design inputs for CRC pavement which provide the basis for design nomographs. The factorial included such design inputs as percent of steel reinforcement and the concrete strength results are for steel stresses, crack widths, and crack spacing. Regression analysis, coefficients, and statistics are reported which are used to build the design nomographs.

3. **TITLE:** Distress Manifestations in Continuously Reinforced Concrete Pavement. Report of the Subcommittee.

AUTHORS/AGENCY/COUNTRY: Transportation Research Board/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Information Series No. 13/October 1979

NUMBER OF PAGES: 10 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: A subcommittee of the Transportation Research Board Committee on Rigid Pavement Design has investigated the distress manifestations which occur in continuously reinforced concrete pavement and has identified the most common forms of distress together with the observed causes. In response to a questionnaire, 29 of 33 States which have constructed CRC pavement listed the causes of distress. The identification of these causes together with the commonly-occurring patterns of distress will be useful to highway engineers in the future design and construction of CRC pavement. Erratic crack patterns and uniform close spacing of transverse cracks are recognized as being characteristic of continuously reinforced concrete pavement in most States. The erratic characteristic patterns of cracking in CRC pavement are produced by wide variations in temperature and moisture, materials, curing conditions, content and location of reinforcing steel, foundation support and other factors. CRC pavement appears to be highly sensitive to poor quality concrete and poor foundation conditions, and precautionary measures to ensure high quality concrete and foundation support are necessary if a satisfactory pavement structure is to be assured. Poor concrete quality and inadequate consolidation of concrete were the most commonly given causes for localized punchouts, radial cracking and distress at construction joints. The use of stabilized bases or subbases is on the increase with some States now requiring stabilized subbase for all CRC pavements.

4. **TITLE:** Final Summary Report of CRC Pavements in Illinois

AUTHORS/AGENCY/COUNTRY: Dhamrait, J.S./Illinois Department of Transportation Bureau of Materials & Physical Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-PR-084/May 1979

NUMBER OF PAGES: 20 p

APPLICABLE CATEGORY: Design

SUMMARY: Determining the economic feasibility and the behavior of continuous reinforcement in portland cement concrete (PCC) pavement and developing essential design criteria are principle objectives of the research this report summarizes. Between 1963 and 1971, experimental continuously reinforced concrete (CRC) pavement were constructed in seven highway districts to gain construction experience and to observe service behavior. Even though contractors, during early projects, developed machines for placing reinforcement, slipform paving that feeds the longitudinal bars through a series of tubes, eliminated the need for transverse bars and evolved as a common method of placing CRC pavement. Early failures revealed that CRC pavements require more careful construction procedures than conventional jointed pavements and, as the pavement aged, load failures attributed to poor drainage, greater than anticipated traffic loads, and concrete disintegration (D-cracking) became evident, particularly in the 178 mm (7 in) slabs. Information in this report also pertains to performance evaluation.

5. **TITLE:** Finite Element Analysis of Jointed or Cracked Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Tabatabaie, A.M.; Barenberg, E.J./University of Illinois/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 671/November 1979

NUMBER OF PAGES: pp 11-19

APPLICABLE CATEGORY: Design

SUMMARY: A finite-element computer program called ILLI-SLAB and written in FORTRAN IV is described. The procedure is based on the classical theory of a medium-thick plate on a Winkler foundation and can be used for the analysis of concrete pavements that have joints or cracks or both. The program can include consideration of various types of load-transfer systems such as dowel bars, reinforcement steel, aggregate interlock, or keyways by treating the dowel bars and reinforcement steel as linear-elastic string elements and the aggregate interlock and keyways as linear-elastic spring elements. The model is also capable of handling the effects of stabilized bases or overlays on the stresses and deflections in concrete pavement and of traffic loadings on concrete shoulders that may or may not have tie bars, continuously reinforced concrete pavements, and slabs of varying thickness. The accuracy of the model for the prediction of stresses and deflections in concrete pavements has been verified by comparison with available theoretical solutions and the results of experimental studies.

6. **TITLE:** Joints in Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Cruickshank, M.W./Cement and Concrete Association of Australia/Australia

SOURCE: Australian Road Research Board

REPORT NUMBER/DATE: Conference Proceedings Vol. 9 No. 4/1979

NUMBER OF PAGES: pp 215-224

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This paper was presented at Session 19 - Pavement Design 1. Increasing traffic loads and volumes, the need for low maintenance pavements and some concern about the cost and availability of bituminous materials has resulted in renewed interest in concrete roads. Significant lengths of plain, reinforced and continuously reinforced concrete roads have been built in Australia since 1970. Joints are a critical factor in concrete road performance. Poor performance of joints in some of our 3- to 50-year old pavements has resulted in doubts about the suitability of concrete for roads. The elimination of wide expansion joints, a greater appreciation of the role of the subbase, better sealant materials and improved design techniques, has led to vastly improved jointing systems. Current jointing practice is reviewed in this paper.

7. **TITLE:** Structural Distress Mechanisms in Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Darter, M.I.; LaCourisere, S.A.; Smiley, S.A./University of Illinois/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 715/1979

NUMBER OF PAGES: pp 1-7

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: A study of distress types and mechanisms in continuously reinforced concrete pavement in Illinois is reported. The major purpose of the study was to determine types and amounts of distress so that improved maintenance and design procedures could be developed. The approximately 1979 km (1230 mi) of Interstate highway surveyed consisted of 180 to 254 mm (7 to 10 in) slabs over granular and stabilized subbases. Edge punchouts, steel ruptures, D-cracking, blowups, joint failures, lug rotation, longitudinal cracking, construction-related distress, pumping, and shoulder deterioration were found. Since the edge punchout is the major structural distress, its mechanism was studied in depth. Heavy truck loads, excess free moisture, deicing salts, construction practice, and poor aggregate quality in the slab are the major causes of distress.

8. **TITLE:** Continuously Reinforced Concrete Pavement Across Clybucca Flat

AUTHORS/AGENCY/COUNTRY: Leask, A.; Penn, H.G.; Haber, E.W.; Scala, A.J./New South Wales Department of Main Roads/Australia

SOURCE: Australian Road Research Board

REPORT NUMBER/DATE: Conference Proceedings Vol. 9 No. 4/1979

NUMBER OF PAGES: pp 203-214

APPLICABLE CATEGORY: Design, Construction

SUMMARY: This paper refers to the construction of the first continuously reinforced concrete pavement (CRC pavement) on a public road in New South Wales and deals briefly with the reasons for the use of CRC pavement. It also describes the design and construction methods adopted with details of manpower and equipment used and rates of work achieved. The paper summarizes recordings obtained from surface observations.

9. **TITLE:** Detection of Voids Underneath Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Birkhoff, J.W.; McCullough, B.F./University of Texas/ United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: CFHR 3-8-75-177-18; FHWA-TX-79-24-177-18/August 1979

NUMBER OF PAGES: 57 p

APPLICABLE CATEGORY: Performance Evaluation, Maintenance

SUMMARY: The basic assumption in pavement design is that there is full support throughout the length of the pavement. When a void develops, this is not true. This report investigates three methods of detecting voids underneath continuously reinforced concrete pavements. The methods: deflection, pumping, and vibration, are evaluated to find which has the highest probability of successfully detecting voids. The deflection method is shown to be very reliable in predicting voids beneath CRC pavement and as such a detailed procedure for void detecting using this technique has been outlined. The successful detection of such voids, by the method outlined in this report, can lead to the repair and subsequent restoration of pavements in which voids have developed. In this way, expensive major rehabilitation of pavements can be prevented.

10. **TITLE:** Failure and Repair of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Anonymous/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: NCHRP, Synthesis of Highway Practice No. 60/July 1979

NUMBER OF PAGES: 48 p

APPLICABLE CATEGORY: Maintenance, Rehabilitation

SUMMARY: Detailed information is presented on maintenance and repair techniques currently used for continuously reinforced concrete pavement. Various practices are discussed, guidelines for repair techniques are included, and areas of needed research are identified.

11. **TITLE:** Roads Protected by Electricity

AUTHORS/AGENCY/COUNTRY: International Road Federation/Minnesota Department of Transportation/United States

SOURCE: Minnesota Department of Transportation

REPORT NUMBER/DATE: World Highways Vol. 30 No. 7/July 1979

NUMBER OF PAGES: 8 p

APPLICABLE CATEGORY: Maintenance

SUMMARY: Potholes and pavement damage in continuously reinforced concrete pavements are caused when the reinforcing steel corrodes. Salt, which is used to control ice on the pavement surface, seeps down to the steel and speeds up the rusting. The actual corrosion is caused when chemical reaction generates a low-powered electrical current which flows out of the steel bar at one point and enters again at another. Researchers at the Minnesota Department of Transportation have installed what they call "the world's first electrical pavement system." They provide a slightly higher current flowing through the reinforcing bar in the opposite direction to the natural corrosive current, canceling out the corrosion of the steel.

12. **TITLE:** Precast Repair of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Elkins, G.E.; McCullough, B.F.; Hudson, W.R./ University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: CTR-3-8-75-177-15; FHWA-TX-79-26-177-15/May 1979

NUMBER OF PAGES: 287 p

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: An investigation into the applicability of precast slabs for rapid repair of CRC pavement is presented. Analytical techniques are used to study loading of repair slabs due to volume change, wheel loads, and lifting, with detailed results presented in several of the appendixes. Rapid repair of CRC pavement with precast slabs appears feasible. Calculations indicate that slabs longer than 2.13 m (7 ft) have potential problems with excessive steel stress at the construction joints. These stresses can be controlled with a weakened plane, which causes the concrete to crack at mid-span, thus lowering the stresses.

13. **TITLE:** Behavior of Experimental CRC Pavements in Illinois

AUTHORS/AGENCY/COUNTRY: Dhamrait, J.S.; Taylor, R.K./Illinois Department of Transportation, Bureau of Materials & Physical Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-PR-82/March 1979

NUMBER OF PAGES: 68 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: Determining the relationships between pavement behavior and the design variables (pavement thickness, type of steel reinforcement and depth of steel reinforcement) was one main objective of a study Illinois started in 1960. The pavement behavior, expressed in terms of deflection, transverse cracking, distress, and riding quality was analyzed and correlated with the design variables. The data were collected from six experimental projects constructed throughout the State during 1963 to 1966. The investigation also includes instruments and procedures used to expand the knowledge of stress levels and ranges in the steel and concrete of CRC pavement. The findings indicate that the 178- and 203-mm (7- and 8-in) CRC slab deflected greater than the edge of the standard 254-mm (10-in) PCC pavement. The CRC slab thickness and the type of reinforcement have no effect on transverse cracking, but the depth of steel reinforcement has a major effect on transverse cracking. At the time of transverse crack development an abrupt change from compression to tension took pace in the steel reinforcements.

14. **TITLE:** Continuously Reinforced Concrete Pavement: Recent Developments in New South Wales

AUTHORS/AGENCY/COUNTRY: Donald, E.W.; Haber, E.W./New South Wales Department of Main Roads/Australia

SOURCE: The Department of Main Roads, New South Wales

REPORT NUMBER/DATE: August 1979

NUMBER OF PAGES: 8 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The Department of Main Roads, N.S.W., is engaged in its third project in CRC pavement. The first was 6 km (3.7 mi) of two-lane rural road on very poor subgrade. The other two projects are both urban dual carriageways about 3 km (1.9 mi) in length. In this paper the behavior of the pavements is compared and the observed effects of the various parameters are discussed.

15. **TITLE:** Effects of Raising Load Limits on Pavements and Bridges in Indiana

AUTHORS/AGENCY/COUNTRY: Yoder, E.; Colucci-Rios, B.B.; Fraczek, J.; Skees, J.A./Purdue University/Indiana State Highway Commission/United States

SOURCE: Indiana State Highway Commission

REPORT NUMBER/DATE: Project C-36-73H/1979

NUMBER OF PAGES: 52 p

APPLICABLE CATEGORY: Design

SUMMARY: Indiana's present weigh limits for trucks are 8200 kg (18,000 lb) on a single axle, 14500 kg (32,000 lb) on a tandem axle, 33200 kg (73,280 lb) gross vehicle weight. Many states have increased their weight limits to 9100 kg (20,000 lb) on a single axle, 15400 kg (34,000 lb) on a tandem axle, and with gross limits of 36300 kg (80,000 lb). This study was conducted to determine possible economic impacts on maintenance of Indiana highways and bridges if weight limits were to be increased in Indiana. The road life records of the Indiana State Highway Commission were searched and pavement sections were evaluated using these data coupled with truck weight information from the weight stations, soil information and performance data on file in the JHRP offices. The types of pavement evaluated included continuously reinforced concrete pavements, jointed reinforced concrete pavements, asphalt pavements, and concrete pavements overlayed with asphalt. The pavement sections were evaluated on a regional basis and climatic effects on possible increased costs were studied. In the case of bridges, the study examined the impact of increasing maximum loads considering needs for structural reinforcement, and bridge deck deterioration.

16. **TITLE:** Effect of Subbase Type and Subsurface Drainage on Behavior of CRC Pavements

AUTHORS/AGENCY/COUNTRY: Dhamrait, J.S.; Schwartz, D.R./Illinois Department of Transportation, Bureau of Materials & Physical Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-PR-083/1979

NUMBER OF PAGES: 40 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: As part of an extensive study conducted to determine the significant relationship between the behavior of CRC pavement and various design features, an evaluation was made of four types of subbases and three types and/or subbase erosion under severe climate and moisture conditions can cause severe pavement distress. To prevent or delay these types of pavement, some type of stable subbase and subsurface drainage system is necessary. The pavement behavior, expressed in terms of transverse cracking and deflections, was analyzed and correlated with the type of subbase and type of subsurface drainage system. The investigation also includes procedure used to evaluate the efficiency of the drainage systems and to expand the knowledge of the stress levels in the steel.

17. **TITLE:** Evaluation of Patching in Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Maxey, D.J.; Darter, M.I.; Smiley, S.A./University of Illinois at Urbana-Champaign/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 727/1979

NUMBER OF PAGES: pp 9-17

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: An evaluation of concrete patching in continuously reinforced concrete pavements (CRC pavement) located in Illinois was made. Problems in designing and constructing permanent concrete patches were identified; the costs of patching were estimated; and the performance of typical patches was evaluated. Illinois has constructed over 4827 m (3000 mi) of CRC pavement, major portions of which are displaying increasing occurrence of distress that requires patching. A survey of over 800 CRC pavement patches showed ¼ requiring placement and 1/5 requiring an adjoining patch.

18. **TITLE:** Failure and Repair of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Transportation Research Board/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: NCHRP Synthesis of Highway Practice No. 60/July 1979

NUMBER OF PAGES: 31 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: The performance of CRC pavement has revealed a number of failure modes that are traceable to design, construction, materials, and maintenance deficiencies and such other factors as environmental conditions and traffic loadings. This report of the Transportation Research Board includes a review of the cumulative experiences of States that have constructed and maintained CRC pavement. Guidelines for repair techniques are included, and areas of needed research are identified.

19. TITLE: Influence of Precipitation, Joints, and Sealing on Pavement Drainage

AUTHORS/AGENCY/COUNTRY: Dempsey, B.J.; Robnett, Q.L./University of Illinois/ United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 70/1979

NUMBER OF PAGES: pp 13-23

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: A study was conducted to determine the influence of precipitation, joints, and sealing on drainage of concrete pavements. Detailed drainage studies were conducted on four pavement test sections. Two jointed concrete pavement test sections were located on I-85 near Atlanta, and one continuously reinforced concrete pavement test section and one reinforced joint concrete pavement test section were located on I-57 near Champaign, Illinois. Subsurface drainage was installed on the Georgia test pavements as part of the test preparation. Subsurface drainage on the Illinois test pavements had been installed previously as part of a shoulder rehabilitation program. All drainage outflows were measured by specially designed flowmeters capable of continuously monitoring volumes.

20. TITLE: Response and Distress Models for Pavement Studies

AUTHORS/AGENCY/COUNTRY: Rauhut, B.J.; Roberts, F.L.; Kennedy, T.W./Austin Research Engineers, Incorporated/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 715/1979

NUMBER OF PAGES: pp 7-14

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Results of a detailed study to select mathematical and other models for the prediction of significant distress for flexible, composite, and rigid pavements are presented. Rigid pavements were subdivided for study into nonreinforced jointed concrete pavements (JCP), jointed reinforced concrete pavements (JRCP), and

continuously reinforced concrete pavements (CRC pavement). The models selected are to be used in establishing optimal material properties for zero-maintenance pavements. The published result of field surveys and other experience wee used to identify, for each type of pavement, distresses that cause considerable maintenance or low of serviceability. Material properties that influence the occurrence of significant distresses were then identified, and theoretical or empirical models were selected to predict these distresses by using material properties and other engineering parameters.

21. **TITLE:** Hampshire's Concrete Guinea-Pig on the Road

AUTHORS/AGENCY/COUNTRY: Acton, P./IPC Building and Contract Journals Limited/ United Kingdom

SOURCE: IPC Building and Contract Journal Limited

REPORT NUMBER/DATE: Surveyor-Public Authority Technology Vol. 154 No. 4559/ October 1979

NUMBER OF PAGES: pp 20-21

APPLICABLE CATEGORY: Performance Evaluation, Overlays

SUMMARY: A thin continuously reinforced concrete pavement was constructed on the A3 near Horndean to overlay a 1600-m (5200-ft) length of faulty concrete originally laid in 1946. Although the original construction was structurally sound, "spalling" and "stepping" at some joints led to below-standard riding quality. One-half the 9-m (30-ft) wide continuous slab was 130 mm (5.1 in) thick, the remainder being 110 mm (4.3 in) thick. The pavement reinforcement, which was placed at mid-depth was a high tensile steel welded fabric of lighter gauge and closer spacing than normally used to minimize "ripple" on the finished surface. Cross sections of longitudinal steel were approximately 0.6 percent for the 130-mm (5.1-in) thickness, and 0.7 percent for the 110-mm (4.3-in) overslab.

ANNOTATED BIBLIOGRAPHY FOR 1980

1. **TITLE:** Nomographs for the Design of Steel Reinforcement - Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Noble, C.S.; McCullough, B.F.; Ma, J.C.M./ Transportation Research Board/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 756/1980

NUMBER OF PAGES: 9 p

APPLICABLE CATEGORY: Design

SUMMARY: The objective of the study was to develop nomographs for CRC pavement design. A system design approach was used. In that, interaction between thickness, reinforcement, subbase and terminal treatment were accounted for. Program CRC pavement-2 predicts crack spacing, crack width, and steel stress. Using a factorial of input data, a set of data was obtained for crack spacing, width and steel stress (design parameters). Linear and nonlinear regressions analysis was used to develop relations between input variables and design parameters.

Crack spacing is proportional to concrete tensile strength, bar diameter, steel thermal coefficient, percentage of reinforcement, and 1/wheel load stress.

Crack width is proportional to concrete tensile strength, bar diameter 1/percentage of reinforcement and 1/wheel load stress. Linear regression equations were used in constructing the design nomographs. Data obtained using the nomographs were compared against CRC pavement-2 results. Nomograph values are within 25 percent of the computed values provided the initial and resulting parameter values fall within a practical range.

Crack spacing was identified as the most important variable affecting the behavior of the pavement. Closer crack spacing is desirable to reduce the friction of restraint between slab and subgrade and the crack width. This procedure must be used in connection with the limiting design criteria that were given in another paper by the same authors for the design of steel percentage.

2. **TITLE:** Design, Construction, and Performance of At-Grade Guideways

AUTHORS/AGENCY/COUNTRY: Mettler, A.R.; Nettles, T.A.; Joque, D.T./AB AM Engineering Inc./United States

SOURCE: AB AM Engineering, Inc.

REPORT NUMBER/DATE: Concrete International: Design and Construction, Vol. 2, No. 7

NUMBER OF PAGES: pp 47-53

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: Continuously reinforced concrete pavement provides the basis for a low-cot, low-maintenance support structure for automated transit systems where the alignment can be run at-grade. Design criteria, solutions, construction methods, and pavement performance are presented for both a rubber-tire system and a steel wheel-on-rail system. The continuously welded rails of the latter are directly fixed to the concrete pavement.

3. **TITLE:** Limiting Criteria For the Design of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Ma, J.C.M.; Noble, C.S./ University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 756/1980

NUMBER OF PAGES: pp 7-15

APPLICABLE CATEGORY: Design

SUMMARY: This paper describes the design-limiting criteria for the structural response including crack spacing, crack width, and maximum steel stress. Previous investigations of the design criteria are reviewed, and the recently developed analytical models are studied. The basic procedures used to establish design criteria include an examination of the major distresses, such as punchout, spalling, and steel rupture, and a study.

4. **TITLE:** Nomographs for the Design of Steel Reinforcement in Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Noble, C.S.; McCullough, B.F.; Ma, J./University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 756/1980

NUMBER OF PAGES: pp 15-23

APPLICABLE CATEGORY: Design

SUMMARY: Regression equations were developed for the prediction of three design parameters (crack spacing, crack width, and steel stress), and then principles of nomography were applied to these mathematical relations to prepare three corresponding nomographs. The choice of equations was made following multiple linear and nonlinear least-square fits to a fractional factorial of simulated observations.

5. **TITLE:** Proceedings of the Continuously Reinforced Concrete Pavement Workshop Held in New Orleans, Louisiana on February 15 and 16, 1978

AUTHORS/AGENCY/COUNTRY: Federal Highway Administration/United States

SOURCE: Federal Highway Administration

REPORT NUMBER/DATE: FHWA-TS-80-231/June 1980

NUMBER OF PAGES: 259 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation, Maintenance/ Rehabilitation, Overlays, Current Research

SUMMARY: This report contains papers presented during the four sessions of the Continuously Reinforced Concrete Pavement Workshop. The following papers were presented during Session I: CRC pavement Then and Now; Abstract - Past, Present, and Future Design Techniques for CRC pavement; Construction of CRC; Identifying distress and Failures in CRC pavement; and CRC pavement and the 3R Program. During Session II, the following papers were presented: A Value Engineering Analysis of Repair of CRC pavement; Rapid Patching of concrete Using Polymer Concrete; Current Continuously Reinforced Concrete Pavement Patching Method; Pavement Subdrainage Needs and Methods; Rehabilitation by Undersealing; and Concrete Shoulders for CRC Pavements. The following papers were presented during Session III: CRC pavement Rehabilitation Needs and Methods; Abstract - "Universal" Overlay Design Methodology; Bituminous Concrete Overlays on Continuously Reinforced Concrete Pavements in Texas; Bituminous Concrete Overlay of CRC Pavement: State of the Art; Crack Relief Overlay Methods for CRC pavement; and Flexible Pavement Overlays on Continuously Reinforced Concrete Pavement. Session IV consisted of the following papers: Concrete Overlays of CRC pavement and for CRC pavement; Rigid Pavement Overlay on U.S. Highway 16 in Wisconsin; Reconstruction with Continuously Reinforced Concrete Pavement in Oregon; Concrete Overlay Study in Georgia; and Closing Comments of the FHWA. The Workshop was held at the Grand Hotel, New Orleans, Louisiana, February 15 and 16, 1978. This may also apply to construction and rehabilitation.

6. **TITLE:** Cathodic Protection for Continuously Reinforced Concrete Pavement in Minnesota

AUTHORS/AGENCY/COUNTRY: Tracy, R.G./United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 762/1980

NUMBER OF PAGES: pp 17-22

APPLICABLE CATEGORY: Performance Evaluation, Maintenance

SUMMARY: The corrosion of steel in concrete can be suppressed by the use of cathodic protection, which involves applying a low-voltage direct current to the steel from a remote anode so that corrosion is transferred to the remote anode and the steel becomes a protected cathode. The results of the application of cathodic protection to continuously reinforced concrete pavement (CRC pavement) in Minnesota are presented and discussed. Several segments of CRC pavement are undergoing rapid, premature deterioration that is directly related to corrosion of the embedded mesh reinforcement.

7. **TITLE:** Maintenance Methods for Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Yoder, E.J./Purdue University/Indiana State Highway Commission/United States

SOURCE: Purdue University School of Civil Engineering

REPORT NUMBER/DATE: C-36-52K-Project-6-20-11 File No. JHRP-8-4-Rpt. FHWA/IN/JHRP-80/4-FHWA/May 14, 1980

NUMBER OF PAGES: 48 p

APPLICABLE CATEGORY: Maintenance/Rehabilitation, Performance Evaluation, Overlays

SUMMARY: Several CRC pavement maintenance methods were designed, constructed, and evaluated on a portion of I-65 south of Indianapolis. Deflections, the amount of cracking, and the amount of breakups were used as criteria for selecting maintenance strategies. A poor section of I-65 was selected for evaluation in which the following maintenance techniques were applied. The test sections were completed in the fall of 1975.

Shoulders
Concrete shoulders were placed to reduce pumping and decrease deflections. The shoulder was 229 mm (9 in) thick at the pavement edge and 152 mm (6 in) thick at the outside edge. Contraction joints were placed at 4.6-m (15-ft) intervals and the shoulder was tied to the CRC pavement with 762-mm (30-in) long No. 4 bars. Rumble strips were formed every 18.3 m (60 ft). Bituminous concrete shoulders existed in sections without this maintenance technique.

Subdrains
Subdrains were placed directly adjacent to the pavement edge and back filled to 76 mm (3 in) from the top of the pavement and then filled with AC to the pavement surface.

Undersealing
Pavements with deflections ≥ 0.02 microns (0.9 mils) were undersealed with asphalt. The undersealing was placed through 51 mm (2 in) diameter holes spaced 2.4 m (8 ft) on centers. The hole was filled with a wooden plug after the undersealing was complete.

AC Overlay
A variable thickness overlay was placed on sections to decrease deflections and prevent water from entering the pavement. The variable thicknesses were used to evaluate the prevention of reflective cracking. The AC overlay consisted of a bituminous base and an emulsion surface. The shoulder consisted of a bituminous base and a sealed shoulder.

Patching
Full-depth concrete patches were placed on all sections studied with the exception of one section which consisted of full-depth bituminous patches. The patches were initially cut 51 mm (2 in) deep at the outer limits of the patch and then cut 127 to 152 mm (5 to 6 in) deep and approximately 0.9 m (3 ft) within the outside edge of the patch. No. 5 longitudinal bars were tied to the existing tie bars and transverse bars were tied at 0.9 m (3 ft) intervals. No dowels were used. There was no discussion of the patch joints.

Performance surveys of the test sections were conducted in the fall and spring of every year after construction, up to the fall of 1978. The survey consisted of the extent of cracking, logging of failures (punchouts), and deflection testing at 7.6-m (25-ft) intervals. Visual surveys continued through 1979.

The results of the failure studies indicated that the AC overlay performed better than the other methods. A considerable amount of failures existed on either end of concrete patches and the subdrain section and concrete shoulder section did not seem to prevent the occurrence of failures in the CRC pavement.

The maintenance techniques were rated by the ability to prevent a particular distress. Each maintenance method is listed in order of the most effective to least effective in preventing further deterioration of the CRC pavement irrespective of cost:

- Asphalt overlay.
- Underseal and overlay.
- Overlay and subdrains.
- Undersealing.
- Bituminous patches.
- Subdrains.
- Concrete shoulders.

8. **TITLE:** Cracking in Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Deen, R.C.; Havens, J.H.; Rahal, A.S./American Society of Civil Engineers/United States

SOURCE: Engineering Societies Library

REPORT NUMBER/DATE: Journal of Transportation Engineering, Vol. 106 No. 2/Mar 1980

NUMBER OF PAGES: pp 155-169

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: Several theories explaining the mechanisms and intervals of cracking of portland cement concrete pavements are reviewed. For plain and jointed pavements, the cracking interval was found to be approximately twice (when expressed in feet) the strength (when expressed in lbf/in^2) of the concrete. For the new concrete with 0.2 MPa (30 lbf/in^2) tensile strength after only a few hours, the drying-shrinkage or cooling crack interval is approximately 18 m (60 ft). This is a basis for sawing joints at approximately 15-m (50-ft) intervals before the concrete is 16 hours old. For concrete with a compressive strength of 31 MPa (4,500 lbf/in^2) and sawed joints, the interval between blowups or crushed joints would be about 1.6 km (1 mi). This is the basis for spacing expansion joints approximately 0.8 to 1.6 km (0.5 to 1 mi) apart.

9. **TITLE:** Serviceable Reinforced Concrete Pavements with Long Life - A Value to the Users

AUTHORS/AGENCY/COUNTRY: Cawley, M.L./Cement and Concrete Association of Australia/Australia

SOURCE:

REPORT NUMBER/DATE: 1980

NUMBER OF PAGES: 74 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: This paper, presented for the Steel Reinforcement Promotion Group, discusses U.S. experience in the design and construction of reinforced pavements. It particularly emphasizes the history, application, and performance of continuously reinforced concrete pavements (CRC pavement) for high-volume roads with heavy truck loadings. It also discusses the use of conventionally reinforced concrete pavements for medium traffic roads with emphasis on current design practices of the States and those recommended by the Wire Reinforcement Institute.

ANNOTATED BIBLIOGRAPHY FOR 1981

1. **TITLE:** Experimental Continuously-Reinforced Portland Cement Concrete Pavement, Interstate 95, Cumberland, Maine

AUTHORS/AGENCY/COUNTRY: Wright, C.C./Maine Department of Transportation/ United States

SOURCE: Maine Department of Transportation

REPORT NUMBER/DATE: Technical Paper 81-4/May 1981

NUMBER OF PAGES: 60 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The 20 major distress manifestations which have been encountered on continuously reinforced concrete pavements built throughout the country, to date, have been described and explained either by industry consensus or the writer's theories. Maine's experiences have, in each case, been described and compared to the experiences of other States. With very few exceptions, CRC pavement distress problems yield up to reasonably simple and convincing explanations and most are correctable by the proper application of known technology applied under adequate controls. Most problems can even be economically addressed due to the fortuitous facts that good design, materials, equipment, personnel, and workmanship often combine to produce good results in the most efficient, cost-effective manner. The problems traceable to studded tire pavement wear may be an exception because the obvious solution is a political one and the only known feasible alternative (long distance

transport of very high quality, specially selected aggregates) may not be a very economical one. Similarly, problems associated with excessive vehicle loading appear insoluble as the weakness of political resolve in controlling truck weights is exceeded only by the lack of financial commitment in support of a highway program truly adequate to respond to the demands of heavy loads.

2. **TITLE:** Design of Continuously Reinforced Concrete for Highways

AUTHORS/AGENCY/COUNTRY: Cawley, M.L./Associated Reinforcing Bar Producers, Highways and Transportation Committee/United States

SOURCE: Associated Reinforcing Bar Procedures

REPORT NUMBER/DATE: Associated Reinforcing Bar Procedures, 1981

NUMBER OF PAGES: 41 p

APPLICABLE CATEGORY: Design

SUMMARY: The design procedure contained in this manual is for determining dimensions of the structural elements of a CRC pavement. It was first introduced by B.F. McCullough and M.L. Cawley at the Second International Conference on Concrete Pavement Design, held by Purdue University at Indianapolis, Indiana in 1981. This design procedure is based on theoretical analysis supplemented with field observations and materials cost considerations. Thickness design and selection of the subbase layer is based upon interaction with the concrete slab thickness requirement. The concrete slab thickness is based on pavement fatigue to a terminal level of serviceability. The longitudinal steel reinforcement design is based on theoretical and empirical findings which relate distress manifestations to design elements. Transverse steel design is based on keeping longitudinal cracks, which may form, tightly closed. General discussions of joints, terminal anchorage, and drainage considerations are presented, and tables and figures in the appendixes are presented for the design convenience in steel design.

3. **TITLE:** Summary and Recommendations for the Implementation of Rigid Pavement Design, Construction and Rehabilitation Techniques

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Hudson, W.R.; Noble, C.S./ University of Texas at Austin/Center for Transportation Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: CTR-3-8-75-177-22-F; FHWA-TX-81-2-177-22F/March 1981

NUMBER OF PAGES: 165 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: In theory, if all variables influencing the performance of a pavement structure could be correctly evaluated in all possible combinations of their magnitude, duration, and probability of occurrence, it would be possible to predict their effects upon the pavement and thus produce an ideal design. Methods previously used for the design and analysis of rigid pavements originated from concepts which were severely limited by the broad assumptions on which they were based. This report describes how these principles were used in the development of improved concrete pavement and overlay design procedures. Maintenance and rehabilitation studies were performed concurrently using information collected from condition survey and surface profile measurements. This information was analyzed in depth in the development of distress prediction models and suitable criteria for use in rehabilitation decision making. The implementation of several innovative rehabilitation techniques is also described.

4. **TITLE:** Continuously Reinforced Concrete Pavement State Standards - Design and Construction Practices of Various States

AUTHORS/AGENCY/COUNTRY: Associated Reinforcing Bar Producers/United States

SOURCE: Associate Reinforcing Bar Producers

REPORT NUMBER/DATE: 1981

NUMBER OF PAGES: 6 p

APPLICABLE CATEGORY: Design, Construction

SUMMARY: This report presents data under the following CRC pavement topics: CRC pavement Thickness-Longitudinal Steel; Method of Securing Longitudinal Splices; CRC pavement Thickness-Transverse Steel and Tiebars; Subbase Type, Width and Depth; Terminal Joints, Use of Slipform Paver and Methods of Installing Steel; and Concrete Properties and Specifications; coarse aggregate, strength, mixing, truck hauling and placing requirements.

5. **TITLE:** CRC Pavement Design Based on Theoretical and Field Performance

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Cawley, M.L./University of Texas/ United States

SOURCE: Purdue University

REPORT NUMBER/DATE: April 1981

NUMBER OF PAGES: pp 239-251

APPLICABLE CATEGORY: Design

SUMMARY: This paper includes a summary of recent developments in pavement design and construction practices which can favorably influence the performance of CRC

pavement. Emphasis will be placed on such pavement elements as the importance of specifying stabilized subbase, proper placement and arrangement of steel, vibration and consolidation of concrete, drainage practices and construction jointing details. The thickness determination chart used by AASHO has been modified to cover a range of loading conditions not previously considered, e.g., edge loading, portland cement, shoulders, etc. Also, charts for determining the k-value in terms of material erodability, thickness, and stiffness will be presented. Proceeding of the Second International Conference on Concrete Pavement Design held at Purdue University, April 14 through 16, 1981.

6. **TITLE:** Design of Experimental Concrete Carriageways on M180 (Sandtoft to Trent Section)

AUTHORS/AGENCY/COUNTRY: Gregory, J.M./England

SOURCE: Transportation and Road Research Laboratory

REPORT NUMBER/DATE: TRRL Supplementary Report N653/1981

NUMBER OF PAGES: 15 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: The design of a major full-scale experimental concrete road investigating the construction, performance and cost of continuously reinforced concrete pavements (CRC pavement) is described. The performance of seven CRC pavement sections, each approximately 1.6 km (1 mi) long, are compared with that of conventional jointed concrete pavements, both unreinforced and reinforced. The thicknesses of the CRC pavement sections are 250, 230 and 210 mm (9.8, 9.1, and 8.3 in) which are respectively 30, 50, and 70 mm (1.2, 2.0, and 2.8 in) less than the control sections.

7. **TITLE:** Design Procedure for CRC Pavement Based on Theoretical Considerations and Service Behavior

AUTHORS/AGENCY/COUNTRY: Haber, E.; Cruickshank, J./New South Wales Department of Main Roads Cement and Concrete Association/Australia

SOURCE: Purdue University

REPORT NUMBER/DATE: April 1981

NUMBER OF PAGES: pp 231-237

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This paper outlines the growth in the use of concrete pavements in Australia in recent years, with particular emphasis upon the most populous province of New South Wales. The development in the use of CRC pavement is traced and its behavior recorded, culminating in the adoption of a simplified design procedure based upon the

environmental cracking approach necessitating some assumptions pertaining to bond strength. Consideration is also given to the specification and control of CRC pavement construction, including the stipulation of an upper limit on concrete strength.

8. **TITLE:** CRC Pavement by Fixed Form Train at Stockport

AUTHORS/AGENCY/COUNTRY: Cement and Concrete Association/United Kingdom

SOURCE: Cement and Concrete Association

REPORT NUMBER/DATE: Concrete Vol 15, No. 12/December 1981

NUMBER OF PAGES: pp 20-21

APPLICABLE CATEGORY: Design, Construction

SUMMARY: This article describes the construction of single-layer continuously reinforced concrete pavement, 2.8 km (1.7 mi) long on the M63 Stockport east-west by-pass, which consists of long three-lane carriageways, using a SGME fixed form paving train. This article also reviews details of the thickness design and other mix details.

9. **TITLE:** Fixed Form Paver on CRC Pavement Project

AUTHORS/AGENCY/COUNTRY: Degerlund, C./Morgan-Grampian (Construction Press) Limited/United Kingdom

SOURCE:

REPORT NUMBER/DATE: November 1981

NUMBER OF PAGES: 17 p

APPLICABLE CATEGORY: Construction

SUMMARY: This describes construction of one of the first United Kingdom applications of CRC pavement techniques on a short section of the M63 Stockport by-pass. Designs of the CRC pavement carriageways, based on TRRL recommendations, consist of a slab thickness of 250 mm (9.8 in) with a subbase of 100 mm (3.9 in) cement-bound granular material over 80 mm (3.1 in) type 1 granular material. Reinforcement comprises 16 mm (0.6 in) steel ribbed bars at 120-mm (4.7-in) centers to provide longitudinal reinforcement with 8-mm (0.3-in) ribbed transverse wires at 200-mm (7.9-in) centers. In this application of CRC pavement the transverse reinforcement is located below the longitudinal reinforcement to eliminate any risk of a surface "ripple" effect. Laying of the concrete is carried out by a fixed-form paver used for the first time in CRC pavement construction in the United States.

10. **TITLE:** Evaluation of Maintenance/Rehabilitation Alternatives for Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Barnett, T.L.; Darter, M.I.; Laybourne, N.R./ University of Illinois/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-UI-185; UIUC-ENG-80-2011/May 1981

NUMBER OF PAGES: 152 p

APPLICABLE CATEGORY: Performance Evaluation, Maintenance

SUMMARY: An evaluation of several maintenance/rehabilitation methods for Interstate Continuously Reinforced Concrete Pavement (CRC pavement) in Illinois is reported. Due to rapidly increasing heavy truck traffic and pavement aging, development of efficient maintenance and rehabilitation methods was the focus of this research. The design, construction, performance, and costs of several maintenance and rehabilitation methods were evaluated including patching, cement grout and asphalt undersealing, epoxying of cracks, and an asphalt overlay. This information may be very useful in the development of future maintenance activities and rehabilitation projects and consequently is applicable to rehabilitation also.

11. **TITLE:** Patching of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Darter, M.I./University of Illinois/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 800/1981

NUMBER OF PAGES: pp 12-17

APPLICABLE CATEGORY: Maintenance

SUMMARY: This paper presents recommendations for the permanent repair of localized distress in continuously reinforced concrete pavements in Illinois. Recommendations for cost-effective patching are provided for selection of patch boundaries, sawing of the concrete, removal of concrete, replacing and splicing the reinforcing steel, preparing the patch area, placement of concrete and during of the patch until the area is reopened to traffic.

12. **TITLE:** Polymer Concrete for Precast Repair of Continuously Reinforced Concrete Pavement on IH 30, Near Mt. Pleasant

AUTHORS/AGENCY/COUNTRY: Meyer, A.H.; McCullough, B.F.; Fowler, D.W./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-TX-81-26-264-1/August 1981

NUMBER OF PAGES: 45 p

APPLICABLE CATEGORY: Maintenance

SUMMARY: This report describes two punchout repair techniques made in a continuously reinforced concrete pavement (CRC pavement) using precast portland cement panels. These techniques provide a rapid method of repair that produces a repair that is structurally as good or better than the surrounding pavement. With a trained crew, the repair time can be reduced and thus reduce lane closure time. Since lane closure time is a critical consideration in high volume highways, this method will be cost effective in those areas.

13. **TITLE:** Precast Repair of Continuously Reinforced Concrete Pavement, Abridgement

AUTHORS/AGENCY/COUNTRY: Elkins, G.E.; McCullough, B.F./Austin Research Engineers, Inc./University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Board No. 800/1981

NUMBER OF PAGES: 3 p

APPLICABLE CATEGORY: Maintenance

SUMMARY: This report is an abridgement of another report on precast repair techniques of CRC pavements using polymer concrete. To maintain continuity in the longitudinal reinforcement, steel connection at the ends of the repair slab were found to be a critical part of the repair technique. Calculation of volummetric change indicated the possibility of excessive steel stresses at the steel connections for longer slabs. A method of crack induction is suggested to limit steel stresses.

14. **TITLE:** Repair and Preventative Maintenance Procedures for Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Darter, M.I.; Barnett, T.L.; Morrill, D.J./University of Illinois/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-UI-191/June 1981

NUMBER OF PAGES: 86 p

APPLICABLE CATEGORY: Maintenance

SUMMARY: Procedures for permanently patching and for pressure grouting of continuously reinforced concrete pavement have been developed. These procedures have been extensively field tested to ensure their practicality and adequacy. The patching procedures reduce costs and lane closure time by considering the different distress types, different methods of construction, and concrete additive and curing for early opening.

15. TITLE: A Rigid Pavement Rehabilitation Design System

AUTHORS/AGENCY/COUNTRY: Seeds, S.B.; Hudson, W.R.; McCullough, B.F./ University of Texas/United States

SOURCE: University of Texas

REPORT NUMBER/DATE: April 1981

NUMBER OF PAGES: pp 367-376

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: This paper summarizes the development, use, and applicability of the new Texas Rigid Pavement Rehabilitation Design System, RPRDS. Like other pavement design systems, RPRDS makes use of the systems concept and incorporates a number of pavement design and analytical models into a computer program, RPRDS-1, for the generation, analysis, and comparison of numerous pavement design strategies. Unlike other design systems, RPRDS only considers structural rehabilitation, i.e., overlay construction, where the design model used is an improved and extended version of the ARE In./FHA and Texas SDHPT rigid pavement overlay design procedures, RPOD1 and RPOD2. The other design and analytical models used to complete this task include 1) a distress/maintenance prediction model, 2) a traffic delay cost (during overlay construction) model, and 3) a model for the prediction of overlay construction cost. The original study which is summarized in this paper was conducted at the Center for Transportation Research at the University of Texas at Austin as part of a cooperative research program with the Texas SDHPT.

16. TITLE: The Edens Expressway Project

AUTHORS/AGENCY/COUNTRY: McLean, C.B./Illinois Department of Transportation/ United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: FHWA-TS-80-231/1981

NUMBER OF PAGES: 4 p

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: This report details the removal of an existing pavement and its replacement with a 254-mm (10-in) continuously reinforced concrete pavement along with a supplemental drain, shoulder reconstruction, bridge redecking, replacement of the median ground rail with a concrete barrier, modification of the acceleration and deceleration lanes, and modernization of the signing, lighting and surveillance methods. This article describes how these goals were accomplished while providing a safe environment for drivers and construction workers with a minimum of public inconvenience.

17. **TITLE:** Evaluation of Longitudinal Steel in Illinois CRC Pavements

AUTHORS/AGENCY/COUNTRY: Wicks, K.W.; Dhamrait, J.S./Illinois Department of Transportation, Federal Highway Administration/United States

SOURCE: Illinois Department of Transportation

REPORT NUMBER/DATE: Phys. Res. No. 89/May 1981

NUMBER OF PAGES: 40 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: Longitudinal steel at CRC pavements keeps the natural cracks forming in this type of pavement, tightly closed, maintains the integrity of the structure for load transfer and retards water entrance into the pavement. Steel corrosion is the result of water with dissolved deicing salts or other corrosion-promoting solutes entering the pavement. This study was a followup to a 1970 study which examined the same problem.

During the study, 147 cores were removed from 122 experimental pavements constructed between 1963 and 1963, 15 cores were removed from the old Vandalia test constructed in 1948 and 1948, and 18 cores were removed from the experimental subbase CRC on U.S. 36 constructed in 1971. Overall, steel corrosion had progressed further, compared to 1970 data, but generally steel condition was rated satisfactory. No correlation was found between surface crack-width measurements and steel corrosion. Soil fines had entered the cracks in some places but no structural distress was attributed to that intrusion.

To evaluate the steel condition, the effect of the following variables was considered:

1. Transverse crack width at steel level and at the pavement surface.
2. Depth of reinforcement (51 mm (2 in), 76 mm (3 in), and at mid-depth).
3. Steel type-deformed bars and welded wire fabric.
4. Age, 13-16 years.
5. Traffic load applications 0 to 24 million ESAL.

One hundred out of the 147 cores were taken over the same crack as the 1970 cores. Subjective corrosion rating in the scale of 1 to 4 were used in both 1970 and 1979 studies. Only the highest rating was associated with reduction in cross-sectional area. Out of the eight steel specimens rated 4, four were obtained from I-57 near Champaign. The pavement was built in 1963 and opened to traffic in 1965. Due to the absence of traffic the crack spacing remained higher than expected resulting in larger crack widths. This increases steel stresses and allows easier penetration of deicing salts to the steel level thus facilitating steel corrosion.

A higher level of steel corrosion is also associated with larger crack widths at steel level. Also the crack width at the steel level increases with age. The 1970 data indicated the same potential for corrosion for all reinforcement depths. The 1979 data indicated that the amount of corrosion increases as the depth of reinforcement increase. Type of reinforcement was not found to influence steel corrosion. However, as the pavement aged, the severity of corrosion increased. Both 1970 and 1979 sets of data were inconclusive as to whether traffic levels affect steel corrosion. In 1979 greater intrusion of foreign material in the cracks was observed. D-cracking was not shown to have an effect on corrosion severity.

Stabilized bases combined with drainage systems should be built with CRC pavements. Lack of bond between concrete and steel was not determined to be a problem.

18. **TITLE:** Another First for Concrete Roads

AUTHORS/AGENCY/COUNTRY: Ridout, G./United Kingdom

SOURCE: IPC Building and Contract Journals Unlimited

REPORT NUMBER/DATE: Contract Journal, Vol 303 No. 5322/October 1981

NUMBER OF PAGES: 33 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: The first continuously reinforced concrete pavements (CRC pavement) built in the United Kingdom with fixed road forms is described. This type of construction is being tried out on the Stockport east-west bypass of the M63 motorway. Although the ground conditions were poor, CRC was chosen by the Department of Transport at this site as part of a review of alternative ways of constructing future generation of roads. The use of steel road forms with rail track for the concrete train welded onto the top face made this type of CRC pavement relatively unique.

19. **TITLE:** Evaluation of Longitudinal Steel in Illinois CRC Pavements

AUTHORS/AGENCY/COUNTRY: Wicks, K.W.; Dhamrait, J.S./Illinois Department of Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-PR-89/May 1981

NUMBER OF PAGES: 44 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: A followup investigation was made of several CRC pavements constructed within Illinois to determine the extent of corrosion occurring on the longitudinal reinforcement at transverse cracks. The effect of crack width, depth of reinforcement, slab thickness, type of reinforcement, infiltration of water and foreign matter, bond between concrete and steel, and D-cracking were studied to determine their influence on the progression of corrosion. The initial investigation was carried out during 1970. The findings indicated that steel corrosion has progressed with the passage of time (from 1970 to 1979) but, at that stage, its effect on the pavement performance is minimal and the steel does not appear to be a potential problem with pavements designed in accordance with present criteria.

20. TITLE: Evaluation of Several Maintenance Methods for Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Yoder, E.J.; Florence, R.H., Jr.; Virkler, S.J./Purdue University/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 800/1981

NUMBER OF PAGES: pp 17-26

APPLICABLE CATEGORY: Performance Evaluation, Maintenance/Rehabilitation

SUMMARY: This research pertains to the evaluation of the performance of CRC pavement in Indiana and makes recommendations relative to design and construction techniques that lead to improvement in the performance of this type of pavement. Primary factors found to contribute to performance of CRC pavement are subbase type, method of construction, and traffic. The usual method of maintaining CRC pavement has been to patch failures by using reinforced concrete. This research provides information with respect to the evaluation of other techniques for maintaining CRC pavement to determine the most cost-effective method.

21. TITLE: Manual for Condition Survey of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Taute, A.; McCullough, B.F./University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-TX-79-42-177-19/February 1981

NUMBER OF PAGES: 53 p

APPLICABLE CATEGORY: Maintenance/Rehabilitation

SUMMARY: A condition survey procedure, which has been used to survey all the rural CRC pavements in Texas, is presented in this report. The procedure involves the objective measurement of the most severe and prevalent forms of distress in CRC pavements. A further procedure for surveying jointed concrete pavement is also presented. This survey has been used to a limited extent on some Texas highways and is largely based on the experience gained from use of the CRC survey procedure.

22. **TITLE:** Summary Report for 1978 CRC Pavement Condition Survey in Texas

AUTHORS/AGENCY/COUNTRY: Gutierrez de Velasco, M.; McCullough, B.F./ University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-TX-79-44-17-20

NUMBER OF PAGES: 144 p

APPLICABLE CATEGORY: Maintenance/Rehabilitation

SUMMARY: With the objective of obtaining historical performance data for design, maintenance, and research, the Texas SDHPT initiated a series of condition surveys of CRC pavement in 1974. A followup survey was conducted in 1978. Using condition survey data for CRC pavement from 1974 and 1978 in Texas, a qualitative analysis of the distress condition of these pavements was performed as described below. (1) The primary objective was to make a summary analysis of the 1978 condition survey data and compare it with the 1974 condition survey data. The results are presented in a summary form with only minimal statistical analysis. (2) The values predicted by the computer program, CRC pavement-2, are compared to the measured crack spacing data. The results indicate that the program is a viable tool that may be used to design the reinforcement for a given set of conditions. (3) In addition, preliminary criteria have been developed for major rehabilitation. Using discriminant analysis, an equation was obtained to weigh the different distress manifestations and assign a score to each CRC pavement section.

23. **TITLE:** Concrete Comes Out on Top in Kent Overlay Trial

AUTHORS/AGENCY/COUNTRY: Ridout, G./United Kingdom

SOURCE: IPC Building & Concrete Journals, Ltd.

REPORT NUMBER/DATE: Contract Journal Vol. 303 No. 5318/September 1981

NUMBER OF PAGES: pp 20-21

APPLICABLE CATEGORY: Overlays

SUMMARY: This report reviews the construction of a 200-mm (7.9-in) thick continuously reinforced concrete pavement overlay on four, 1-km (0.6-mi) long sections over an existing flexible carriageway of the A2 Boughton and Harbledown bypasses the design used the guidelines of Road Note 29, for a 20-year life, and 6.5 million, equivalent standard axles. The unexpected growth in commercial traffic led to a rapid deterioration of the road structure after only 5 years of service. Aspects of alternate designs are presented along the details of the CRC overlay construction.

24. **TITLE:** Improvements to the Materials Characterization and Fatigue Life Prediction Methods of the Texas Rigid Pavement Overlay Design Procedure

AUTHORS/AGENCY/COUNTRY: Taute, A.; McCullough, B.F.; Hudson, W.R./ University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-TX-81-30-249-1/1981

NUMBER OF PAGES: 328 p

APPLICABLE CATEGORY: Overlays

SUMMARY: This report presents certain improvements to the Texas Rigid Pavement Overlay Procedure (RPOD2) with regard to materials characterization and fatigue life predictions. Suggestions are made for characterizing rigid pavement layers from Dynaflect deflections and material tests, and some guidelines for selecting design selections along the length of a road are presented. Finite element analysis is used to quantify the effect of pavement discontinuities on the stresses obtained from layered theory. Failure of CRC pavements is defined using condition survey data in terms of a rate of defect (punchout and patch) occurrence, and the prediction of the above fatigue equations are compared to the lives of in service CRC pavements.

25. **TITLE:** Experimental Concrete Carriageways on M180

AUTHORS/AGENCY/COUNTRY: Hunt, D.G./West Yorkshire Metropolitan County Council/United Kingdom

SOURCE: Whitehall Press Ltd.

REPORT NUMBER/DATE: Highway Engineer Vol. 28 No. 4/May 1981

NUMBER OF PAGES: pp 9-11

APPLICABLE CATEGORY: Overlays

SUMMARY: This paper describes briefly the first major experimental concrete road contract carried out in the United Kingdom in order to evaluate the design, construction, and performance of Continuously Reinforced Concrete Pavements (CRC pavement). The contract includes seven different sections of CRC pavement carriageway, each 1.6-km (1-mi) long and of varying depth and reinforcement position, together with comparative lengths of conventional jointed concrete pavement, both unreinforced and reinforced. The background to the experiment and the possible use of this form of pavement in the future are also considered.

ANNOTATED BIBLIOGRAPHY FOR 1982

1. **TITLE:** A New Look at Shrinkage Cracking

AUTHORS/AGENCY/COUNTRY: Base, G.D./University of Melbourne and Murray, M.H./Capricornica Institute of Advanced Education/Australia

SOURCE: The Institute of Engineers

REPORT NUMBER/DATE: Civil Engineering Transactions, Boston, Vol. CE 24 No. 2/ May 1982

NUMBER OF PAGES: pp 171-176

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This paper defines what is meant by shrinkage cracking and outlines the situations in which shrinkage cracking can or cannot occur. It shows that the simplistic model of shrinkage cracking suggested by most researchers to date is fundamentally in error. Whereas the simple theory predicts that shrinkage cracks continue to increase in width with increasing shrinkage, this paper shows that in fully restrained members containing more than the critical reinforcement ration the crack widths in fact rapidly approach a limiting value. On the other hand, it is shown that although the simple theory indicates that if the shrinkage strain is relatively small it is possible to limit crack widths to very small values (say 0.1 mm), in practice it is virtually impossible to limit crack widths to less than a certain, expected shrinkage strain and the reinforcement ration required to limit crack widths to a specified value is shown to be grossly misleading. Design formulas and graphs are tentatively presented and procedures, some controversial and contrary to current practice, for limiting shrinkage cracking are discussed in the light of particular examples.

2. **TITLE:** Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Pinon, R./Concrete Society Terminal House/England

SOURCE: Concrete Society Terminal House

REPORT NUMBER/DATE: 1982

NUMBER OF PAGES: 13 p

APPLICABLE CATEGORY: Design

SUMMARY: Belgium was the first country in Europe to use continuously reinforced concrete pavement techniques. The author examines the development of the technique, the criteria which determine the quantity of steel to be used, and the methods of calculating the percentage of steel reinforcement. The use of continuously reinforced concrete surfacing on motorway bridges is discussed, and mention is made of some examples of bridges under construction in Belgium. Papers presented at the International Symposium on Concrete Roads, Tara Hotel, Kensington, London, September 13 through 15, 1982.

3. **TITLE:** CRC Pavement Design Based on Theoretical and Field Performance

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Cawley, M.L./University of Texas/ United States

SOURCE: University of New Mexico

REPORT NUMBER/DATE: January 1982

NUMBER OF PAGES: 21 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: This paper summarizes recent developments in pavement design and construction practices which favorably influence the performance of Continuous Reinforced Concrete pavement. Emphasis is placed on such pavement elements as the importance of specifying stabilized subbase, proper placement and arrangement of steel, vibration and consolidation of concrete, drainage practices and construction jointing details.

4. **TITLE:** Critical Appraisal of CRC Design, Construction, and Maintenance

AUTHORS/AGENCY/COUNTRY: Ledbetter, W.B./Texas Transportation Institute/United States

SOURCE: University of New Mexico

REPORT NUMBER/DATE: January 1982

NUMBER OF PAGES: 11 p

APPLICABLE CATEGORY: Construction, Maintenance/Rehabilitation

SUMMARY: This paper examines the state of the art in CRC pavement design, construction and maintenance, emphasizing the areas where problems have arisen and raising some

critical questions about some current practices. If we would quit trying to go against the nature of concrete and learn how to work correctly within its limitations, excellent CRC pavements can be built. May apply to construction and maintenance of CRC pavement also.

5. **TITLE:** The Economics of Concrete Road Pavements in the United Kingdom

AUTHORS/AGENCY/COUNTRY: Mercer, G.; Bullett, A.W./Concrete Society Terminal House/United Kingdom

SOURCE: Whitehall Press Ltd.

REPORT NUMBER/DATE: 1982

NUMBER OF PAGES: 27 p

APPLICABLE CATEGORY: Construction, Maintenance/Rehabilitation

SUMMARY: The paper examines present United Kingdom design standards and practices for flexible and rigid pavements and compares costs of provision and costs of structural maintenance for pavements with different design life expectations constructed on soils of various CBR strengths. United Kingdom tendering practice requires contractors to submit prices for both rigid and flexible pavements when tendering for major highway contracts: the least cost form of construction meeting the design and specification requirements is accepted. Unreinforced concrete designs used since 1969 are about 12 percent cheaper than reinforced concrete and are therefore most frequently used. Dowelled joints are used throughout. A summary of total costs using constant prices and present values at a 1981 base year indicates the greater benefits of the longer life pavement design. The advantages of CRC pavement are seen to be good load-carrying characteristics, no joints to construct or maintain, suitability for use in areas subject to settlement and the ease of overlaying initially or later to add strength. The costs of CRC pavement are approximately 20 percent higher than unreinforced concrete slabs. CRC pavement is now being used for some of the most heavily trafficked roads in the United Kingdom. There is also advantage in using high-strength concrete to reduce early cracking tendencies, surface wear and joint spalling.

6. **TITLE:** Concrete Roads in Sydney

AUTHORS/AGENCY/COUNTRY: New Zealand Concrete Research Association/New Zealand

SOURCE: New Zealand Concrete Construction

REPORT NUMBER/DATE: New Zealand Concrete Construction Vol 26/December 1982

NUMBER OF PAGES: pp 18-19

APPLICABLE CATEGORY: Construction

SUMMARY: The concrete roads constructed in Sydney are used as an example of how the concrete road could become an economic proposition in New Zealand. Continuously reinforced concrete pavement (CRC pavement) is being used for motorway construction where severe traffic problems are caused by lane closures for maintenance. By using longitudinal reinforcement of up to 0.7 percent of the cross-sectional area, construction joints can be omitted. In lighter trafficked areas, where construction is on a low strength concrete subbase, contraction joints sawn on the shear at random spacing between 4 and 5 m enables both reinforcement and load transfer dowels to be omitted.

7. **TITLE:** Cathodic Protection of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Korfhage, G.R./Minnesota Department of Transportation/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 860/1982

NUMBER OF PAGES: pp 36-40

APPLICABLE CATEGORY: Maintenance

SUMMARY: Some sections of continuously reinforced concrete pavement (CRC pavement) in Minnesota are experiencing a spalling-type deterioration caused by corrosion of the reinforcing steel. In an attempt to develop a method of stopping this corrosion, a cathodic protection system was designed and installed along a 305-m (1,000-ft) section of an Interstate just north of St. Paul. This paper appeared in Transportation Research Record No. 860, Snow Control, Traffic Effects on New Concrete, and Corrosion.

8. **TITLE:** Performance and Maintenance of Continuously Reinforced Concrete Pavement in Indiana

AUTHORS/AGENCY/COUNTRY: Yoder, E.J./Purdue University/Indiana State Highway Commission/United States

SOURCE: University of New Mexico

REPORT NUMBER/DATE: Proceedings of the Nineteenth Paving Conference and Symposium on CRCP/January 1982

NUMBER OF PAGES: 14 p

APPLICABLE CATEGORY: Design, Performance Evaluation, Maintenance

SUMMARY: The evolution of the design of continuously reinforced concrete pavement in Indiana is outlined and details are given of a maintenance evaluation study. The latter consisted of a reconnaissance study, statewide condition survey, condition analysis,

evaluation surveys, evaluation of all field and laboratory work, and maintenance recommendations. A cost-effectiveness study of maintenance costs. The studies showed that maintenance must account for all factors that influence the pavement's distress.

9. **TITLE:** A Study of PCC Pavement Texturing Characteristics in Illinois

AUTHORS/AGENCY/COUNTRY: Dierstin, P.G./Illinois Department of Transportation, Bureau of Materials and Physical Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-PR-82-095/February 1982

NUMBER OF PAGES: 59 p

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: Seven textures (transverse tine, transverse broom, artificial-turf, transverse roller, artificial-turf/transverse tine combination, longitudinal tine, and longitudinal broom) formed in the plastic surface of a continuously reinforced concrete pavement. Construction observations indicated that separate machines for texturing and for applying curing compound are preferred since the timing of the two operations is sometimes incompatible. During texturing, care must be taken to avoid overlapping transverse textures, edge damage, and surface deformation caused by the pressure of the device. Friction tests indicate that grooved textures are superior to broom and artificial-turf textures, with the artificial-turf/transverse tine combination being the best. A Macrotexture Index, based on both treaded-tire and smooth-tire friction numbers, shows promise as a surrogate texture-depth indicator. The index can determine, with a high degree of certainty, whether a surface has a coarse, medium, or a fine texture. Smoothness tests verified that surface texture can influence Roughness Index values, with transverse-grooved textures being rougher than longitudinal textures. Most motorists can easily detect when they are on the transverse-roller texture, because its wider and deeper 51 mm (2 in) spaced grooves result in a humming noise like that produced by rumble strips. The transverse roller texture was eliminated as a final finish candidate because of its noise.

10. **TITLE:** Continuously Reinforced Concrete Pavement Inventory

AUTHORS/AGENCY/COUNTRY: Halverson, A.D.; Hagen, M.G./Minnesota Department of Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-MN-RD-82-05/1982

NUMBER OF PAGES: 24 p

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: A typical concrete pavement has expansion and contraction joints across and along the pavement surface. The joints allow the pavement to change in dimension with changes in temperature. A continuously reinforced concrete pavement does not have expansion or contraction joints. Random, closely spaced cracks are expected to develop naturally and allow for expansion and contraction due to temperature changes. The many random cracks eliminate expensive joint maintenance. This maintenance-free service life feature has not occurred in Minnesota. During past years, an increasing number of CRC pavement's have exhibited deterioration where pieces of concrete separate from the surface of the pavement and potholes result. This is termed spalling. A comprehensive program was initiated by MN/DOT to study this problem and develop possible solutions. This CRC pavement inventory is a physical evaluation of the extent of corrosion on random sections of pavement.

11. **TITLE:** CRC Overlay of Existing CRC pavement

AUTHORS/AGENCY/COUNTRY: Crawley, A.B./Mississippi State Highway Department, Research and Development Division/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-MSHD-RD-82-074/March 1982

NUMBER OF PAGES: 96 p

APPLICABLE CATEGORY: Overlays

SUMMARY: This report describes the design and construction of a 152-mm (6-in) thick unbonded continuously reinforced concrete (CRC) overlay of a 20-year-old continuously reinforced concrete pavement (CRC pavement) along with crack surveys for the first 9 months after construction. This is the first time a CRC overlay has been placed over an existing CRC pavement. The existing CRC pavement was an experimental project when built. It had several features being tried for the first time in Mississippi, one of which led to the need for the overlay. The CRC overlay project had several items new to Mississippi, including: (1) a new statistically oriented quality assurance specification for rigid pavements; (2) the alternative use of either Type I cement, Type IP cement, or a blend of Type I cement with fly ash; and (3) plain concrete paved shoulders. The report includes discussion of the procedures, contract award provisions, traffic control features, post construction evaluation, and some interim recommendations.

ANNOTATED BIBLIOGRAPHY FOR 1983

1. **TITLE:** Criteria for the Design, Construction and Maintenance of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: McCullough, B.F./Australian Research Board/Australia

SOURCE: Australian Road Research Board

REPORT NUMBER/DATE: Australian Road Research Vol. 13 No. 2/June 1983

NUMBER OF PAGES: pp 79-99

APPLICABLE CATEGORY: Design, Construction, Maintenance/Rehabilitation

SUMMARY: The basic objective of the paper is to provide methodologies and criteria for the design and construction of continuously reinforced concrete pavement (CRC pavement) in Australia. Based on the information presented in the paper, the following inclusions and recommendations are made. The design technology may be transferred to Australia, although the range of input variables in the design charts should be examined in terms of local conditions. The design charts are based on the critical criteria of repetitive loading, crack spacing, crack width, and steel stress developed from combining field observations and theoretical modeling. Key steps or decisions that may be made during design and construction, such as coarse aggregate construction, as indicated in the paper. The end product of using the procedures outlined should be a smooth riding pavement that will provide years of maintenance free performance.

2. **TITLE:** Use of Spectral Analysis of Surface Waves Method for Determination of Moduli and Thicknesses of Pavement Systems

AUTHORS/AGENCY/COUNTRY: Nazarian, S.; Stoke, K.H., III; Hudson, W.R./ University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 930/1983

NUMBER OF PAGES: pp 38-45

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: The spectral analysis of surface waves (SASW) method is a nondestructive method for determining moduli and thicknesses of pavement systems. Testing performed on an asphaltic concrete pavement, a continuously reinforced concrete pavement, and a natural soil occupying the SASW method are compared with those determined by means of crosshole seismic tests and Dynaflect measurement. Moduli determined by the SASW method are in agreement with those from crosshole tests, whereas moduli backcalculated from Dynaflect measurements compare rather unfavorably with moduli determined by the other two methods. This paper appeared in Transportation Research Record 930, Pavement Design, Performance, and Rehabilitation

3. **TITLE:** Detection of Cracks on Highway Pavements

AUTHORS/AGENCY/COUNTRY: Chien, C.H.; Martin, W.N.; Meyer, A.H.; Aggarwal, J.K./University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-TX-83-7-256-3/1983

NUMBER OF PAGES: 61 p

APPLICABLE CATEGORY: Performance Evaluation, Maintenance

SUMMARY: In a maintenance management program for continuously reinforced concrete pavement (CRC pavement), it is desirable to determine the rate of change of the crack spacing. When the crack spacing becomes smaller than the designed spacing there is a potential for failure and therefore preventive maintenance may be considered. Algorithms for detection of cracks of highway pavements in aerial photographs are presented in this report.

4. **TITLE:** Precast Repair of CRC Pavements

AUTHORS/AGENCY/COUNTRY: Meyer, A.H.; McCullough, B.F./University of Texas/ United States

SOURCE: Engineering Societies Library

REPORT NUMBER/DATE: Journal of Transportation Engineering, Vol. 109 No. 5/Sep 1983

NUMBER OF PAGES: pp 615-630

APPLICABLE CATEGORY: Performance Evaluation, Maintenance

SUMMARY: This report presents a summary of the results of an investigation into the design, fabrication, and installation of precast concrete panels for the repair of CRC pavements. Factors affecting the design of precast panels for CRC repairs are presented.

5. **TITLE:** Design Chart for the Design of HMAC Overlays on PCC Pavements to Prevent Reflection Cracking

AUTHORS/AGENCY/COUNTRY: Diaz, A.M.; McCullough, B.F./University of Texas, Center for Transportation Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-84/56-249-6/November 1983

NUMBER OF PAGES: 166 p

APPLICABLE CATEGORY: Maintenance/Rehabilitation

SUMMARY: The purpose of this study was to develop design procedures for Hot Mix Asphalt (HMAC) overlays on Portland Cement Concrete (PCC) pavements. Minimization of reflective cracking was a primary design objective. Overlay life was predicted using regression equations with tensile strain/stress generated in the overlay by the horizontal movements of the concrete slab at the joints or cracks as the independent variable. Simulated observations were obtained using program ARKRC-2. This study is not directly related to CRC pavements.

6. **TITLE:** Evaluation of Overlayed CRC Concrete on I-65 near Greenwood, Indiana

AUTHORS/AGENCY/COUNTRY: Sudol, J.J.; Duncan, T.L./Indiana Department of Highways/United States

SOURCE: Indiana Department of Highways

REPORT NUMBER/DATE: October 1983

NUMBER OF PAGES: 23 p

APPLICABLE CATEGORY: Maintenance/Rehabilitation, Performance Evaluation, Overlays

SUMMARY: A CRC experimental pavement was evaluated in 1975 by Purdue University and Indiana State Highways which consisted of a non-overlaid CRC pavement and a CRC pavement with 51, 76, and 127 mm (2, 3, and 5 in) of AC overlay. This study presents the findings of Dynaflect deflection testing of these pavements after 8 years of traffic loadings (1982). Pavement surface deflections were obtained for both the overlaid and the non-overlaid CRC pavements. Sections of the AC overlay (2.4 m by 2.4 m (8 ft by 8 ft)) were removed from the overlaid CRC pavements in two locations for each overlay thickness section. Dynaflect deflection testing was obtained before and after this removal to obtain the pavement response of the overlaid section and the bare CRC pavement. A 305-m (1,000-ft) section of the non-overlaid CRC pavement was tested with the Dynaflect at 15.2-m (50-ft) intervals. The results of this testing are listed below:

- All cracks in the CRC pavement found in the removal areas were tight and were visibly not as wide as in the non-overlaid pavement.
- Sensor 1 Deflection values for the removal section (0.009 microns (0.37 mils)) were lower than in the non-overlaid CRC pavement (0.012 microns (0.47 mils)). Both indicate a sound concrete pavement.
- No subsealing was required in the overlaid sections based on sensor 5 deflections.
- 18 percent of the non-overlaid section required subsealing. This section was subsealed in 1981.
- AC overlay was severely rutted. This was thought to be caused by an unstable mix and poor construction techniques.
- The overlaid pavement was entirely free of reflection cracking.

The results of the study indicate that overlaying a CRC pavement consisting of little deterioration will prolong the occurrence of further deterioration. This study was based, largely on raw deflection values. No backcalculated modulus values of the pavement structure were determined for comparison.

7. **TITLE:** Application of Thermal Imagery on CRC Pavement and Bridge Decks

AUTHORS/AGENCY/COUNTRY: Hafermann, G.R./Donohue & Associates, Inc./ Wisconsin Department of Transportation, Special Services Section/United States

SOURCE: Wisconsin Department of Transportation

REPORT NUMBER/DATE: FHWA-WI-83-1/July 1983

NUMBER OF PAGES: 33 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: A previous study determined that a van-mounted thermal scanning system provided a practical method of identifying subsurface delamination in continuously reinforced concrete pavements. A 1-year extension of that study was initiated to determine if earlier stages of delamination could be measured. The report describes the data acquisition, data analysis, problems, conclusions, and recommendations of that 1-year extension. The extended research involved scanning sections of three highway pavements and six bridge decks. Cores 102 mm (4 in) in diameter were taken at 39 locations to evaluate the accuracy of the thermographic system.

8. **TITLE:** The Effect of Coarse-Aggregate Type on CRC Pavement Thickness

AUTHORS/AGENCY/COUNTRY: Torres-Verdin, V.; McCullough, B.F.; Peck, G.B./ Texas Transportation Institute/United States

SOURCE: Federal Highway Administration

REPORT NUMBER/DATE: FHWA-TX-84-47-249-7/December 1983

NUMBER OF PAGES: 77 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The effect of coarse-aggregate type on CRC pavement performance is analyzed in this report by using laboratory data and condition survey information in conjunction with design equations and a distress-prediction model for CRC pavement. Three different approaches were followed to estimate thickness equivalencies for continuously reinforced concrete pavements constructed with the two coarse aggregates most commonly available in Texas: crushed limestone and siliceous river gravel. Condition survey information shows that, for similar conditions, limestone CRC pavements exhibit less distress than CRC pavement pavements constructed with siliceous river

gravel. A similar observation was made for thickness equivalencies obtained: i.e., less slab thickness than siliceous river gravel. Findings developed herein could be used to determine approximate equivalence thicknesses for the two aggregate types considered in this study if there is no need for a detailed analysis. Additionally, by using the recommended thickness equivalencies, the contractor could have enough information to estimate costs of construction of a CRC pavement section when he is allowed to employ either limestone or siliceous river gravel coarse aggregate. Examples for the application of equivalent thicknesses are provided in order to facilitate the implementation of the results of the various analyses carried out in this report.

9. **TITLE:** A Study of Materials to Inhibit Reflective Cracking in Asphalt Overlay Placed Over CRC Pavement

AUTHORS/AGENCY/COUNTRY: Sanders, M.R./South Carolina Department of Highways and Public Transportation/United States

SOURCE: South Carolina Department of Highways and Public Transportation

REPORT NUMBER/DATE: January 1983

NUMBER OF PAGES:

APPLICABLE CATEGORY: Overlays

SUMMARY: The objective of this study is to evaluate the effectiveness of different treatment methods in inhibiting reflective cracking in asphalt overlays placed over CRC pavements. Treatment methods include: 1) engineering fabric; 2) single bituminous surface treatment; and 3) rubber asphalt chip seal. Inspections will be made semiannually for the 10-year period to include measuring the linear m (linear ft) of reflective cracking observed in driving lanes. Calculations for the percent increase of reflective cracking for each material will be made.

10. **TITLE:** Continuously Reinforced Concrete Overlay of Existing Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Crawley, A.B.; Sheffield, J.P./Mississippi State Highway Department/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 924/1983

NUMBER OF PAGES: pp 1-9

APPLICABLE CATEGORY: Overlays

SUMMARY: The design and construction of a 152-mm (6-in) unbonded continuously reinforced concrete (CRC) overlay of a 20-year-old continuously reinforced concrete

pavement (CRC pavement) are described. This is the first time a CRC overlay has been placed over an existing CRC pavement. The existing CRC pavement was an experimental project when built and had several features that were being tried for the first time in Mississippi. One of these features, smooth wire fabric reinforcement, led to the need for the overlay. The CRC overlay project had several items new to Mississippi, including a new statistically oriented quality assurance specification for rigid pavement; the closing of one side of an Interstate highway to traffic; and plain concrete shoulders paved monolithically with CRC mainline overlay. The distress in the 20-year-old pavement, design, and construction procedures, contract and provisions, traffic control features, and post construction evaluation are discussed and some interim recommendations are presented.

11. **TITLE:** Summary and Recommendations for the Implementation of a Rigid Pavement Overlay and Design System

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Torres-Verdin, V.; Hudson, W.R./ University of Texas/United States

SOURCE: Center for Transportation Research

REPORT NUMBER/DATE: FHWA-TX-85-33-249-8F/November 1983

NUMBER OF PAGES: 148 p

APPLICABLE CATEGORY: Overlays

SUMMARY: This report briefly describes the major accomplishments of Research Study 249, which can be classified within three main areas: 1) condition surveys, 2) network level analysis, and 3) project level analysis. First, condition survey data processing is discussed. Collection and processing of data vary with type of pavement (continuously reinforced concrete pavement and jointed concrete pavement) and level of analysis (project and network). Second, the development of a scheme for prioritizing and scheduling rehabilitation of a rigid pavement network is summarized. Program PRP01 schedules rehabilitation of rigid pavements (JCP, JRCP, and CRC pavement) within a certain design period. This program requires as input data condition survey information for every project in the network being analyzed. A summary of the 1982 CRC pavement condition survey in Texas is also included in this report. Results from this statewide monitoring are compared with those corresponding to the condition surveys previously conducted.

ANNOTATED BIBLIOGRAPHY FOR 1984

1. **TITLE:** Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Gregory, J.M./United Kingdom

SOURCE: Transportation Engineering Group, Institute of Civil Engineers

REPORT NUMBER/DATE: Proc. Inst. Civil Engineers, Part 1/May 1984

NUMBER OF PAGES: pp 449-472

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report is basically a discussion on various aspects of creep. The factors examined, including temperature conditions at the time of laying, slab thickness, concrete strength and depth of reinforcement, have been shown to influence crack samplings.

2. **TITLE:** Concrete Interstate Widened and Recycled Under Traffic

AUTHORS/AGENCY/COUNTRY: Technical Publishing Corporation/United States

SOURCE: Engineering Societies Library

REPORT NUMBER/DATE: Highway and Heavy Construction, Vol. 127 No. 9/Sept 1984

NUMBER OF PAGES: pp 42-43

APPLICABLE CATEGORY: Design

SUMMARY: A 51.5-km (32-mi) length of busy, four-lane Interstate between Madison and Wisconsin Dells has undergone a massive $52-million reconstruction and widening program planned by the State's DOT. Working under traffic and an "off the road on weekends" specification, contractors constructed the largest highway reconstruction project in Wisconsin's history. The worn concrete pavement is being broken, crushed and recycled as aggregate in the new continuously reinforced concrete pavements, with all rebars being epoxy coated.

3. **TITLE:** Concrete Road Building - Designs and Techniques

AUTHORS/AGENCY/COUNTRY: Reuben, H./Donnelley Corporation/United States

SOURCE: Engineering Societies Library

REPORT NUMBER/DATE: World Construction Vol. 37. No. 6/June 1984

NUMBER OF PAGES: pp 29 and 39

APPLICABLE CATEGORY: Design

SUMMARY: A number of different designs can be used for concrete pavement on various highway systems. These include plain or unreinforced concrete with or without dowels, depending on local preference and the volume of traffic and types of subbase used under the concrete pavement. Conventionally reinforced pavements are those with a layer of distributed steel, usually prefabricated wire mesh. Dowels are used at

the joints. Joint spacing is usually two to three times that of unreinforced pavement. Finally, there is continuously reinforced concrete pavement (CRC pavement), which has no transverse joints but a large amount of reinforcing steel in the longitudinal direction.

4. **TITLE:** Proceedings of the P.C. Concrete Pavement Patching Conference for Region 5 and 7 States

AUTHORS/AGENCY/COUNTRY: Federal Highway Administration/United States

SOURCE: Federal Highway Administration

REPORT NUMBER/DATE: FHWA-TS-83-211/February 1984

NUMBER OF PAGES: 188 p

APPLICABLE CATEGORY: Maintenance

SUMMARY: The conference was attended by Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin, Iowa, Kansas, and Nebraska. Papers were presented on patching of both conventional and continuously reinforced concrete pavement. Patches should be provided with load transfer; areas to be patched should be double sawed and preferably removed by lifting; bituminous patches are frequently used when the pavement is to receive a bituminous overlay; calcium chloride is used for quick set of the PCC patch when traffic demands a short curing time; pressure relief joints are often used in conjunction with PCC patches; use forms on the outside of the patch; seal the patch joints; reinforcing not used in conventional PCC patches.

5. **TITLE:** Consolidation of Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Winn, D.P.; Olsen, M.P.J.; Ledbetter, W.B./Texas Transportation Institute/United States

SOURCE: Texas Transportation Institute

REPORT NUMBER/DATE: FHWA-TX-85-13+341/August 1984

NUMBER OF PAGES: 183 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: An extensive literature review of current consolidation practices and a laboratory investigation to determine the effects of coarse aggregate factor, maximum aggregate size, vibrator spacing, the method of vibrator mounting, and the use of superplasticizers with and without set retarders on the achieved consolidation of continuously reinforced concrete pavement (CRC pavement) were performed. Also studied were variations in consolidation throughout the depth of CRC pavement slabs and a new technique utilizing acceleration as a method of monitoring the consolidation

progress in the fresh concrete. The consolidation varies throughout the depth of concrete slabs with the greatest density existing in the bottom. For the aggregate gradations used, a maximum coarse aggregate factor of 0.80 and a maximum aggregate size of 38 mm (1½ in) yielded the best consolidation.

6. **TITLE:** Development of a Deflection Distress Index for Project-Level Evaluation of CRC Pavements, Interim Reports

AUTHORS/AGENCY/COUNTRY: Torres-Verdin, V.; McCullough, B.F./University of Texas, Center for Transportation Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-86/25+388-1/1984

NUMBER OF PAGES: 178 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report presents the development of a new parameter for project-level evaluation of continuously reinforced concrete pavements (CRC pavement). This was accomplished through the simulation of many distress manifestations commonly found in CRC pavements by means of a discrete-element computer program. The program predicts the immediate response to any selected wheel load, in terms of maximum deflection, in the presence of every distress manifestation analyzed. This maximum deflection was the CRC pavement response used to assess the severity of a given distress manifestation thus the parameter proposed for project-level evaluation of CRC pavement is designated as the Deflection Distress Index (DDI). An input guide for DDI1 is included in this report along with several application examples. A project-level condition survey manual was prepared to present definitions and descriptions of the various distress manifestations considered in the scheme for project-level evaluation of CRC pavement.

7. **TITLE:** Development of a Deflection Distress Index for Project-Level Evaluation of CRC Pavements

AUTHORS/AGENCY/COUNTRY: Torres-Verdin, V.; McCullough, B.F./University of Texas, Center for Transportation Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-86/25+388-1/October 1984

NUMBER OF PAGES: 178 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The objective of this study was to develop a scheme for project-level evaluation of CRC pavements. For this purpose, deflection data obtained using a discrete element program simulating specific distresses were used to develop a Deflection Distress Index (DDI). Also, a procedure was suggested to estimate the required sample size for project-level CRC condition surveys.

Distresses simulated included minor and severe punchout and pumping. Equations for DDI as a function of axle load repetitions were provided. Rehabilitation strategies at the project level were recommended. DDI ranges from 0 to 100 percent for terminal and ideal condition of a CRC pavement lane, respectively.

Some of the conclusions of the study are:

1. Deflections depend on both crack spacing and load transfer. Deflections increase as crack spacing is decreased and decrease as load transfer is improved.
2. Deflections on CRC pavements with rigid shoulders are lower than those with flexible shoulders.
3. The occurrence of two adjacent severe punchouts leads to high deflections in the distressed area.
4. Pumping also results in higher deflections.
5. A scheme to estimate DDI from condition survey data was developed and incorporated in computer program DDI1.

8. **TITLE:** Study of Factors Influencing Deflections of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Uddin, W.; Meyer, A.H./University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 993/1984

NUMBER OF PAGES: pp 47-54

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The results of an investigation of the effects of temperature and location variables on Dynaflect deflections measured on rigid pavements are presented. All the experimental work described in this paper was carried out during the fall and summer of 1981 on a new 254-mm (10-in) thick continuously reinforced concrete pavement near Columbus, Texas. The findings of this study are included in a procedure recommended for making Dynaflect measurements and for applying suitable temperature corrections to deflections measured near the pavement edge. This paper appeared in Transportation Research Record No. 993, Factors Affecting Pavement Performance.

ANNOTATED BIBLIOGRAPHY FOR 1985

1. **TITLE:** Cathodic Protection of a Four-lane Divided Continuously Reinforced Concrete Pavement

   AUTHORS/AGENCY/COUNTRY: Halverson, A.D.; Korfhage, G.R./Minnesota Department of Transportation/United States

   SOURCE: Transportation Research Board

   REPORT NUMBER/DATE: Transportation Research Record No. 1041/1985

   NUMBER OF PAGES: pp 16-23

   APPLICABLE CATEGORY: Design, Maintenance/Rehabilitation

   SUMMARY: The design and construction in 1982 of a second cathodic protection system for continuously reinforced concrete pavement by the Minnesota Department of Transportation is described. Corrosion of the reinforcing steel in this type of pavement has been a severe maintenance problem. An initial cathodic protection research project was successful in retarding this corrosion, so the Department contracted for the design of a second separate power source. They are (a) a trench system with the anodes placed in a trench 1.2-m (4-ft) deep by 0.3-m (1-ft) wide (b) a shallow-post-hole system with the anodes placed in augured post holes 3.7-m (12-ft) deep, and (c) a deep-post-hole system with the anodes placed in augured post holes 4.6-m (15-ft) deep. The pavement is grounded every 70.0 m (200 ft) of each roadway by attaching wire to the reinforcing steel.

2. **TITLE:** Experimental Repair Methods for Continuously Reinforced Concrete Pavement

   AUTHORS/AGENCY/COUNTRY: Hagen, M.G./Minnesota Department of Transportation, Office of Research and Development/United States

   SOURCE: Minnesota Department of Transportation, FHWA

   REPORT NUMBER/DATE: FHWA/MN/RD-85/05/August 1985

   NUMBER OF PAGES: 105 p

   APPLICABLE CATEGORY: Construction, Maintenance/Rehabilitation, Performance Evaluation, Overlays

   SUMMARY: This report documents efforts to minimize corrosion in CRC pavements in Minnesota. Surveys performed in 1976 and 1980 indicated that corrosion potential measurements were higher than the corrosion threshold of -350 millivolts. High chloride contents were recorded on all sites and evidences indicated that all the CRC pavements were in danger of premature deterioration. In 1980 an investigation of methods for stopping or at least reducing the rate of corrosion in CRC pavement was

undertaken. The methods investigated were 1) Cathodic Protection and 2) Low Slump Dense Concrete (LSDC) Overlay.

Cathodic Protection System

The test site for the cathodic protection was a 305-m (1,000-ft) long segment of CRC pavement on southbound I-35 W in Blaine, Minnesota. A survey was performed previous to the cathodic protection installation that indicated all areas where tension failures existed. The bars in these areas were spliced to restore electrical continuity. The cathodic protection system included a trench along the outside of the shoulder of the CRC pavement. Anodes were buried in the trench and back filled with conductive coke aggregate. Ground connectors were attached to the rebar steel. When energized a potential field was created between the anodes and the steel in the CRC pavement. Current flows from the anodes through the soil to the steel, which becomes the cathode of the system. Since the rebar is in a current receiving mode, stray current discharge is stopped and no corrosion will occur.

Two systems were evaluated. The first was a trench system which included anodes spaced at 15.2-m (50-ft) intervals. Conductive coke breeze aggregate was back filled with increased the effective area of the anode. The second system included post holes spaced at 15.2-m (50-ft) intervals in which anodes were placed and back filled with coke breeze aggregate. The rectifier controller (constant current rectifier) was located near the midpoint of both systems. Details as to the construction process are located in the text. Both systems were effective at partial protection from further corrosion, although the trench system was more efficient due to the lower required power level. A delamination survey of the entire roadway indicated that the area with cathodic protection exhibited smaller and fewer delaminations.

Low Slump Dense Concrete (LSDC)

Corrosion prevention and repair was also investigated with overlays. A low slump dense concrete overlay was selected for evaluation because of success with this type of rehabilitation over bridge structures. The existing pavement was scarified by shot blasting and paved with a 51- and 76-mm (2- and 3-in) LSDC overlay.

Chloride content testing was performed to record the ability of the LSDC overlay to control the chloride content. Within 2 years a considerable amount of chloride had penetrated into the upper increments of the LSDC overlay. The level had exceeded the corrosion threshold range after 5 years of service. Corrosion testing indicated that the LSDC overlay did not have a profound effect on halting corrosion, although it does delay the occurrence of delamination.

Costs for the cathodic protection and the LSDC overlay are located in the appendix.

3. **TITLE:** Joints in Concrete Roads: Aspects of Construction and Performance. Report of a Concrete Society Working Party

AUTHORS/AGENCY/COUNTRY: Carroll, L.J.; Grey, J.W.; Law, K.E./Concrete Society/England

SOURCE: Concrete Society, Devon, England

REPORT NUMBER/DATE: Report No. 28/1985

NUMBER OF PAGES: 24 p

APPLICABLE CATEGORY: Design

SUMMARY: The report deals with the main types of joints in concrete roads (contraction joints, expansion joints, longitudinal joints and transversal construction joints) and the problems associated with them. It also includes discussion on CRC pavements in the context of United Kingdom and international experience.

4. **TITLE:** Evaluation of Continuously Reinforced Concrete Overlays and Repairs on Interstate Route 90, Erie County, Pennsylvania

AUTHORS/AGENCY/COUNTRY: Turgeon, R.; Ishman, K.D./Pennsylvania Department of Transportation/United States

SOURCE: Pennsylvania Department of Transportation and USDOT FHWA

REPORT NUMBER/DATE: RP 79-1/November 1985

NUMBER OF PAGES: 256 p

APPLICABLE CATEGORY: Maintenance/Rehabilitation, Performance Evaluation, Overlays

SUMMARY: Interstate 90 in Pennsylvania is a 254-mm (10-in) jointed reinforced concrete pavement. In 1974 and 1976 this pavement was overlaid with 178 mm (7 in) of CRC pavement over a 25-mm (1-in) bond breaker (sand asphalt) leveling course. The performance of repair techniques for this overlay is documented in this report.

Repair methods were selected based on the performance of previous patch and repair methods. Construction repair techniques included epoxy mortar and polymer resin materials (type I), rapid set concrete materials (type II), full-scale concrete repairs using high early strength concrete (type III). The full-scale concrete repairs varied in geometries and steel percentages.

Type I repairs only involved removing loose, broken concrete materials and replacing with epoxy material. Two epoxy mix materials were used. The first, Colma-Dur LV (Sikastix 36, $85 per repair cost) performed well. The second, Sika-Dur Lo-Mod LV (Sikastix 320) performed poorly with severe surface scaling.

Type II repairs included removal of broken, loose concrete down to the original jointed concrete pavement. The CRC steel was left in place and a polyethylene sheet was placed as a bond breaker. Seven different mixes were used for repair in which all performed poorly. The mixes used were Set 45, Bostik 276, Hora 240, Tigercrete, Quickdeck Polymer Resin, HES cement concrete with 2 percent calcium chloride, and HES cement concrete. The magnesium-phosphate mortars and polymers which have compressive, flexural, and bond strength performed considerably worse as compared to

the weaker HES cement concrete. It was thought that the rapid set materials would set between batch placements resulting in cold joints and creating planes of weakness.

Type III repairs extended the full width and depth of the overlay and original pavement. HES cement concrete was used for all Type III repairs. The overall success rate of the Type III patches by 1982 was 63 percent.

Nondestructive deflection testing was conducted on the CRC overlay in 1977. Benkleman Beam and Roadrater deflection measuring equipment were used. These values were used to determine areas in need of structural repair.

Crack survey of the CRC overlay were conducted on four occasions. The first survey indicated the largest amount of cracking as would be expected with CRC pavements.

Aerial photographs were taken in 1971 and 1977 (pre-overlay and post-overlay). These were used to evaluate the crack patterns of both the original concrete pavement and the CRC overlay. Pressure grouting with cement was performed in areas of weak subgrade or underlying voids.

5. **TITLE:** Construction and Performance of an Experimental Thin-Bonded Concrete Overlay Pavement in Houston

AUTHORS/AGENCY/COUNTRY: Bagate, M.; McCullough, B.F.; Fowler, D./United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1040/1985

NUMBER OF PAGES: pp 25-33

APPLICABLE CATEGORY: Performance Evaluation, Overlays

SUMMARY: During the summer of 1983, an experimental 305 m (1,000 ft) of thin-bonded concrete overlay pavement was placed on Interstate 610 (Loop 610), a four-lane divided freeway in Houston, Texas. The original pavement structure is a continuously reinforced concrete pavement. Five design sections were constructed. Concrete reinforcement and overlay thickness were used at three and two levels, respectively. The experimental design is discussed, along with project specifications, and a measurement program. Actual construction is present and salient features outlined.

6. **TITLE:** Continuously Reinforced Concrete Pavements (Discussion)

AUTHORS/AGENCY/COUNTRY: Gregory, J.M./Transport and Road Research Laboratory/United Kingdom

SOURCE: Institution of Civil Engineers

REPORT NUMBER/DATE: Proceedings, Part 1 Vol 78/August 1985

NUMBER OF PAGES: pp 1009-1015

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: The article presents a brief discussion on a number of aspects concerning the construction and durability of continuously reinforced concrete pavement (CRC pavement) in the United Kingdom. The discussion includes such aspects as the performance and crack spacing of CRC pavement, the corrosion of steel reinforcements, its use on motorways and airfield runways, and the effects of construction quality and workmanship on durability.

7. **TITLE:** Evaluation of Continuously Reinforced Concrete Overlay and Repairs on Interstate Route 90, Erie County, Pennsylvania - Final Report

AUTHORS/AGENCY/COUNTRY: Turgeon, R.; Ishman, K.D./Pennsylvania Department of Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-PA-85-007/1985

NUMBER OF PAGES: 256 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report covers the construction and maintenance of a CRC pavement over an RCC pavement in Erie County, Pennsylvania. Various investigation techniques, studies of maintenance materials and performance of these materials are reported. Failures of the overlay are investigated and patching techniques are tested and evaluated. Deflection equipment performance, crack evolution and decision processes are discussed and evaluated. Maintenance contracts and repair costs are presented with reference to previous construction activities and decisions. This report also pertains to pavement maintenance.

8. **TITLE:** Field Study on Consolidation of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Olsen, M.P.J./Texas Transportation Institute/United States

SOURCE: Texas Transportation Institute

REPORT NUMBER/DATE: August 1985

NUMBER OF PAGES:

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: This study investigated the influence of vibrator spacing, orientation and elevation on the consolidation achieved in continuously reinforced concrete pavements. The investigation was based on a series of 30.5-m (100-ft) minimum test sections included in a Texas construction project. The study also included evaluation of the recently developed vibrator monitoring system (VMS).

9. **TITLE:** Condition Surveys and Pavement Evaluation of Existing and Overlaid Rigid Pavements

AUTHORS/AGENCY/COUNTRY: Saraf, C.L.; McCullough, B.F.; Hudson, W.R./ University of Texas, Center for Transportation Research/United States

SOURCE: Texas Department of Transportation - FHWA

REPORT NUMBER/DATE: 388-SF FHWA/TX-86/35+388-SF/November 1985

NUMBER OF PAGES:

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: Condition surveys have been collected in Texas in 1974, 1978, 1980, 1982 and 1984 of all the rigid pavements in the State. The survey method and evaluation has been improved many times over these years. The combination of distress types and severity levels are represented by a single index termed the "Distress Index." This value ranges from 0 to 1 or 0 to 100 and is defined here for CRC pavements:

$$DI = 1.0 - 0.065FF - 0.009SS$$

where DI = Distress Index, FF = number of failures per mi, and SS = percentages of cracks with sever spalling.

The pavements within the State system are prioritized with the equation:

$$PI = 13.5 - 0.4(\text{Rainfall, in}) - 0.23(\text{Freeze-thaw cycle/year}) - 0.71x10^{-3}(ADT) + 12.9PSI + 0.43DI$$

The condition surveys were collected every 0.6 km (0.4 mi) by two people riding in a van at 24 km/h (15 mi/h). The distresses were keyed in a computer for direct storage of data on diskette. The program for data input is titled "Quickspur." The details of the condition survey method are presented in research report 388-3.

Some of the major conclusions of the report follow: 1) providing for adequate training greatly reduces personal judgement errors in recording pavement distresses; 2) visual identification of distresses are less reliable at 24 km/h (15 mi/h) (compared with 3.2 to 8.0 km/h (2 to 5 mi/h)); 3) transverse crack spacing can be increased by preforming cracks; 4) lightweight aggregates in pavements resulted in less transverse cracking than standard aggregate pavements but did not maintain their structural quality better in the long term.

10. **TITLE:** The Falling Weight Deflectometer for Nondestructive Evaluation of Rigid Pavements

AUTHORS/AGENCY/COUNTRY: Ricci, E.A.; Meyer, A.H.; Hudson, W.R.; Stoke, K.H. III/University of Texas, Center for Transportation Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-86/44+387-3F/November 1985

NUMBER OF PAGES: 102 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The objective of the study was to evaluate a Model 8000 Dynatest FWD to be used in testing rigid pavements. The variability and repeatability of the FWD data were found to be statistically acceptable and equal to or less than those of other NDT devices. The variability is less for loads above 26.7 kN (6,000 lb). Temperature was found to influence the polymeric spring system used in the FWD and tests below 10 °C (50 °F) may be erroneously interpreted. Load transfer efficiency at joint or cracks can be measured and voids can be detecting using the FWD.

11. **TITLE:** Development of a Distress Index and Rehabilitation Criteria for Continuously Reinforced Concrete Pavements Using Discriminant Analysis

AUTHORS/AGENCY/COUNTRY: Chou, C.P.; McCullough, B.F./United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1117/1985

NUMBER OF PAGES: 7 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This paper focused on using distress concepts in a Pavement Management System. CRC pavement distress definitions and descriptions were provided. Discriminant analysis (DA) was used to develop the distress index. DA is a statistical technique used to classify data into groups by maximizing the differences between group means. The study concluded that 1) PSI values did not correlate with the rehabilitation decision; 2) punchouts and patches were the primary distresses influencing the distress index; and 3) the method provides a ranking system for rehabilitation needs for network level analysis.

12. **TITLE:** Manual for Condition Survey of Continuously Reinforced Concrete Pavements and Jointed Concrete Pavements - Interim Report

AUTHORS/AGENCY/COUNTRY: Saraf, C.; Torres-Verdin, V.; McCullough, B.F./ Center for Transportation Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-86/26+388-3/1985

NUMBER OF PAGES: 46 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report covers the development of condition survey procedures to collect data for the Rigid pavement Evaluation System currently under development by the Texas SDHPT. The gathered data have been used to prioritize the rehabilitation needs of the rigid-pavement network in Texas. This report also presents an input guide for a microcomputer program that facilitates the entry and storage of condition survey data when the recommended procedures for collecting distress information on rigid pavements at the network level are followed.

13. **TITLE:** Portland Cement Concrete Pavement Evaluation System (COPES)

AUTHORS/AGENCY/COUNTRY: Darter, M.I.; Becker, J.M.; Snyder, M.B.; Smith, R.E./University of Illinois/United States

SOURCE: University of Illinois

REPORT NUMBER/DATE: NCHRP Report No. 277/September 1985

NUMBER OF PAGES: 181 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The primary objectives of this report were to develop a system for State and nationwide evaluation of concrete pavement performance, and to demonstrate and refine the system in cooperation with State highway departments. The major finding of this project is that COPES developed under NCHRP Project 1-19 is capable of efficiently collecting, processing, and evaluating large amounts of pavement data to improve the design, construction, materials, and maintenance of concrete pavements. COPES is developed to include jointed plain, jointed reinforced, and continuously reinforced pavements.

14. **TITLE:** California PCC Pavement Faulting Studies: A Summary

AUTHORS/AGENCY/COUNTRY: Neal, B.F./California Department of Transportation, Office of Transportation Laboratory/United States

SOURCE: California Department of Transportation, FHWA

REPORT NUMBER/DATE: 54-633366 FHWA/CA/TL-85/06/December 1985

NUMBER OF PAGES: 37 p

APPLICABLE CATEGORY: Performance Evaluation, Maintenance/Rehabilitation

SUMMARY: California has evaluated their materials, construction practices and repair methods with respect to faulting or loss of subgrade support of rigid pavements. It was found that cement treated base material produces fines that are pulled into joints and cracks from the curling action of concrete pavements. A lean concrete base or asphalt concrete have been proven to be more resistant to abrasion and still provide a non-erodible base. Other improvement method include the use of edge drains to remove water from permeable bases and subgrade material and grouting with liquid silicone for raising sunken slabs and filling voids. No reference to CRC pavement was found in this report.

15. **TITLE:** Fibrous Portland Cement Concrete Overlay Research in Greene County, Iowa

AUTHORS/AGENCY/COUNTRY: Betterton, R.M.; Knutson, M.J.; Marks, V.J./United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1040/1985

NUMBER OF PAGES: pp 1-7

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report reviews a project constructed in October 1973 to evaluate the performance of steel fiber-reinforced concrete. The fibrous concrete sections consisted of four continuous reinforced concrete sections, two mesh-reinforced sections, and two sections with transverse reinforcing. Each section was rated relative to each other on a scale of 0 to 100 at ages of 5 to 10 years. All sections are essentially unbonded to or debonded from the underlying slab. All experimental overlay sections experienced only limited additional deterioration in the 5- to 10-year period. The 102-mm (4-in) thick, nonfibrous continuously reinforced concrete pavement overlay sections provided the best performance. The performance of the fibrous overlays was directly related to the fiber content of the concrete mix. The 76-mm (3-in) thick fibrous concrete overlays performed substantially better than the 51-mm (2-in) thick fibrous overlays. In general, the thicker, nonfibrous pavement overlay sections constructed at a lower unit cost than the fibrous sections performed better than the fiber-reinforced concrete overlays.

ANNOTATED BIBLIOGRAPHY FOR 1986

1. **TITLE:** Mechanical and Environmental Stresses in Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Saxena, S.K.; Dounias, G.T./United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1099/1986

NUMBER OF PAGES: 10 p

APPLICABLE CATEGORY: Design

SUMMARY: The examination of the combined effects of mechanical and environmental stresses on continuously reinforced concrete (CRC) pavements is accomplished by superimposing the effects of the one onto those of the other. The mechanical stresses are evaluated by a three-dimensional analysis and thermal stresses by two-dimensional analysis. It has been demonstrated that environmental loads constitute the severest loads the pavement is subjected to. Also studied is the comparison of stresses due to one single axle 80.07 kN (18 kip) load to stresses due to two trucks and a car on a three-lane highway. The ratios of maximum stresses by the two loadings may be very useful for a comprehensive understanding of pavement performance when it is designed by the equivalent 80.07 kN (18-kip) concept.

2. **TITLE:** Research Pays Off - Illinois Improves Patching Procedures for Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Anonymous/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: TR News No. 124/May-June 1986

NUMBER OF PAGES: pp 8-9

APPLICABLE CATEGORY: Construction, Maintenance/Rehabilitation

SUMMARY: Since 1962, the State of Illinois has constructed more than 4300 lane km (2,700 lane mi) of continuously reinforced concrete pavements. CRC pavement incorporates continuous longitudinal reinforcement in the pavement slab to eliminate the need for transverse contraction joints. Contraction joints control the pattern of inevitable cracks caused by shrinkage of the pavement slab after placement. Because CRC pavement has no contraction joints, an uncontrolled cracking pattern develops; however, the cracks are held to negligible widths because of the continuous reinforcement. A majority of Illinois CRC pavement was built as part of the Interstate Highway System. As various sections of pavement neared the end of their service lives, it became apparent that improved repair procedures were needed.

This report presents the results of research of improved patching procedures for continuously reinforced concrete pavements. Two distinct patching techniques were developed. The first technique incorporated a shorter-tied overlap of existing steel and new steel and provided a shorter working area in the center of the patch. The second technique shortened the overlay of steel even further by welding the existing steel to the new steel and using a tied-lap splice in the center of the patch to avoid potential buckling of the reinforcement. Tests indicated that mechanically coupling the new

reinforcement to the exposed reinforcement at the ends of the patch is a satisfactory alternative to tying the rebars.

3. **TITLE:** Construction of Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Concrete Reinforcing Steel Institute/United States

SOURCE: Concrete Reinforcing Steel Institute

REPORT NUMBER/DATE: 1986

NUMBER OF PAGES: 37 p

APPLICABLE CATEGORY: Construction

SUMMARY: Construction related information from subgrade preparation to concrete finishing and curing is provided in this report. Subgrade must provide a stable construction platform and uniform support throughout the design life. Special presentations must be taken when a section is constructed on top of expansive soils. A non-erodible subbase is critical to good pavement performance. During final trimming it is important not to create an erodible plane on top.

The importance of drainage is emphasized. Contamination and segregation of the drainage layer and collapsing, breaking or clogging of the underdrain pipes must be avoided. Non-erodible stabilized subbases improve pavement performance. Thickness and density must be frequently checked during construction. Fine grading should be a slight cutting operation to minimize loss of density and non-uniformity.

Longitudinal bars should not be placed more than 229 mm (9 in) apart or less than 102 mm (4 in) or twice the maximum aggregate size, whichever is greater. The minimum concrete cover should be 64 mm (2½ in). A vertical placement tolerance of 13 mm (½ in) is acceptable provided the minimum cover requirement is satisfied. The minimum splice length is 25 bar diameters or 406 mm (16 in), whichever is greater. A skewed or staggered pattern is allowed. Similar placement requirements are established for the transverse bars.

Longitudinal joints must be tied if the transverse bars are interrupted at the joint. Reinforcement supports or chassis must be placed close enough to secure proper placement without prohibiting proper concrete placement. "Tube feeding" of longitudinal bars during concrete placement is also allowed and is the most widely used mechanical method for placing steel is CRC pavement.

Aggregates resistant to freeze-thaw action and alkali reactivity must be selected. Concrete flexural concrete between 3.45 and 4.48 MPa (500 and 650 lbf/in^2) and 28 days is usually specified. Air entrainment is used to increase durability. Care must be exercised to ensure uniform concrete batches are produced at the plant. Concrete can be placed using slip-form pavers or fixed-forms. Either way the position of reinforcement must be frequently checked. Concrete must be consolidated with mechanical equipment. Internal or external vibration may be used. Most agencies

specify vibration frequency and in the case of internal vibration also the vibrator spacing. Honeycombing and segregation/blending are associated with under- and over-vibration, respectively.

Machine finishing is usually adequate for good uniform quality concrete. The surface should be checked for irregularities with a 3.0-m (10-ft) straightedge. A turf drag and metal comb are used to provide surface texture. Curing is critical in CRC pavements since it affects not only strength and durability but also the early transverse crack formation. Curing methods and procedures depend a lot on the weather conditions during and immediately after placement.

Details for proper joint construction and terminal treatments are provided in the report. Concrete ramps may be CRCP, JPCP, or JRCP. For CRC pavements, 152 mm (6 in) concrete shoulders are adequate. The longitudinal joint with the pavement may be keyed, tied or left untied. Corrugations may be used to visually distinguish the shoulder from the main pavement.

Inspection guidelines and sample specifications are provided in the report.

4. **TITLE:** CRC Pavement Performance - An Evaluation of Continuously Reinforced Concrete Pavements in Six States

AUTHORS/AGENCY/COUNTRY: Neff, T.L.; Ray, G.K./Concrete Reinforcing Steel Institute/United States

SOURCE: Concrete Reinforcing Steel Institute

REPORT NUMBER/DATE: after 1986

NUMBER OF PAGES: 22 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: Over 45 000 km (28,000 mi) of CRC pavement in 35 States have been built in the U.S. However, only 13 states awarded CRC pavement contracts the last 4 years preceding the study. The objective of this study was to evaluate the overall performance of CRC pavements. Projects from the states of Georgia, Illinois, Oregon, Texas, Virginia, and Wisconsin were evaluated.

Most of the projects surveyed had been designed 25 to 51 mm (1 to 2 in) thinner than "equivalent" jointed pavements. Thicknesses on the projects in this study ranged from 178 to 254 mm (7 to 10 in). The percentage of steel ranged from 0.5 to 0.6 in the south to 0.6 to 0.7 in the north. Most of the States use stabilized subbases with the exception of Wisconsin where granular subbases are extensively used with an effective k on top of the subbase for design purposes. Drainage was not provided in most of the projects (excluding the surface runoff due to cross slopes). In Virginia shoulders with free draining aggregate material and underdrains in low-lying areas have been used.

Proper steel placement is one of the most difficult problems during construction. In Wisconsin improper placement has been tied to most of the distresses observed. Virginia is the only State where steel placement is routinely checked during construction.

Construction joints often result in performance problems associated mostly with concrete quality.

Longitudinal joints may or may not be routinely sealed in various States. Concrete patches are used to repair CRC pavement.

From interviews with State engineers, subbase quality and pavement thickness were identified as the most important factors influencing performance.

In Illinois, Texas, and Georgia, punchouts are one of the major forms of distress. Corrosion and blowups are major problems in Wisconsin. Construction joint failures are common in all States. D-cracking and alkali-reactivity are the most common material related problems. CRC pavement performance is exceptional in Oregon.

The recommendations of the study were: 1) provide positive drainage; 2) do not use aggregates that would contribute to D-cracking and alkali-reaction; 3) provide adequate vibration to ensure proper consolidation during placement; 4) control and ensure proper steel placement; 5) evaluate personnel involved in CRC pavement design, construction and maintenance.

5. **TITLE:** Overlaying Flexible Pavement with Concrete

AUTHORS/AGENCY/COUNTRY: Whisker, D.; Barfoot, J./Concrete Society/Great Britain

SOURCE: Concrete Society of Great Britain

REPORT NUMBER/DATE: Concrete Vol. 20 No. 5/May 1986

NUMBER OF PAGES: pp 26-27

APPLICABLE CATEGORY: Overlays

SUMMARY: This article discussed the construction and cost of continuous reinforced concrete pavement (CRC pavement) when used as a repair for a blacktop motorway. CRC pavement was shown to cost less than other methods of repair; 33 percent less than complete reconstruction in flexible materials and 17 percent less than a bitumen overlay repair. The contract started in July 1985 and averaged something in excess of 300 m (984 ft) of overlay construction per day. The overlay was placed using a 4-piece SGME concrete train, worked by 10 operatives, which laid the concrete in two strips of 7.5 m (24.6 ft) each, after the surface had been planed and regulated to plus or minus tolerance of 6 mm (0.2 in).

ANNOTATED BIBLIOGRAPHY FOR 1987

1. **TITLE:** Investigation of Punchouts in Continuously Reinforced Concrete Overlay on I-94 in Jackson and Moore Counties

   AUTHORS/AGENCY/COUNTRY: Parry, J.M./Wisconsin Department of Transportation/ United States

   SOURCE: Wisconsin Department of Transportation

   REPORT NUMBER/DATE: Research Project 0624-42-41, Study No. 85-5

   NUMBER OF PAGES:

   APPLICABLE CATEGORY: Performance Evaluation

   SUMMARY: This report describes the investigation of punchouts in a recently constructed CRC pavement overlay on an existing jointed concrete pavement. Several laboratory and field tests were conducted to determine the mechanism of failure. Many of the punchouts noted in the study were located near a joint in the existing jointed pavement. As part of the construction process, a bituminous bond breaker layer was placed between the existing pavement surface and the new concrete overlay. A punchout causing mechanism was suggested based on the field observations and the laboratory and field test results.

2. **TITLE:** Evaluation of Design Changes and Experimental PCC Construction Features

   AUTHORS/AGENCY/COUNTRY: Neal, B.F./California Department of Transportation, Office of Transportation Laboratory/United States

   SOURCE: California Department of Transportation, FHWA

   REPORT NUMBER/DATE: 54-633366 FHWA/CA/TL-85-07/July 1987

   NUMBER OF PAGES: 103 p

   APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

   SUMMARY: This report presents the results of an evaluation of rigid pavements in California. The study consisted of a control section (California standard pavement), a CRC pavement, and unreinforced short spaced jointed pavement, a plain concrete pavement with high cement content, an extra thick plain thick concrete pavement, and a plain concrete with a lean concrete base. These sections were located on I-5 in San Joaquin County, east of Tracy and just north of the I-5/580 interchange. The control section was a 0.2 m (0.7 ft) PCC with a joint spacing pattern of 4.0-5.8-5.5-3.7 m (13-19-18-12 ft) over a 0.14 m (0.45 ft) class A cement treated base over an aggregate subbase. The CRC pavement section was divided into 3 subsections each consisting of 0.2-m (0.7-ft) thick pavement over an aggregate subbase. Subsections were constructed for a CRC pavement with longitudinal steel only (0.56 percent), a CRC

pavement with longitudinal and transverse steel, and a CRC pavement with welded wire fabric.

The pavement sections were constructed in 1971 from May 19 to June 19. Details of the construction are listed in the report. The longitudinal steel in subsection A consisted of No. 5 deformed bars at 165-mm (6.5-in) spacing which were placed automatically through tubes. The depth of steel placement was difficult to control (placed lower than planned). Subsection B consisted of the same longitudinal steel as Subsection A and was tied with No 4 transverse steel bars spaced at 1524-mm (60-in) intervals. This steel assembly was placed on chairs, and the depth of steel was accurately controlled. The longitudinal bars on both A and B were lapped and spliced lagging across the width of the pavement. Subsection C consisted of welded wire mats as described in the text. The mats were set in freshly poured concrete and then depressed to the proper depth by a machine following the paver. Numerous lap failures occurred from interactions of the machine and the previous mat.

In 1985, nearly 14 years after construction, a condition survey was conducted on all the test sections which included crack counts, rideability, overall condition and photographs. Crack spacing was recorded to have not changed in the past 8 years and was noted as an average of 1.3 m (4.3 ft) in Subsection A, 0.9 m (3 ft) in Subsection B, and 0.7 m (2.3 ft) in Subsection C. Subsection A resulted in the widest cracks which was attributed to the placing of the longitudinal steel. Subsection C exhibited greater map cracking than in the other two subsections.

The ride was collected with the Transportation Laboratory Roadmeter before 1985 and with the Highway Maintenance Roadmeter after 1985. The results of these two pieces of equipment can not be correlated, although the relative different of the calculated PSI from both can be compared. PSI values are calculated from ride only at 6 months, 3 years, 6 years, and 14 years.

A followup condition survey was conducted in 1987. This resulted in no changes for all the CRC pavement sections except a 3.7 m by 3.7 m (12 ft by 12 ft) removal section in Subsection C which was attributed to lap failures.

From the study, California has concluded that the unreinforced short slab pavement will perform adequately in low traffic volume conditions and can be constructed at a relatively low cost.

3. **TITLE:** Breaking and Seating of Rigid Pavements

AUTHORS/AGENCY/COUNTRY: Sharp, G.W.; Anderson, M.; Deen, R.C./University of Kentucky, Transportation Research Program/United States

SOURCE: Transportation Research Program

REPORT NUMBER/DATE: UKTRP-87-26/October 1987

NUMBER OF PAGES: 24 p

APPLICABLE CATEGORY:

SUMMARY: Breaking and seating of rigid pavements has been used extensively in Kentucky since 1982. The majority of pavements have been specified to a 457-mm (18-in) nominal crack spacing accomplished with a whip hammer or pile-driving hammer. Rollers weighing 32 and 45 metric tons (35 and 50 tons) are used for the seating procedure. Asphalt overlays have ranged from 102 to 178 mm (4 to 7 in). Deflection testing was performed before, during and after breaking and seating in which elastic theory was used to determine typical cracked concrete modulus values for various crack spacing.

No documentation of breaking and seating of CRC pavements was apparent in this report. Reference is made to "rigid" pavements only. It is the opinion of this reviewer that the breaking and seating is limited to JRCP and possibly JPCP, therefore, this reference is of little use to the CRC pavement study.

4. **TITLE:** Methods of Analyzing and Factors Influencing Frictional Effects of Subbase

AUTHORS/AGENCY/COUNTRY: Wimsatt, A.W.; McCullough, B.F.; Burns, N.H./ University of Texas, Center for Transportation Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-88t459-2F

NUMBER OF PAGES: 84 p

APPLICABLE CATEGORY: Design, Construction

SUMMARY: The objective of this study was to obtain friction information for stabilized subbases. An extensive literature review was conducted and field tests were performed. The most important conclusions from the study are summarized in the following.

1. For asphalt subbases: a) texture was not significant in the frictional restraint; b) subbase thickness may affect the frictional restraint; c) frictional resistance decreased with higher temperatures; d) overburden pressure did not significantly affect frictional resistance; e) for a subbase layer of 51 mm (2 in) the failure plane was at the interface between the subbase and the underlying material; f) for a subbase of 127 mm (5 in), the failure plane was within the subbase.
2. The CRC pavement program can accurately predict actual crack spacing in CRC pavement.
3. The indirect tensile test may be used in estimating frictional resistance.
4. Subbase friction affects the performance of CRC pavement.
5. Stabilized bases can increase from 5 to 25 times the tensile stresses in JCP pavements.

5. **TITLE:** Continuously Reinforced Concrete Experience of the Slotted Steel Strip Reinforcement Flexarm

AUTHORS/AGENCY/COUNTRY: Guerin, G.; Nissoux, J.L.; Aunis, J.; Nicot, J.M./France

SOURCE:

REPORT NUMBER/DATE:

NUMBER OF PAGES: 9 p

APPLICABLE CATEGORY: Design, Construction

SUMMARY: Flexarm is a product developed in France to replace conventional steel in CRC pavements. The material is a plain carbon steel, which can be welded and is treated to bring the elastic limit up to 700 MPa (102,000 ksi) and is not brittle. The steel is 40 mm (1.57 in) wide and 2 mm (0.08 in) thick. The Flexarm steel exhibits the following qualities:

- The ratio of adhesion surface per unit length = 10.5 as opposed to a value of 2.5 for conventional bars of 16 mm (0.6 in) diameter.
- Winding of the Flexarm steel is possible without permanent deformation.
- Slotted to provide for greater adherence.
- Sufficient to mobilize the tensile strength of the reinforcement completely by adhesion in concrete from 48 h after setting.

A test site was constructed in June 1986 on the A6 Paris-Lyon expressway over a 1000-m (3300-ft) stretch. Sections with the Flexarm strips and 16-mm (0.6-in) steel bars were constructed. Six slab sections were constructed, each with the following steel percentage:

16 mm (0.6 in) steel	- 0.3 - 0.4 - 0.67
steel strips	- 0.2 - 0.3 - 0.4

A visual crack survey after construction and again in January 1987 indicated that the strips revealed a much faster control of cracking and a more regular distance between cracks. It was also found that the 0.3 percent strips performed similar to the 0.67-percent 16-mm (0.6-in) steel bars. The strips were not protected against corrosion and resulted in about 1 percent loss of steel in this section due to corrosion.

A second site was constructed on the A6 Paris-Lyon Expressway. Steel reinforcement was provided with 0.3-percent Flexarm strips where 0.67-percent 16-mm steel bars were designed. The concrete slab was 229 mm (9 in) thick. The strip reinforcement was comprised of 36 strips divided between two layers. The strips were manually unrolled off of reels just ahead of the slipform paver. The section performed similar to the remaining CRC pavement constructed with 16-mm (0.6-in) steel bars.

A third test site was constructed in November 1988 on the A6 Paris-Lyon expressway. The reinforcement consisted of 54 galvanized strips placed in the middle of the slab. The paving operation was led by two carriers which unrolled the Flexarm strips in place. The operation consisted of less than 20 workers which achieved production rate of 1000 m (3300 ft) per day with no difficulty. The site resulted in a non uniform crack spacing but crack widths remained tight.

Three sites are planned for future construction and testing of Flexarm steel strips.

6. **TITLE:** Cathodic Protection of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Korfhage, G.R.; Halverson, A.D./Minnesota Department of Transportation/United States

SOURCE: Minnesota Department of Transportation

REPORT NUMBER/DATE: April 1987

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design, Construction, Maintenance/Rehabilitation

SUMMARY: A cathodic protection system was designed and constructed on a 1.6-km (1-mi) section of four-lane continuously reinforced concrete pavement to reduce or stop corrosion of the reinforcing steel and the spalling that occurs as a result of this corrosion. Evaluation is by means of electrical potential measurements and observing the rate of pavement deterioration. Construction of CRC pavement is also discussed in this report.

7. **TITLE:** Concrete Pavement Design Update

AUTHORS/AGENCY/COUNTRY: Hudson, W.R.; McCullough, B.F./University of Texas/ United States

SOURCE: University of Texas

REPORT NUMBER/DATE: Contract No. 0010(11); HP&R/September 1987

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: The objective of this study is to upgrade portland cement concrete pavement design methods for use by the Texas State Department of Highways and Public Transportation including new and overlaid pavements. The work will include at least two sub-objectives: 1) study, revise, and update program JRCP and CRC pavement with knowledge gained from recent research studies and findings; and 2) update design

standards and standard detail sheets utilizing results of computer programs and other new information.

8. **TITLE:** TTICRC pavement, A Mechanistic Model for the Predictions of Strains and Displacements in Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Palmer, R.P.; Olsen, M.P.J.; Lytton, R.L./Texas Transportation Institute/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-88/371-2F/November 1987

NUMBER OF PAGES: 262 p

APPLICABLE CATEGORY: Design

SUMMARY: This report covers the development of the TTI CRC pavement Analysis model assuming that the bond stress relationship between the concrete and the steel can be approximated accurately by a bond stress-slip function. The function was used for the generation of a system of linear, 2nd order differential equations that describe the CRC pavement slab. The model also involves time dependency to allow for multi-day analysis along with material properties, environmental conditions and wheel bonds.

9. **TITLE:** A New Process for the Laying of Monolithic Composite Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Charonnat, Y.; Augoyard, J.P.; Ponsart, L./France

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1110/1987

NUMBER OF PAGES: pp 59-64

APPLICABLE CATEGORY: Construction

SUMMARY: This report addresses new developments of rigid pavement construction techniques in France for heavy traffic roads. CRC pavement with use of local aggregates is preferred. A monolithic composite structure made up of two layers of concrete of different composition is increasingly used. New techniques, involving continuous reinforcing and double-layer rigid pavement, have called for the development of specific equipment in order to produce good functional characteristics while allowing for construction performance and quality equivalent to that found at more traditional construction sites. This paper appeared in Transportation Research Record No. 1110, Concrete and Concrete Construction.

10. **TITLE:** Consolidation of Concrete (Papers Presented at the Symposium at the ACI Spring Convention)

AUTHORS/AGENCY/COUNTRY: Gebler, S.H./United States

SOURCE: American Concrete Institute

REPORT NUMBER/DATE: Publication SP - American Concrete Institute 96/1987

NUMBER OF PAGES: 250 p

APPLICABLE CATEGORY: Construction, Maintenance

SUMMARY: This symposium proceedings contained 13 papers. The topics covered include: concrete consolidation mechanical equipment; superplasticized concrete mix consolidation; compacted portland cement based mixture compressive strength; roller compacted concrete density; tunnel concrete consolidation by internal and external vibrations; consolidation effect on concrete; fresh concrete consolidation experimental considerations; energy requirements for concrete internal vibration; fiber reinforced concrete behavior under compaction; double-mixed concrete properties under vibrating compaction.

11. **TITLE:** Development of a Distress Index and Rehabilitation Criteria for Continuously Reinforced Concrete Pavements Using Discriminant Analysis

AUTHORS/AGENCY/COUNTRY: Chou, C.P.; McCullough, B.F./University of Texas/ United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1117/1987

NUMBER OF PAGES: pp 76-82

APPLICABLE CATEGORY: Performance Evaluation, Rehabilitation

SUMMARY: Discriminant analysis is applied to developing the distress index and rehabilitation criteria of the network-level pavement management system for continuously reinforced concrete pavements in Texas. The results are intended to provide the Texas State Department of Highway and Public Transportation with guidelines for evaluating the present pavement condition and for scheduling rehabilitation. For the discriminant analysis, historical condition survey data were evaluated and separated into two groups, overlaid and nonoverlaid pavements, for which detailed descriptions were given. Each set of data comprised several distress manifestations.

12. **TITLE:** Condition Monitoring of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Quinn, K./Oregon Department of Transportation/United States

SOURCE: Oregon Department of Transportation

REPORT NUMBER/DATE: June 1987

NUMBER OF PAGES:

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The purpose of this study is to determine and analyze the rates, types and causes of deterioration occurring in continuously reinforced concrete pavements. Fourteen different sites were monitored by measuring cracking, spalling, rutting, and pavement deflection.

13. **TITLE:** Consolidation of Continuously Reinforced Concrete Pavement (Paper Presented at the Symposium at the ACI Spring Convention)

AUTHORS/AGENCY/COUNTRY: Olsen, M.P.J./American Concrete Institute/United States

SOURCE: American Concrete Institute

REPORT NUMBER/DATE: Publication SP - American Concrete Institute 96/1987

NUMBER OF PAGES: pp 39-56

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: Current consolidation practices and a recently completed laboratory investigation to determine the effects of coarse aggregate factor, maximum aggregate size, vibrator spacing, and the method of vibrator mounting on the achieved consolidation of CRC pavement is reviewed. Also reviewed are the theory and principle of consolidation by internal vibration. The parameters found to be of importance are the vibrator spacing, concrete mix design, and acceleration in the concrete.

14. **TITLE:** Effect of Rainfall on the Performance of Continuously Reinforced Concrete Pavements in Texas

AUTHORS/AGENCY/COUNTRY: Saraf, C.L.; Chou, C.P.; McCullough, B.F./University of Texas, Center for Transportation Research/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1121/1987

NUMBER OF PAGES: 4 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The effect of rainfall on the performance of continuously reinforced concrete (CRC) pavements in Texas was studied by analyzing the condition survey data on CRC pavements throughout the State. A study of the annual rainfall data within the State of Texas indicated that it varies from 254 to 1321 mm (10 to 52 in). For the purpose of this study, the data were grouped into districts, and the average performance of pavements in each district was estimated for each survey year. The average performance of CRC pavements was determined by adding the number of patches and punchouts in the pavement and estimating the number of failures/mi. The average rate of failures/mi per year was estimated for a period of 10 years for each district and a simple relationship was determined: log (RFPM) = -4.05 + 2.35 log (P) where P is the average annual precipitation in the district. The results of this study indicated that the effect of average annual rainfall on the performance of CRC pavements in Texas is significant. This study indicated that the initial performance of pavements located in different rainfall areas is practically the same. However, when the pavement starts developing failures, the RFPM is affected by the average rainfall of the area. Pavements located in 254-mm (10-in) rainfall areas generally showed an almost zero rate of failure development, whereas pavements located in 1321 mm (52 in) rainfall areas developed failures at a rate of about one failure/mi per year.

15. **TITLE:** Evaluation of Design Changes and Experimental PCC Construction Features. Final Report

AUTHORS/AGENCY/COUNTRY: Neal, B.F./California Department of Transportation/ United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-CA-TL-85-07; Report 54-633366/June 1987

NUMBER OF PAGES: 112 p

APPLICABLE CATEGORY: Design, Construction, Performance Evaluation

SUMMARY: This report is divided into four parts. Part I deals with a continuously reinforced concrete pavement (CRC pavement) and other experimental features intended as design improvements to reduce pavement maintenance costs. Part II covers field trials with four different types of joints sealant materials. It also reports on the first edge drain installation in California for the purpose of removing surface infiltrated water. Part III concerns experimental shoulder treatments, the prime variable being PCC shoulders. Part IV deals with other experimental FHWA Construction - Evaluated Research Program. These features include: 1) bridge approach slabs containing accelerated-set concrete mixtures, 2) the use of asphalt treated permeable base (ATPB) as both a drainage layer and a base for PCC pavement, and 3) the use of a cement treated permeable base (CTPB) in a highway roadbed structural section as a drainage layer for groundwater control. Although firm conclusions are not warranted

by the limited data from some projects, the findings from certain experimental construction has led to further installations and, in some cases, the adoption of those practices for current projects. For example, the use of edge drains, along with ATPB and CTPB, is now required on new pavement construction. This report has some application related to design improvements.

16. **TITLE:** The Performance of Continuously Reinforced Concrete Pavements in Texas

AUTHORS/AGENCY/COUNTRY: Scullion, T./Transportation Engineering - Economics Research/United States

SOURCE: National Asphalt Pavement Association

REPORT NUMBER/DATE: October 1987

NUMBER OF PAGES: 118 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: This report presents a study between 1960 and 1972 in Texas of the performance of continuously reinforced concrete pavements built and which have reached the end of their initial performance period. Four highway districts with markedly different climates were analyzed. All pavements were 203-mm (8-in) thick CRC pavement pavements. It was found that performance was greatly affected by environment and material types.

17. **TITLE:** A Mechanistic Design for Thin-Bonded Concrete Overlay Pavements

AUTHORS/AGENCY/COUNTRY: Bagate, M.; McCullough, B.F.; Fowler, D.W./Center for Transportation Research/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-88+457-3; CTR3-86-457-3

NUMBER OF PAGES: 70 p

APPLICABLE CATEGORY: Overlays

SUMMARY: This report is concerned with the design of concrete overlays of old concrete pavements with some remaining fatigue life considering three criteria: wheel load stresses, volume change stresses, and interface bond stresses. The finite element method is used for the wheel load stresses and accounts for a more precise modeling of continuously reinforced concrete pavements with various loading configurations: at edge, at joint, and at cracks.

18. **TITLE:** A Study of the Effect of Construction Variables on the Bond Behavior of the CRC pavement Overlays

AUTHORS/AGENCY/COUNTRY: Solanki, A.I.; Fowler, D.W.; McCullough, B.F./ University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-88+457-4; Research Report 457-4/October 1987

NUMBER OF PAGES: 50 p

APPLICABLE CATEGORY: Overlays

SUMMARY: This report describes a series of research activities concerned with the development of the bond between an existing CRC pavement pavement and a new CRC pavement overlay. The report includes a summary of activities related to preparation of the surface, and determination of the effect of moisture level, grout condition, vibration level, and location in CRC pavement overlays. Results of general linear model (GLM) analysis are used to find the best and worst interaction of variables.

19. **TITLE:** Concrete Paves the Way

AUTHORS/AGENCY/COUNTRY: Swan, R./United Kingdom

SOURCE:

REPORT NUMBER/DATE: International Construction Vol. 26 No. 9/September 1987

NUMBER OF PAGES: pp 76-78

APPLICABLE CATEGORY: Design, Overlays

SUMMARY: Two interesting British Developments which point to a healthy future for continuously reinforced methods involve bituminous material as well as concrete. On a different section of the M18, Humberside County Council are pioneering the use of CRC pavement as a remedial overlay to a failing blacktop motorway. The second innovation is best described as the "son of CRC pavement." The new British Dtp Departmental Standard on Paving Design, which is due to be published this autumn (1987), is thought to include the provision of continuously reinforced concrete roadbase (CRCR) alongside CRC pavement as an approved method of construction. This method, which is sometimes referred to as CRCB (for Base), essentially a lighter CRC pavement slab acting as the roadbase, upon which is laid a bituminous wearing course.

20. **TITLE:** Rutting of Asphalt Concrete Overlays on Continuously Reinforced Concrete Pavements in Texas

AUTHORS/AGENCY/COUNTRY: Saraf, C.L.; McCullough, B.F.; Aslam, M.F./ University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1109/1987

NUMBER OF PAGES: pp 56-59

APPLICABLE CATEGORY: Overlays

SUMMARY: Rutting history data on asphalt concrete pavement (ACP) overlays on rigid pavements are being collected by the Center for Transportation Research to study ACP overlay behavior under the traffic and environmental conditions of Texas. Overlaid sections located in three counties of the State were selected for this study. These sections were originally built as continuously reinforced concrete pavement. Using the limited data available at the present time, it was observed that the rate of rutting was maximum in the first year because of the initial compaction of material in the wheelpaths. In the second year, the material between the wheelpaths experienced more compaction than that in the wheelpaths themselves, and therefore rutting was observed to decrease in the second year. The analysis of available data indicated that overlay thickness was an important predictor of rutting in overlays.

ANNOTATED BIBLIOGRAPHY FOR 1988

1. **TITLE:** Reinforcement Design for CRC Pavements - A Probabilistic Approach

AUTHORS/AGENCY/COUNTRY: Saraf, C.L.; McCullough, B.F.; Aslam, M.F./University of Texas, Center for Transportation Research/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Paper presented at 67th Annual Meeting/January 11-14, 1988

NUMBER OF PAGES: 5 p

APPLICABLE CATEGORY: Design

SUMMARY: This report presents a probabilistic approach to the design of CRC pavement based on the inherent variabilities of the pavement and material properties which are included in the steel stress, crack width, and crack properties which are included in the steel stress, crack width, and crack spacing design equations. These component variabilities are included in an overall variance which leads to a reliability based approach assuming normal distribution probability density functions for each component.

2. **TITLE:** Comparison of Early-Age Crack Width Formulas for Reinforced Concrete

AUTHORS/AGENCY/COUNTRY: Hughes, B.P.; Cifuentes, C.V./United Kingdom and Chile

SOURCE: American Concrete Institute Structural Journal

REPORT NUMBER/DATE: ACI Journal, Proceedings Vol. 84 No. 2/March-April 1988

NUMBER OF PAGES: pp 158-166

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Cracking can be considered to be controlled when cracks are either prevented from forming, induced to form at prearranged locations where their effects can be dealt with, or permitted to form and the reinforcement and/or joint spacings are so detailed that the crack widths conform to certain design criteria. The mechanism of thermal cracking has been well documented, and a method of designing and detailing crack control reinforcement proposed by Evans and Hughes, was incorporated for the first time in a British code of practice, recognizing in that way the importance of early thermal cracking. The economic implications of this code provided the stimulus for further research and apparently contradictory opinions have subsequently emerged. Various equations have been developed that attempt to predict the width of cracks. The equations are very different, their results are contradictory, and it is very difficult to discern any common ground among them. The paper examined the mechanisms of early thermal cracking of fully restrained thin concrete members by comparing existing formulas and their associated theoretical assumptions in relation to a general bond slip theory. The paper deals only with the early thermal and shrinkage cracking of thin sections of immature concrete. A theoretical model is developed, based on bond slip theory, to denote equations that predict the cracking behavior and two particular cracking mechanisms (maximum and minimum) are highlighted in the analysis. These are then compared with the various formulas suggested by different researchers.

3. **TITLE:** A Mechanistic Model for the Prediction of Stresses, Strains and Displacements in Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Palmer, R.P.; Olsen, M.; Lytton, R.L./Texas A&M University, Texas Transportation Institute/United States

SOURCE: Texas A&M University, Texas Transportation Institute

REPORT NUMBER/DATE: FHWA/TX-88/371-2F/July 1988

NUMBER OF PAGES: 276 p

APPLICABLE CATEGORY: Design

SUMMARY: The accuracy of the CRC pavement-1, CRC pavement-2, and CRC pavement-3 models developed by the Center for Transportation Research at the University of Texas for predicting the behavior of continuously reinforced concrete pavements (CRC pavement) is limited in part by many of the simplifying assumptions that were made in their development. Modeling the bond stresses distribution between the concrete and steel reinforcing as an average stress acting over a development length is, in particular, a gross simplification of actual behavior. The TTI CRC pavement model was

developed by assuming that the bond stress relationship between the concrete and the steel could be approximated accurately by a bond stress-slip function. The function was used for the generation of a system of linear, 2nd order differential equations that describe the CRC pavement slab. The correct solution to the system of differential equations yields the displacement functions of the concrete and the steel, which in turn allow the stress distributions for the steel and the concrete to be found. Time dependency was incorporated into the model to allow for multi-day analysis of a CRC pavement system. Material properties, drying shrinkage, environmental conditions, and wheel loads were all assumed to be usefulness rating: high time dependent.

4. **TITLE:** Development of an Overlay Design Procedure for Pavements in Indiana

AUTHORS/AGENCY/COUNTRY: White, T.D./Indiana Department of Highways/United States

SOURCE: Indiana Department of Highways

REPORT NUMBER/DATE: December 1988

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: The primary objective is to develop an easily implementable overlay design technique and to determine the input required for this technique so as to predict the optimum overlay design thickness. Particular emphasis will be placed on the use of nondestructive testing devices for ascertaining pavement deflection which may be used in design for a given set of conditions.

5. **TITLE:** Evaluation of Proposed Texas SDHPT Design Standards for CRC Pavement

AUTHORS/AGENCY/COUNTRY: Won, M.; McCullough, B.F./University of Texas, Center for Transportation Research/United States

SOURCE: University of Texas, Center for Transportation Research

REPORT NUMBER/DATE: FHWA/TX-88+472-1/April 1988

NUMBER OF PAGES: 41 p

APPLICABLE CATEGORY: Design

SUMMARY: This report details proposed design standards for the Texas SDHPT for CRC pavement. The primary factors considered in the design of CRC pavement are the structural responses of crack spacing, crack widths, and steel stress. The structural responses are based on material properties, environmental conditions, and traffic loading. The effects of deformed bars and deformed were fabric were also considered.

6. **TITLE:** Performance of Wisconsin's Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Parry, J.M./Wisconsin Department of Transportation, Division of Highways and Transportation Services/United States

SOURCE: Wisconsin Department of Transportation

REPORT NUMBER/DATE: 0624-32-19/August 1988

NUMBER OF PAGES: 19 p

APPLICABLE CATEGORY: Construction, Maintenance/Rehabilitation, Performance Evaluation, Overlays, Current Research

SUMMARY: Wisconsin has been monitoring the long-term pavement performance of their CRC pavements for 22 years. Two reports previous to this present a comprehensive summary of the data and conclusions from the first generation of CRC pavements. This report focuses on the new generation of CRC pavements in Wisconsin designed in 1984. These pavements are generally 254-mm (10-in) thick, which is an increase of 51 mm (2 in) from the original first generation CRC pavements due to heavier traffic loadings.

In 1988 the CRC pavements constructed in 1984 were evaluated. The results of this evaluation are briefly described below.

Visual Condition Survey
Wisconsin's visual condition survey (PDI) was refined to accommodate CRC pavement distresses. An expert panel comprised of Wisconsin DOT personnel established appropriate modifications. The changes included surveying the entire CRC pavement section instead of 0.16-km (1/10-mi) samples used for other pavement types, and the weighting factors in the PDI formula for pavement deterioration and patching were adjusted. The average PDI for all CRC pavement statewide prior to 1987 was 34.

Steel Corrosion
Cores extracted from CRC pavement built in 1983 with uncoated steel showed corrosion of the longitudinal steel and delamination in the vicinity of transverse cracks. In contrast, cores extracted from CRC pavements constructed in 1984 with epoxy-coated steel exhibited no signs of corrosion. Cores were evaluated for corrosion from recycled aggregate. Recycled aggregate has a higher corrosion potential than virgin aggregate due to the high chloride content of the old aggregate. All cores with the recycled aggregate contained epoxy coated steel and no corrosion was present.

Wisconsin utilizes chairs and transverse steel to support and place the longitudinal steel. From 1969 to 1981 longitudinal steel was placed automatically through tubes on the paver, thus eliminating the need for chairs and transverse steel. This method resulted in poor control over the depth of steel placement. For this reason, chairs and transverse steel have been used since 1981. Core examination indicated that the placement of longitudinal steel was within the minimum cover.

Crack Count
An average crack spacing of 1.2 to 1.3 m (4.0 to 4.2 ft) was noted after 4 years of service, and 20 to 23 percent of the cracks were spaced less than 0.6 m (2 ft) apart. Crack spacing did not seem to be dependent on pavement thickness when compared to a 203-mm (8-in) CRC pavement.

Several CRC pavement rehabilitation techniques were constructed in 1988 for a new research study in Wisconsin. A brief discussion of these techniques follows.

Thin Bonded PCC Overlay
A thin bonded overlay of 64 mm (2.5 in) with no steel reinforcement placed in 1984 was evaluated. Cores extracted from the bonded CRC pavement indicated that a strong bond still existed at the pavement/overlay interface. Cracks reflected through after the first year of construction. In 1987, additional transverse cracks developed, which penetrated 25 to 51 mm (1 to 2 in) into the surface of the overlay. This was believed to be due to differential moisture or thermal shrinking of the overlay from that of the underlying CRC pavement. Wisconsin suggests to use the same source of aggregate in the overlay as in the underlying pavement. Only 0.35 percent of the total surface area of the bonded overlay required patching as of October 1989.

Structural HMA Overlay
A 76-mm (3-in) HMA overlay was placed over I-90/94 in Juneau County between Lyndon Station and Mauston in 1985. Patching was the predominant distress recorded. The most severe of these was due to bituminous patches in the underlying CRC pavement reflecting up. Rutting averaged 7.6 mm (0.3 in).

Patching
Full-depth concrete patches have performed satisfactorily on CRC pavements. Some patches exhibited extra transverse cracks which were thought to be due to differences in thermal coefficients of the patch and the concrete.

7. **TITLE:** A Summary of Studies of Bonded Concrete Overlays

AUTHORS/AGENCY/COUNTRY: Suh, Y.C.; Lundy, J.R.; McCullough, B.F.; Fowler, D.W./University of Texas, Center for Transportation Research/United States

SOURCE: Texas Department of Highways and Public Transportation

REPORT NUMBER/DATE: FHWA/TX-89+457-SF/November 1988

NUMBER OF PAGES: 48 p

APPLICABLE CATEGORY: Design, Construction, Maintenance/Rehabilitation, Performance Evaluation, Overlays

SUMMARY: This report presents the performance of bonded concrete overlays (BCO), recommendations for construction, evaluation of BCO material types, and evaluation of the strength, durability, an economics of adopting different thickness for the overlay

from findings of laboratory and field test conducted by the Center for Transportation Research.

Pavement distresses including transverse and longitudinal cracks, spallings, punchouts, patches and rideability were recorded in the field to decrease substantially by placement of a 102-mm (4-in) bonded concrete overlay. This overlay also decreased the amount of deflection recorded indicating an increase in structural condition. The fatigue lie of BCO's was evaluated with an accelerated load testing facility. It was found from this study that the overlay increased the fatigue life even when an overlay was placed on a failed slab. A substantially larger fatigue life was obtained when an overlay was placed on a slab with some remaining life than a deteriorated failed slab. It was also found that the BCO increased load transfer.

A field experiment was conducted to define the relationship between construction variables and bond strength of the two slabs. The construction variables evaluated were surface preparation, moisture condition, use of grout, vibration level, location of core, seasonal effect, mix design, and curing. A brief list of the results follows:

- Most problems occurred during the winter pour. Some of these problems, such as low slump, were due to the cold temperatures although a majority of the problems were due to equipment, personnel, and mix problems that occur at any time of the year.
- Shot blasting showed better performance for bond than cold milling, however, more delamination problems occurred with shot blasting.
- Bond strength at the corner of a slab was much lower than at the middle.
- Higher vibration is recommended when grout is not used and at the corner of the slab. Higher vibrations at the middle of the slab may result in lower bond strength.
- Ungrouted sections gave higher bond strength when the surface is in dry condition.

A test section on the South Loop 610 in Houston was comprised of a 203-mm (8-in) CRC pavement on 152 mm (6 in) of CTB was overlaid with a 51- and 76-mm (2- and 3-in) BCO with fibrous reinforcement, steel-mat- reinforcement, and no reinforcement. The fibrous concrete overlay was far superior to the other sections in controlling longitudinal and transverse cracking. The effect of overlay thickness for reduction of surface deflections is most effective when the underlying concrete surface deflections are high. Steel-mat-reinforced concrete overlays exhibited the largest reduction in surface deflection.

Epoxy resin was compared with cement grout as a bonding agent in a laboratory experiment. Debonding between the overlay and the original slab were recorded with the epoxy resin. A sound bond was obtained for slabs with cement grout bonding agent.

Chemical durability problems occur from a reaction between reactive silica of the aggregate and alkalis contained in the cement. Concrete expands when this reaction occurs based on the nature and amount of silica, particle size of the aggregate, and the amount of available silica. The report suggests methods to control degree of this reaction. A petrographic study on cores taken from the North Loop of 610 in Houston

revealed that alkali-silica gel deposits existed in a thin zone adjacent to the interface between the two slabs. The study indicated that the expansive force of the gel deposits might cause debonding of the two slabs.

Based on findings from the field and laboratory tests the following recommendations are noted for BCO construction.

- The overlay should be placed before the existing pavement has failed. Distresses of the existing pavement should be repaired.
- All loose materials should be removed from the existing pavement before the overlay is placed.
- Roughening the surface results in better bond at the interface.
- A comparison of different scarification methods is listed in table 5.1.
- Overlays should be placed the same day or at least the day after the shot blasting operation.
- Cold milling should be followed with vacuuming of the surface to remove all loose fragments of concrete.
- It has been shown that more beneficial effects occur when grouting agents are placed on a wet surface as opposed to a dry surface.
- Overlays should be placed before the grout dries. If the grout is allowed to dry before the overlay placement, the bonding capacity of the overlay will be considerably reduced.
- Position of steel bars does not affect the bond capacity of the reinforcing steel. Steel can be placed directly on the surface of the existing pavement, saving contractor time and cost.

8. **TITLE:** A Study of the Influence of the Temperature of the Substrate on the Construction of Bonded Portland Cement Concrete Overlays

AUTHORS/AGENCY/COUNTRY: Koesuo, S.; Papaleontiou, C.G.; Meyer, A.H.; Fowler, D.W./Center for Transportation Research, University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-89t24-1F/November 1988

NUMBER OF PAGES: 54 p

APPLICABLE CATEGORY: Construction, Maintenance/Rehabilitation

SUMMARY: The objective of the study was to evaluate the effect of varying substrate temperatures on overlay construction. The effect was evaluated in terms of bond strength in shear and tensions. Field and laboratory work was described. The most important conclusions of the study were:

a. Laboratory tests indicated that grout application before overlaying resulted in lower shear bond strength. Field tests indicated no effect on bond strength for sections with or without grout. This is contradictory to other studies which have indicated the beneficial effect of grout on bond strength.

b. Laboratory tests indicated that placing overlays on dry surfaces results in higher bond strengths. No difference in bond strength for dry or moist interfaces was indicated from field test.
c. Lower tensile bond strengths were measured in the laboratory for temperatures greater than 29.4 °C (85 °F). Temperature had no effect on shear bond strength tests in the laboratory.
d. Winter placement in the field resulted in lower shear bond strength than summer placement.
e. Shear bond at the middle of the slab had the highest values.
f. There was no relationship between shear and tensile bond strength.

9. **TITLE:** Estimating User Costs of Asphalt and Concrete Pavement Rehabilitation

AUTHORS/AGENCY/COUNTRY: Memmot, J.L.; McFarland, W.F./Transport Engineering-Economics Research; National Asphalt Pavement Association/United States

SOURCE: National Asphalt Pavement Association

REPORT NUMBER/DATE: 1988

NUMBER OF PAGES:

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: This report presents estimates of rehabilitation costs, and user costs during construction of a sample of highway rehabilitation projects in Texas. Two types of pavement rehabilitation were studied: (1) rehabilitation of jointed reinforced concrete pavement or continuous reinforced concrete (CRC pavement), with repairs of the concrete pavement and then overlaid with an asphaltic concrete surface; and (2) rehabilitation or level-up of asphaltic concrete pavement, and then overlaid with asphaltic concrete. One study site had a thin-bonded concrete overlay on an existing CRC pavement.

10. **TITLE:** Evaluation of Mechanical Couplers in Continuously Reinforced Concrete Pavement Patches

AUTHORS/AGENCY/COUNTRY: Hunt, J.E./Pennsylvania Department of Transportation Bureau of Bridge and Roadway Technology/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-PA86-046+86-103

NUMBER OF PAGES: 15 p

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: In an effort to develop a more cost-effective method for repairing continuously reinforced concrete pavements, mechanical couples for reestablishing the continuous reinforcing steel when installing full-depth pavement patches were installed for comparison to PennDOT's standard method of lap splicing and tieing.

11. **TITLE:** Evaluation of the Performance of Bonded Concrete Overlay on Interstate Highway 610 North, Houston, Texas

AUTHORS/AGENCY/COUNTRY: Koesno, K.; McCullough, B.F./University of Texas/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1196/1988

NUMBER OF PAGES: pp 201-211

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The objective of the study was to evaluate the performance of the bonded concrete overlay project on IH 610 North in Houston and implement the findings in other studies on bonded concrete overlay. The performance of the bonded concrete overlay was monitored on 10 experimental sections selected from the 5.6-km (3.5-mi) project and ranging from 122 to 183 m (400 to 600 ft) long. Periodic field measurements were conducted, and an assessment of overlay pavement life was made. The resulting conclusions and recommendations were to be used by the TSDHPT to design overlays for rehabilitation programs on continuous reinforced concrete pavement.

12. **TITLE:** Development of a Long Term Monitoring System for Texas CRC Pavement Network

AUTHORS/AGENCY/COUNTRY: Chou, C.P.; McCullough, B.F.; Hudson, W.R.; Saraf, C.L./Center for Transportation Research, University of Texas/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-89t472-2/October 1988

NUMBER OF PAGES: 154 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The long-term objective of this study was to develop a CRC pavement design equation. The short-term objective was to develop an experimental design for network level condition survey in order to evaluate CRC pavement performance in Texas. During the study the following indices and models were developed:

a. A Distress Index (DI) as a function of various distresses.

b. A Decision Criteria Index (DCI) defined as the limiting value of the distress index. When the DI of any section reaches the predetermined DCI value some type of rehabilitation is immediately required.

c. A Performance Prediction Model which in this study is the DI as a function of time and various fundamental pavement parameters (i.e., slab thickness, material properties, traffic, etc.)

Periodical condition surveys are necessary to develop the Performance Prediction Model.

CRC pavements may provide an acceptable ride even when reaching the end of their design life and the structural capacity is inadequate. This is the primary reason for which distress in addition to roughness must be taken into account during pavement evaluation.

Condition surveys were performed in 1974, 1978, 1980, 1982, and 1984 in rural districts and in 1976, 1981, 1982, and 1984 in urban districts. Transverse cracks, localized cracks, spalling, pumping, punchouts, and patches were recorded by a two man crew from a van traveling at 8.05 km/h (5 mi/h) with the exception of the 1984 survey which was conducted at 24.14 km/h (15 mi/h).

Using discriminate analysis a distress index equation was developed based on minor and severe punchouts and total number of patches/mi.

Following an extensive review of the AASHTO equations, mechanistic models, and field survey studies of rigid pavements the following fundamental pavement parameters were selected to be included in a data base because of their influence on distresses and pavement performance: Slab Thickness, Coarse Aggregate Type, Subbase Type, Roadbed Soil, Average Annual Rainfall, Average Annual Lowest Temperature, Age, and Roadbed Grading Type.

Analysis of the collected data indicated:

a. The distress index was highest for pavement on cut sections and lowest for pavements on transition between cut and fill.
b. DI decreases with pavement age.
c. Climatic conditions influence pavement performance.
d. Swelling soil influence pavement performance primarily in areas of high rainfall.
e. Coarse aggregates influence the crack spacing - LMS (limestone) pavement have almost double the crack spacing of SRG (silicious river gravel) pavements.
f. In the humid areas as well as the cold areas of the State crack spacing is smaller for both types of aggregates.

13. TITLE: Evaluation of Concrete Pavement Using Nondestructive Testing Techniques

AUTHORS/AGENCY/COUNTRY: Barenberg, E.J.; Dietz, D.A.; Woods, M.L./University of Illinois; Illinois DOT/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/IL/UI 218/May 1988

NUMBER OF PAGES: 193 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: The objective of the study was to develop systematic procedures for determining the structural and rehabilitation needs of concrete pavements using NDT data. Mostly jointed pavements were tested.

Programs for NDT data reduction were written. Procedures for void detection were developed and described. Recommendations as to the number and spacing of NDT data points, frequently of testing and temperature and seasonal effects were made. Some work was done on testing of CRC pavements but since this was an interim report and the study was not completed at the time, no major conclusions were presented.

14. **TITLE:** Performance of CRC Overlays - A Study of Continuously Reinforced Concrete Resurfaced Projects in Four States

AUTHORS/AGENCY/COUNTRY: Concrete Reinforcing Steel Institute/United States

SOURCE: Concrete Reinforcing Steel Institute

REPORT NUMBER/DATE: Around 1988

NUMBER OF PAGES: 13 p

APPLICABLE CATEGORY: Performance Evaluation, Overlays

SUMMARY: This purpose of the report was to demonstrate the reliable and cost effective performance of CRC overlays under varying environmental and traffic conditions.

The design and performance of CRC overlays in four States (Arkansas, Texas, Illinois, and Oregon) is documented. The projects range from 8 to 23 years in age and 152 mm to 229 mm (6 in to 9 in) in thickness. Distresses were mostly associated with poor drainage and subgrade pumping.

15. **TITLE:** Overlaying the M. 18 with Concrete

AUTHORS/AGENCY/COUNTRY: Blanshard, S./United Kingdom

SOURCE: Highways and Transportation

REPORT NUMBER/DATE: Highways and Transportation Vol 35 No. 2/February 1988

NUMBER OF PAGES: pp 29, 31, 33-35

APPLICABLE CATEGORY: Overlays

SUMMARY: CRC pavement have been used extensively for the construction of major roads in the United States and Belgium over the past 25 years. While other European countries have now started to follow suit, their use in the United Kingdom has been very limited. In 1985, the Department of Transportation selected the northbound carriageway of the M18 between Junction 6 near Thome and Junction 35 of the M62 for an important trial in the use of CRC as an overlay. This was the first time it had been used to overlay a motorway in the United Kingdom

16. **TITLE:** Performance of Bonded Concrete Overlays

AUTHORS/AGENCY/COUNTRY: Lundy, J.R.; McCullough, B.F./University of Texas/ United States

SOURCE: University of Texas

REPORT NUMBER/DATE: Texas Civil Engineer Vol 58 No. 9/November 1988

NUMBER OF PAGES: pp 18-22

APPLICABLE CATEGORY: Overlays

SUMMARY: Bonded concrete overlays have been successfully placed in Texas over CRC pavements. The performance of the experimental section constructed on the South Loop of IH 610 has been excellent for 4 years. Deflections and the extent of cracking have been substantially reduced. As of 1987, no delaminated areas have been found and there is every reason to believe that the section will continue to perform well. The North Loop BCO project also significantly reduced deflection and the extent and severity of cracking. Reduction in these parameters indicate an increase in the expected life of the facility. However, debonding of some areas may substantially reduce the life of the overlay.

17. **TITLE:** Performance Evaluation of Concrete Overlays

AUTHORS/AGENCY/COUNTRY: Lippert, D.L.; DuBose, J.B./Illinois Department of Transportation; Federal Highway Administration/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: Phys. Res. Report No. 101; FHWA/IL/PR-101/November 1988

NUMBER OF PAGES: 22 p

APPLICABLE CATEGORY: Overlays, Current Research

SUMMARY: The objective of this study was to evaluate the performance of existing concrete overlays. Both jointed plain and CRC pavement overlays were examined. Generally,

178- and 203-mm (7- and 8-in) overlays performed much better than the 152 mm (6 in) overlay. Percent steel did not seem to affect pavement performance. It was recommended to build concrete overlays to the same width and alignment as the pavement being overlayed.

ANNOTATED BIBLIOGRAPHY FOR 1989

1. **TITLE:** Field and Laboratory Study of the Effects of Water Pumping Beneath Concrete Pavement Slabs

   AUTHORS/AGENCY/COUNTRY: Hansen, E.C.; Johannssen, R./University of Florida; Florida Department of Transportation/United States

   SOURCE: Florida Department of Transportation

   REPORT NUMBER/DATE: FL/DOT/JMO-89-370/August 1989

   NUMBER OF PAGES: 202 p

   APPLICABLE CATEGORY: Design

   SUMMARY: The objective of the study was to evaluate the effects of pumping through an extensive literature review, laboratory and field testing. The basic mechanism of pumping and the resulting faulting was once more verified. The study is not directly connected to CRC pavement pavements although pumping has been observed in CRC pavement. Therefore, a detailed summary is not provided for this study.

2. **TITLE:** Maximum Entropy Spectral Analysis of Transverse Crack Spacing in Continuously Reinforced Concrete Pavements

   AUTHORS/AGENCY/COUNTRY: Lu, J.; McCullough, B.F.; Saraf, C.L./University of Texas/United States

   SOURCE: Transportation Research Board

   REPORT NUMBER/DATE: Transportation Research Record No. 1227/1989

   NUMBER OF PAGES: pp 219-224

   APPLICABLE CATEGORY: Design, Performance Evaluation

   SUMMARY: The characteristics of cracks of CRC pavement are generally evaluated by analyzing the distribution of transverse crack spacing in the pavement. Statistical analysis of data produces the mean and the standard deviation of crack spacing. However, these parameters are not always sufficient for characterizing the crack spacing of CRC pavement. Therefore, this paper proposes an alternate method for analyzing the transverse crack spacing data. This method, maximum entropy spectral analysis (MESA), analyzes the data in the frequency domain rather than in the space

domain. In this paper, the uniformity and variability of crack spacing are also defined. By using MESA, the uniformity and variability of crack spacing can be observed in the frequency domain. The results of analyses using MESA indicate that this method can intuitively distinguish the characteristics of transverse crack spacing distribution in CRC pavement containing different types of coarse aggregates.

3. **TITLE:** A Twenty-Four Year Performance Review of Concrete Pavement Sections Made with Siliceous and Lightweight Course Aggregate

AUTHORS/AGENCY/COUNTRY: Won, M.; Hawkins, K.; McCullough, B.F./Center for Transportation Research/United States

SOURCE: Texas DOT - FHWA

REPORT NUMBER/DATE: 472-3 FHWA/TX-90+472-3/April 1989

NUMBER OF PAGES: 50 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: Two experimental CRC pavement roadways were constructed on frontage roads of Interstate Highway 610 (South) in Houston, Texas during 1963-1964. One test area consists of CRC pavement made with siliceous gravel coarse aggregate. The second test area consists of CRC pavement made with lightweight coarse aggregate. Both test slabs consist of 152-mm (6-in) thick concrete on a subbase of 152-mm (6-in) cement stabilized oyster shell. Each test area was divided into sections with differing steel percentages. The bond area to volume of concrete ratio was held constant for all sections cine previous studies showed this to be an important factor. Preformed cracks were set at the design crack spacing.

Condition surveys were performed in 1964, 1974, 1984, and 1988 which included deflection measurements, spacing between cracks, spalling, and other visual distresses. Crack spacing for the lightweight aggregate after 24 years of traffic loadings was very close to the design crack spacing of 2.4 m (8 ft). The conventional aggregate section crack spacing was much smaller than the design optimal crack spacing. The conventional aggregate had more spalling as compared to the lightweight aggregate sections where no spalling was noted. The small steel percentage sections of the conventional concrete exhibited severe punchouts. No severe punchouts were noted in the lightweight aggregate sections.

Heavily reinforced sections seem to be stiffer then lightly reinforced sections up to a certain age, after which the data are more random. Overall, lightweight aggregate sections continued to show less deflections up to 1974.

Patches were not found in the lightweight aggregate sections. Several patches were required in the conventional aggregate sections and increase as the percent of steel decreases.

The lightweight aggregate concrete exhibited a lower modulus and significantly different thermal properties from the conventional aggregate concrete.

Comparison of actual crack pacing to predicted crack spacing by the program CRC pavement was found to be reasonable for the conventional aggregate but did not predict the lightweight aggregate crack spacing very well.

4. **TITLE:** Rigid Pavement Analysis and Design, Final Report, Phase I

AUTHORS/AGENCY/COUNTRY: Heinrichs, K.W.; Liu, M.J.; Darter, M.I.; Carpenter, S.H.; Ioannides, A.M./University of Illinois/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-RD-88-068; NCP 3C1b-1012/June 1989

NUMBER OF PAGES: 375 p

APPLICABLE CATEGORY: Design, Performance Evaluation

SUMMARY: This study was conducted to characterize and compare currently available rigid pavement analysis models and design methods and to develop new rigid pavement designs to be evaluated in full-scale experimental projects in an actual highway environment. The analysis models considered include: ILLI-SLAB, JSLAB, WESLIQID, WESLAYER, JCS-1, H51, CRC pavement-2, and RISC. The design methods include 1985 AASHTO Guide, Zero-Maintenance JCP-1, California DOT, PCA, RPS-3 Texas SDHPT, ARBP-CRSI, and Illinois DOT. A set of rigid pavement designs, featuring trapezoidal cross sections, widened truck lanes, permeable drainage layer, longitudinal drainage pipe, precoated dowels, shorter joint spacing (for JRCP) and tied PCC shoulders was developed for field testing through experimental projects in the various climatic zones of the United States. A project description form is provided for the interested State agencies.

5. **TITLE:** A Study of New AASHTO Pavement Design Guide - Phase I

AUTHORS/AGENCY/COUNTRY: Humphries, W.K.; Ray, G.K.; Baus, R.L./University of South Carolina, Department of Civil Engineering/United States

SOURCE: South Carolina Department of Highways and Public Transportation

REPORT NUMBER/DATE: July 1989

NUMBER OF PAGES: 87 p

APPLICABLE CATEGORY: Design

SUMMARY: This report is a presentation of a comparison of designs with AASHTO Interim Guide and the 1986 AASHTO Guide. Recommended input variables are suggested for

South Carolina's design procedure. Final conclusions noted that use of resilient modulus is a better indicator of subgrade then the previous subgrade support value. No reference is made to CRC pavement design.

6. **TITLE:** General Condition Survey of Continuously Reinforced Concrete Pavement on I-95

AUTHORS/AGENCY/COUNTRY: Shah, G.N./Maryland Department of Transportation/ United States

SOURCE: Maryland Department of Transportation

REPORT NUMBER/DATE: FHWA/MD-89/03/March 1989

NUMBER OF PAGES: 35 p

APPLICABLE CATEGORY: Construction, Performance Evaluation

SUMMARY: An evaluation of I-95 from the Baltimore Beltway to the Washington Beltway from 1981 to 1985 (5 years) is presented. The evaluation included visual ratings, roughness, friction, and deflection measurements. The CRC pavement design was based on an experimental section on I-83. I-95 is constructed of 203 and 229 mm (8 and 9 in) of CRC over 178 and 152 mm (7 and 6 in) of crusher-run aggregate in the median outside and center lanes and shoulder outside and center lanes, respectively. 0.6 percent steel was used in both thickness sections for reinforcement. On four of the contracts the longitudinal steel was placed with a tube assemble, and one the longitudinal steel was depressed into fresh concrete. The steel on the remaining contracts was preset on chair supports.

Visual condition surveys indicated that the pavement was in excellent condition during this period. The flange beam at the construction joint was deteriorated and replace with bituminous concrete.

Roughness was measured with a Mays Ride Meter. Results indicated that the rideability is satisfactory for this level of roadway. Annual friction tests indicated that the roadway surface provides an acceptable level of friction for safe travel. Deflections collected with a Road Rater indicate that the structural condition of the pavement is in adequate condition based on allowable deflections for concrete pavements set by Maryland. Traffic data indicate that traffic volume has increased substantially in all areas of the evaluated pavement.

7. **TITLE:** Rehabilitation Performance and Cost-Effectiveness - 10 Year Case Study

AUTHORS/AGENCY/COUNTRY: Hall, K.T.; Darter, M.I./University of Illinois/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: Transportation Research Record No. 1215/1989

NUMBER OF PAGES: pp 268-281

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: This paper documents a 10-year case study of pavement rehabilitation performance conducted by the Illinois Department of Transportation. The pavement section, a 203-mm (8-in), continuously reinforced concrete pavement on Interstate 57 south of Chicago, Illinois, was rehabilitated in 1978. Full-depth repair, epoxy crack sealing, undersealing, and underdrain installation were performed prior to placement of an asphalt concrete overlay. Combinations of these rehabilitation techniques were applied to six test sections on the project. The analysis investigates three components of this definition as it relates to this project: (1) What rehabilitation is appropriate, (2) How much preoverlay repair is adequate, and (3) The most appropriate time to place an overlay. The results indicate that, although the rehabilitation work performed on this project was appropriate and successful, it may not have been the most appropriate rehabilitation that could have been performed.

8. TITLE: A Continuously Reinforced Concrete Pavement Database

AUTHORS/AGENCY/COUNTRY: Dossey, T.; Weissman, A.J./Center for Transportation Research, University of Texas/United States

SOURCE: Texas Department of Transportation/Federal Highway Administration

REPORT NUMBER/DATE: 472-6 FHWA/TX-90+472-6/November 1989

NUMBER OF PAGES: 60 p

APPLICABLE CATEGORY: Performance Evaluation

SUMMARY: A data base was developed by CTI from condition network surveys dating from 1974. These surveys consisted of items that can be recognized from a visual condition survey such as crack spacing and punchouts. Diagnostic data including deflections, crack width, pavement temperature, and rut depth were measured and included in the data base since 1988.

One of the uses of the CRC pavement data base is to model pavement behavior. Data from parameters that are not included in the data base one needed. Therefore, the following relationships have been included in the data base based on previous research.

Drainage Coefficients

$$Cd = 2.171 - 0.0149(RAIN) + SBT$$

where: Cd = coefficient of drainage
RAIN = average annual rainfall, in
SBT = -0.3649 (for asphalt-treated subbases)
= -0.2784 (for cement-treated subbases)
= -0.4641 (for crushed-stone subbases)

Traffic data were not available for most of the CRC pavement data base sections. To estimate traffic in these areas several models were developed in an attempt to correlate existing data with traffic performance of a recorded section. These correlations are listed in the text and are only valid for Texas roadways.

An experiment was conducted to determine which variables influence CRC pavement performance. It was decided that these variables would be collected for data base entry. They are: design criteria, environmental factors, traffic, and pavement age.

It was decided that the data base would be written in SAS because of its permanence, ease of use, power, portability, and documentation. The data base includes a master file which is connected to condition survey data, traffic data, and diagnostic survey data.

9. **TITLE:** Fibrous P.C. Concrete Overlay Research in Greene County, Iowa, Fifteen Year Report

AUTHORS/AGENCY/COUNTRY: Marks, V.J./Iowa Department of Transportation/United States

SOURCE: Iowa Department of Transportation

REPORT NUMBER/DATE: Research Project HR-165/August 1989

NUMBER OF PAGES: 36 p

APPLICABLE CATEGORY: Overlays

SUMMARY: The Greene County, Iowa, overlay project, completed in October 1973, was evaluated in October 1978 after 5 years, in October 1983 after 10 years, and most recently in October 1988 after 15 years of service. The 33 fibrous concrete sections, four CRC pavement sections, two mesh reinforced and two plain concrete sections with doweled reinforcement were rated relative to each other on a scale of 0 to 100. The rating was conducted by original members of the Project Planning Committee, Iowa DOT, Iowa County, Federal Highway Administration, and industry representatives. All experimental overlay sections had performed quite well in the period from 5 through 15 years, experiencing only limited additional deterioration. The 102-mm (4-in) thick bar reinforced overlay section performed second best. The best performance of a fibrous reinforced concrete section was obtained with 95 kg/m^3 (160 lb/yd^3) of fiber. There was no significant difference in the performance of the 64-mm (2.5-in) long and 25-mm (1-in) long fibers. The 76-mm (3-in) thick fibrous concrete overlays yielded substantially better performance than the 51-mm (2-in) fibrous overlays. Substantial bonding was not achieved on any of the fibrous concrete overlay sections and, therefore, no conclusion can be reached in regard to the type of bonding. In general, the thicker, nonfibrous pavement overlay sections performed better than the fibrous reinforced concrete overlays.

ANNOTATED BIBLIOGRAPHY FOR 1990

1. **TITLE:** Continuously Reinforced Pavements: Punchouts and Other Distresses and Implications for Design

   AUTHORS/AGENCY/COUNTRY: Zollinger, D.G.; Barenberg, E.J./University of Illinois/ United States

   SOURCE: Illinois Department of Transportation

   REPORT NUMBER/DATE: FHWA/IL/UI/227/March 1990

   NUMBER OF PAGES: 405 p

   APPLICABLE CATEGORY: Design, Performance Evaluation

   SUMMARY: This report covers the causes for distress in CRC pavements. The primary types of distress leading to reduction in service life were noted to be punchouts and crack spalling. The causes for both the punchout and spalling distresses were determined to be loss of support below the pavement slab. A mechanism is detailed describing the process of punchout development. A method of CRC pavement evaluation is suggested along with a framework for the mechanistic design of this particular pavement type. The design procedure is dependent on crack spacing and consequently, it is necessary to be able to predict crack spacing before the design procedure can be applied. It was also noted that while crack spacing can be controlled to some extent by the amount of reinforcing steel and steel placing, the dominant factor in crack spacing appears to be climatic conditions at the time of construction. This report points out the need for controlled crack spacing in CRC pavements.

2. **TITLE:** Implementation of the New AASHTO Pavement Design Procedure in Louisiana

   AUTHORS/AGENCY/COUNTRY: Temple, W.H; Carpenter, W,, Jr./Louisiana Transportation Research Center/United States

   SOURCE: Louisiana Department of Transportation

   REPORT NUMBER/DATE: 218 FHWA/LA-90/218/June 1990

   NUMBER OF PAGES: 110 p

   APPLICABLE CATEGORY: Design

   SUMMARY: This report documents Louisiana's recommended inputs for the new AASHTO Design Guide. A computer program was developed to calculate equivalent ESAL's and required pavement thickness based on test results of materials commonly used in Louisiana. No reference is made to CRC pavements.

3. **TITLE:** Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Federal Highway Administration/United States

SOURCE: Federal Highway Administration

REPORT NUMBER/DATE: Technical Advisory T5080.14/June 5, 1990

NUMBER OF PAGES: 12 p

APPLICABLE CATEGORY: Design, Construction, Maintenance/Rehabilitation

SUMMARY: Recommended practices for the design, construction, and repair of CRC pavement are presented in this advisory. Observations during the 1970's and early 1980's indicated that CRC pavement built thinner than jointed concrete pavements (JCP) developed distresses sooner than expected. It is therefore, recommended to use slab thicknesses equal to JCP unless local performance of thinner CRC pavement designed with an accepted method is satisfactory.

Both design and construction practices were connected to premature CRC pavement failures. Specifically: (1) construction practices resulting in pavements not meeting design requirements; (2) designs resulting in excessive deflections under heavy loads; (3) inferior quality bases; (4) combinations of the above and other undesirable factors. It is recommended to use at least 0.6 percent longitudinal steel (0.7 percent when the average minimum monthly temperature is below -12.2 °C (10 °F)). Longitudinal steel should be Grade 60, spaced not less than 102 mm (4 in) or 2½ times the maximum size aggregate, whichever is greater and not more than 76-mm (3-in) 4 minimum ratio of 0.012 mm^2 (0.03 in^2) of steel bond area per mm^3 (in^3) of concrete is recommended. Longitudinal steel should be placed at ⅓ to ½ of the depth from the surface of the pavement. A minimum concrete over 64 mm (2½ in) should be used. A minimum lap of 25 bar diameters is recommended for splicing. The splice pattern may be skewed (at least 30° from perpendicular to centerline) or staggered (not more than ⅓ of the bars should terminate in the same transverse plane and the minimum distance between staggers should be 1.2 m (4 ft)). If epoxy coated steel is used, the lap and bond area should be increased by 15 percent. If transverse reinforcement is omitted, the longitudinal joints should be tied.

Stabilized bases are recommended for pavement under heavy traffic. Positive drainage and erosion resistant bases have contributed to better CRC pavement performance. Polyethylene sheeting should not be used as bondbreaker between the slab and the base, unless the low friction is accounted for in the design. CRC pavement should not be built on top of expansive or frost susceptible soils.

Joint details and construction recommendations are included in this Technical Advisory.

4. **TITLE:** Design of Continuously Reinforced Concrete for Airports

AUTHORS/AGENCY/COUNTRY: ACI Committee 325/American Concrete Institute/United States

SOURCE: American Concrete Institute

REPORT NUMBER/DATE: ACI 325.SR-90

NUMBER OF PAGES: 12 p

APPLICABLE CATEGORY: Design

SUMMARY: The report presents a design procedure for airport CRC pavements. It is not directly related to highways, therefore an extensive summary was not prepared.

5. **TITLE:** Mechanistic Design Consideration for Punchout Distress in CRC Pavement

AUTHORS/AGENCY/COUNTRY: Zollinger, D.G.; Barenberg, E.J./Transportation Research Board/United States

SOURCE: Transportation Research Board

REPORT NUMBER/DATE: 1990

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design, Current Research

SUMMARY: As part of a study to develop a mechanistic design for CRC pavements which accounts for punchout distresses, mechanisms related to the loss of load transfer and the punchout development were proposed.

Four basic failure modes leading to punchout distress were identified from an indepth field study. These modes are: fracture due to reinforcing bar pullout from the surrounding concrete, spalling of the transverse crack, loss of load transfer along transverse cracks and longitudinal cracking (due to excessive bending stresses in the transverse direction). Finite element program ILLI-SLAB was used to calculate stresses and deflections for some typical distress configurations observed in the field. The effects of tied shoulders, widened lanes, partial subgrade support and locally reduced slab stiffness were accounted for using ILLI-SLAB. The effect of crack width, pavement stiffness and load transfer on the failure mechanisms was demonstrated. The paper provides a basis for future CRC mechanistic design procedures.

Non-erodible subbase, uniform and adequate subgrade support, and high load transfer efficiency at the cracks are critical to good CRC pavement performance. The optimum crack spacing was identified as 0.9 to 1.2 m (3 to 4 ft).

6. **TITLE:** Quality Workmanship in Rapid Repair of Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Carmichael, R.F., III/American Concrete Institute/United States

SOURCE: American Concrete Institute

REPORT NUMBER/DATE: Concrete International: Design & Construction Vol. 12 No. 3/ March 1990

NUMBER OF PAGES: pp 42-47

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: This article points out the importance of quality workmanship on rapid repair projects, and notes the National Cooperative Highway Research Program's (NCHRP) Project 10-24 which identified, described, and evaluated methods that have been and are being used for rapid replacement of full lane-width segments of CRC pavement, JRCP, and JCP pavements. The article presents summary findings for planning, design, construction, and performance that are the result of literature surveys and interviews with State and national agencies in 1982, initial site visits by the researchers in 1983, long-term repair performance monitoring from 1983 to 1987, and final repair visits and reviews in 1987.

7. **TITLE:** A Study of Patching Methods for CRC Pavements

AUTHORS/AGENCY/COUNTRY: Sanders, M.R./South Carolina Department of Highways and Public Transportation/United States

SOURCE: South Carolina Department of Highways and Public Transportation

REPORT NUMBER/DATE: 1990

NUMBER OF PAGES:

APPLICABLE CATEGORY: Current Research

SUMMARY: The primary objective of this study is to evaluate the effectiveness of patching procedures versus other methods of patching CRC pavement. Also, this research project will evaluate the overall rehabilitation project's effectiveness concerning the drainage, longitudinal crack sealing and joint sealing procedures.

8. **TITLE:** A New Design Approach for Control of Cracking in Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Yoichi A.; Syoichi K.; Ryoichi S.; Yoshitaka H.

SOURCE: 2nd International Workshop on the Theoretical Design of Concrete Pavements (CROW) held in Madrid, Spain

REPORT NUMBER/DATE: October 1990

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: Crack width, crack spacings, and shear transfer at cracked sections of Continuously Reinforced Concrete Pavements (CRC pavement) have been investigated by full-scale experimental pavement and laboratory experiment. It is verified in the laboratory experiment that the crack width has to be kept within 0.5 mm (0.02 in) to ensure satisfactory load transfer at cracked section. New design equations for deciding the amount and the position of the reinforcing bars have been developed to control crack width. The equations are based on the bond stress - slip relationship between reinforcing bars and concrete in consideration of the effects of both reinforcement ratio and eccentric arrangement of reinforcing bars. The equations have been verified through the experimental pavements. As a result, the validity of the proposed method for controlling the crack width and reinforcement stress have been confirmed.

9. **TITLE:** The Effect of Heavy Loads on the Stress Distribution at the Surface of a CRC Pavement

AUTHORS/AGENCY/COUNTRY: Deleurence, J.; Petit, J.; Van Cauwelaert, F.; Verhoeven, K.

SOURCE: 2nd International Workshop on the Theoretical Design of Concrete Pavements (CROW) held in Madrid, Spain

REPORT NUMBER/DATE: October 1990

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: A continuously reinforced concrete pavement has been laid in 1984 within the steel mill Sidmar near the city of Ghent in Belgium. This paper deals with the tests performed in 1987 on the pavement and the analysis of the results. A French device, called "Ovalimètre," made it possible to measure the strains at several levels in a series of boreholes under the passage of the load. Expansion strains, evidently due to tensile stresses, were observed at the surface. A computer model has been developed in order to take into account surface shear stresses. The values of the shear stresses, computed from the measured strains, were high enough to induce longitudinal superficial cracks, which indeed have been observed.

10. **TITLE:** Control of Cracking in Continuously Reinforced Concrete Pavements - Research Needs

AUTHORS/AGENCY/COUNTRY: J. Silfwerbrand/Royal Institute of Technology, Department of Structural Mechanics and Engineering/Sweden

SOURCE: 2nd International Workshop on the Theoretical Design of Concrete Pavements (CROW) held in Madrid, Spain

REPORT NUMBER/DATE: October 1990

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: It has been shown that there is an optimum crack spacing resulting in a minimum distress, a prolonged pavement life and thus reduced costs. Consequently, the aim is to control cracking in continuously reinforced concrete pavements in the sense of forcing the transverse cracks to form with a regular and uniform spacing equal to this optimum.

Based on an extensive literature survey, the following items are defined as topics in need of research: (1) research and development of methods to provide a concrete structure with weakness sections; (2) determination of the necessary amount of strength reduction in the artificially created weakness section; (3) determination of crack control; (4) further development of predictions of crack spacings in concrete pavements; and (5) studies concerning possibilities to govern the crack spacing by varying material properties and environmental factors.

11. **TITLE:** Spalling of CRC Pavement

AUTHORS/AGENCY/COUNTRY: D.G. Zollinger; S.P. Senadheera; T. Tang/United States

SOURCE: Journal of Transportation Engineering, ASCE, Volume 120, No. 3

REPORT NUMBER/DATE: May/June 1990

NUMBER OF PAGES: 19 p

APPLICABLE CATEGORY: Design

SUMMARY: A study on the mechanism of spalling was conducted. Both field and analytical studies were conducted. It was found that spalling of concrete pavements originates from delaminations created in the pavement at an early age as a result of differential shrinkage.

12. **TITLE:** Illinois Pavement Feedback Data and Management System

AUTHORS/AGENCY/COUNTRY: M.I. Darter; J.P. Hall/United States

SOURCE: Illinois Highway Cooperative Research Program, University of Illinois, Urbana, Illinois

REPORT NUMBER/DATE: 517-7F/August 1990

NUMBER OF PAGES: 24 p

APPLICABLE CATEGORY: Evaluation, Rehabilitation

SUMMARY: An overview of the Illinois Pavement Feedback Data and Management System is provided. The system incorporates a comprehensive data base for over 500 pavement sections along the Illinois Interstate Highway Network. The system allows useful analysis of the performance of JRCP, CRC pavement, and AC overlays.

13. **TITLE:** Mechanistic Analysis of CRC Pavement Considering Material Characteristics, Variability, and Fatigue (CRC Pavement-5)

AUTHORS/AGENCY/COUNTRY: M. Won; K. Hankins; B.F. McCullough/Texas Department of Transportation/United States

SOURCE:

REPORT NUMBER/DATE: April 1990/1169-2

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: Provides a background to the development of CRC pavement-5 model for mechanistic analysis of CRC pavement subjected to various environmental and loading conditions. The computer program allows estimation of steel stress, crack widths, and crack spacing based on concrete properties at various ages.

ANNOTATED BIBLIOGRAPHY FOR 1991

1. **TITLE:** Final Construction Report: Experimental Thin Bonded Concrete Overlay Pavement in Houston, Texas, Demonstration Project 561

AUTHORS/AGENCY/COUNTRY: Alkier, K.W.; Ward, W.V./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: TX-91/561-1F TxDOT 561-1F/March 1991

NUMBER OF PAGES: 25 p

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: An experimental thin bonded continuous concrete pavement was constructed in Houston, Texas, July-August 1983. It was monitored until 1990. The final evaluations of this TBCO test section in March and December of 1990 seem to confirm what earlier findings reported; the pavement is in very good condition and is expected to continue to provide excellent service for the foreseeable future. After more than 7 years of continued heavy traffic of about 140,000 vehicles per day, the overall condition and appearance seem identical to any other typical CRC pavement of the

same age in the Houston area, made from the same material and subjected to the same traffic load. The overall useful life expectancy of this TBCO test section is judged to be about 15 to 20 years from date of construction in 1983. After that length of time, increasing transverse and longitudinal pavement cracking will combine to form blocks and punchouts of varying sizes, leading eventually to the need for extensive repairs and maintenance.

2. **TITLE:** A Study of Materials to Inhibit Reflective Cracking in Asphalt Overlay Placed Over CRC Pavement - Final Report

AUTHORS/AGENCY/COUNTRY: Sanders, M.R./South Carolina Department of Highways and Public Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-SC-91-01/June 1991

NUMBER OF PAGES: 61 p

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: The South Carolina Department of Highways and Public Transportation has a large investment in continuously reinforced concrete (CRC) pavements. Adequate rehabilitation of CRC pavements to protect this major investment is vital. A rehabilitation technique used on a section of I-95 in Dillon County was to remove severely distressed portions of the pavement, replace with partial or full-depth concrete patches, and overlay with asphaltic concrete. There was concern that cracks in the CRC pavement might reflect through the overlay. This study was initiated to determine if reflective cracking was a problem and to evaluate the effectiveness of several different methods of inhibiting reflective cracking (engineering fabrics, single bituminous surface treatment, and rubber asphalt chip seal). The cracks typical of CRC pavement did not present a problem in any of the test or control sections. However, reflective cracks were noted in the overlay at the boundaries of patches placed in the CRC pavement. None of the reflective crack inhibiting methods or materials used were judged to be effective in reducing or retarding these cracks.

3. **TITLE:** Development and Application of Randomness Index for Continuously Reinforced Concrete Pavements

AUTHORS/AGENCY/COUNTRY: Suh, Y.C; McCullough, B.F.; Hankins, K.D./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: Transportation Research Record No. 1307/1991

NUMBER OF PAGES: pp 136-142

APPLICABLE CATEGORY: Evaluation

SUMMARY: Transverse cracks in continuously reinforced concrete CRC pavements have various shapes in the field. The randomness of a crack increases the probability of the formation of secondary cracks and consequently increases the possibility of punchouts and Y-cracks, which are the major form of distress in CRC pavements. If the factors affecting the randomness of cracks can be identified and controlled, the pavement life will be increased. So far insufficient attention has been given to the shapes of cracks in concrete pavement design and construction. As a first step toward the study of randomness, a methodology for objectively quantifying the degree of randomness of the crack was developed. The concept for a randomness index, to be used as a tool to represent the degree of randomness, is introduced. The technique used in the derivation of present serviceability index (PSI) was used in developing the randomness index. An example of the application of the randomness index to an experimental study is also presented. It was found from the experimental study that the construction season, coarse aggregate type, and time of crack occurrence significantly affect the randomness of cracks.

4. **TITLE:** Performance of Asphalt Concrete Resurfacing of Jointed Reinforced Concrete Pavement on the Illinois Interstate Highway System

AUTHORS/AGENCY/COUNTRY: Hall, K.T.; Darter, M.I.; Hall, J.P./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: Transportation Research Record No. 1307/1991

NUMBER OF PAGES: pp 180-187

APPLICABLE CATEGORY: Evaluation, Rehabilitation

SUMMARY: A study was conducted on the survival of asphalt concrete (AC) overlays on the Illinois Interstate Highway System. Data were obtained from the Illinois Pavement Feedback System (IPFS) data base for 410 AC overlay construction sections placed on jointed reinforced and continuously reinforced concrete pavement (JRCP and CRC pavement) between 1964 and 1989. The overlays ranged in thickness from 38 to 152 mm (1.5 to 6.0 in). Both inservice life and 80 kN (18 kip) equivalent single-axle loads (ESALs) carried to rehabilitation of the overlay were analyzed through the use of survival curves. The survival of the 213 AC overlays of JRCP sections is reported. The mean age and accumulated ESAL's at the time of overlay rehabilitation were estimated for categories of overlay thickness (thin and thick) and portland cement concrete durability (with and without D-cracking). The analysis indicated that each of the factors considered, along with traffic level, had a significant effect on the life of the overlays. Thick overlays lasted substantially longer and carried substantially more traffic than thin overlays on both D-cracked and non-D-cracked pavement. Both thin and thick overlays performed much better on pavements without D-cracking than on pavements with D-cracking.

5. **TITLE:** Analysis of Three Concrete Restoration Techniques

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Fowler, D.W.; Lundy, J.R.; Hoskins, B.E./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: Transportation Research Record No. 1307/1991

NUMBER OF PAGES: pp 249-255

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: Three concrete pavement restoration techniques are described and the field performance of each is evaluated. Two of the three methods are used to restore the condition of continuously reinforced concrete pavements (CRC pavement) and the other was used to repair failed joints and broken slabs in an old plain jointed concrete pavement (JCP). Each of the techniques and the analysis results are described. A repair technique using polymer concrete to restore load transfer and seal surface cracks in several lane km (mi) of IH 610 in Houston, Texas, is described. This project, constructed in 1980, was surveyed in 1990. Results indicated that the majority of the repairs were intact after 10 years of heavy traffic. The area encompassing these polymer concrete repairs is currently being rehabilitated using a bonded overlay. One experimental section in the overlay project investigated the effectiveness of methyl methacrylate as a mop on pretreatment of the existing CRC pavement. Falling weight deflectometer (FWD) measurements taken before and after the treatment, as well as core analyses, indicated this technique to be only marginally effective in reducing deflection. A second technique used to repair longitudinal construction joints in CRC pavement before rehabilitation is described. Load transfer was reestablished by epoxying reinforcing steel in slots cut perpendicular to the joint. FWD measurements demonstrated this technique to be of significant benefit. Analyses indicated that the stress was reduced by as much as 40 percent through the use of this technique. The restoration of a two-lane JCP constructed in the 1930's was undertaken as part of an experimental test program to assess several rehabilitation options available for JCP. Deflection measurements were taken near transverse joints and longitudinal cracks before and after the repairs were made. Repairs were effected using precast joints and polymer concrete.

6. **TITLE:** Design and Construction of Bonded Concrete Overlays

AUTHORS/AGENCY/COUNTRY: W. Van Metzinger; J.R. Lundy; B.F. McCullough; D. Fowler/United States

SOURCE: Center for Transportation Research, The University of Texas at Austin

REPORT NUMBER/DATE: 1205-4F/January 1991

NUMBER OF PAGES: 82 p

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: The report summarizes studies made of the performance of bonded concrete overlays, presents information on the failure mechanisms of the overlays, and documents and improved design model for bonded overlays. The study was based on the bonded overlays placed in Houston, Texas.

ANNOTATED BIBLIOGRAPHY FOR 1992

1. **TITLE:** A Study of Patching Methods for Continuously Reinforced Concrete Pavement - Final Report

AUTHORS/AGENCY/COUNTRY: Sanders, M.R./South Carolina Department of Highways and Public Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-SC-92-03/June 1992

NUMBER OF PAGES:

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: The South Carolina Department of Highways and Public Transportation (SCDHPT) has over 966 lane km (600 lane mi) of continuously reinforced concrete (CRC) pavement on its Interstate Routes. Much of this pavement is showing signs of distress primarily in the form of punchouts. In 1985, a section of CRC pavement on I-77 in Chester and Fairfield Counties was rehabilitated under contract. A full-depth patching technique, previously developed by Department personnel that was faster and less labor intensive than other methods widely used at the time, was included in the contract. This study was initiated to evaluate the performance of these patches as well as the effectiveness of drainage measures and crack and joint sealant operations used on the project. Though the SCDHPT patches performed adequately, punchouts developed in the pavement adjacent to many of the patches. Steel reinforcing bars placed in the patches were epoxied into the adjacent pavement. It is theorized that the epoxy prevented the bars from moving, thus developing large stresses over the short distance they were embedded in the pavement. A revised patching design is being developed and plans are to place patches by the revised method on a future project. The drainage technique, shoulder drains with no longitudinal drains, was judged to be ineffective. Considering the lack of adequate drainage, the sealant operations were judged to be satisfactory though some failures occurred.

2. **TITLE:** Monitoring of Siliceous River Gravel and Limestone Continuously Reinforced Concrete Pavement Test Section in Houston 2 Years After Placement, and Development of a Crack Width Model for the CRCP-7 Program - Interim Report

AUTHORS/AGENCY/COUNTRY: Jimenez, M.A.O.; McCullough, B.F.; Hankins, K./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/TX-92+1244-4 Res Rept 1244-4 CTR 2/3-8-90/2-1244-4/March 1992

NUMBER OF PAGES: 120 p

APPLICABLE CATEGORY: Evaluation

SUMMARY: In describing the effect of coarse aggregate type on the performance of CRC pavement, this report documents the design, construction, and monitoring of 32 test sections in Houston, Texas. Constructed to evaluate the performance of pavements built in accordance with the CRCP-89(B) design detail recently developed by TxDOT, these test sections were monitored to determine the field performance of CRC pavement 2 years after construction, looking in particular at crack spacings and crack width. Then, using the observed performance of the different coarse aggregates, the study team evaluated the recently developed CRCP-89(B) design detail. Finally, using the CRCP-7 computer program, the predicted performance was compared with the measured performance of the CRC pavement test sections. Based on this comparison, a new model to be used with the CRCP-7 program -- one capable of predicting crack widths -- was developed.

3. **TITLE:** Design and Construction of Bonded Fiber Concrete Overlay of Continuously Reinforced Concrete Pavement

AUTHORS/AGENCY/COUNTRY: Temple, W.H.; Cumbaa, S.L.; King, W.M., Jr./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: Transportation Research Record No. 1335/1992

NUMBER OF PAGES: pp 36-39

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: The purpose of this research was to study the design and construction of a bonded steel-fiber-reinforced concrete overlay on an exiting 203 mm (8 in) continuously reinforced concrete pavement on Interstate 10 south of Baton Rouge, Louisiana. The existing 16-year-old CRC pavement, which is estimated to have carried twice its design load, contained several edge punchout failures per km (mi). The research objectives were to provide an overlay with a high probability for long term success by using a high strength concrete mix with internal reinforcement and good bonding characteristics. A 102-mm (4-in) concrete overlay containing steel fibers was designed. An inverted U-shaped reinforcing bar was added at the edge of the pavement to provide positive edge bonding. Shot blast surface cleaning of the existing tine surface easily met a specification requiring an average texture depth of 1.14 mm (0.045 in). Water-cement grout was applied to the cleaned surface, producing bond strengths in excess of 6.21 MPa (900 lbf/in^2). The concrete overlay in combination with 229

mm (9 in) tied concrete shoulders reduced edge deflections by 60 percent under a 97.86 kN (22,000 lb) moving single axle load applied 0.6 m (2 ft) from the edge. In general, the serviceability index of the pavement increased from 3.4 to 4.4, with measured profile index levels typically below the 79-mm/km (5-in/mi) specification. The bonded overlay has been in service since August 1990 and carries average daily traffic of 41,000 vehicles. Cores taken over transverse cracks in the overlay indicated reflection cracking from transverse cracks in the original pavement. Anticipation of reflective cracking was one consideration in using the steel fibers, which provide three-dimensional reinforcement.

4. **TITLE:** One-Dimensional Model for Analysis of CRC Pavement Growth

AUTHORS/AGENCY/COUNTRY: Xin, D.; Zollinger, D.G.; James, R.W./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: Journal of Transportation Engineering No. 4/July 1992

NUMBER OF PAGES: pp 557-575

APPLICABLE CATEGORY: Design

SUMMARY: The paper describes a one-dimensional model for predicting the structural response of continuously reinforced concrete pavement due to increasing temperature and alkali-silica reaction (ASR), taking into consideration the slip between concrete and reinforcing bar and friction between concrete and subbase material. The development and use of the model are described. The study showed that ASR may have the potential to cause larger pavement growth than normal annual temperature cycles, depending on the extent of ratcheting, which may contribute to the annual cyclic, thermally induced growth. The effect of lugs on the restraining pavement movement was found to be significant, and the present lug designs, while apparently not providing perfect restraint, appear to cause significant restraining forces. This and other findings are discussed.

5. **TITLE:** Report of the 1992 U.S. Tour of European Concrete Highways

AUTHORS/AGENCY/COUNTRY:

SOURCE:

REPORT NUMBER/DATE: FHWA-SA-93-012/December 1992

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design, Construction

SUMMARY: Report documenting the findings of a visit by U.S. pavement engineers to study concrete pavement practices and performance in European countries. Countries visited

were France, Austria, Germany, Netherlands, and Belgium. A good discussion of CRC pavement practices in the different countries is presented. European countries generally use about 0.67 to 0.85 percent steel and report good performing CRC pavement. Also, higher strength concrete and good base/subbase support were routinely used. The use of design catalogs by the Europeans is also discussed.

6. **TITLE:** Design and Construction of a Bonded Fiber Concrete Overlay of CRCP

AUTHORS/AGENCY/COUNTRY: W.M. King, Jr./United States

SOURCE: Louisiana Transportation Research Center, Baton Rouge, Louisiana

REPORT NUMBER/DATE: FHWA/LA-92-266/January 1992

NUMBER OF PAGES: 25 p

APPLICABLE CATEGORY: Rehabilitation

SUMMARY: A study was conducted to evaluate the use of a bonded steel fiber reinforced concrete overlay on an existing 203 mm (8 in) CRC pavement on I-10, south of Baton Rouge, Louisiana. The project also utilized curb type reinforcement bars epoxied into the existing CRC pavement. The bonded overlay thickness was 102 mm (4 in). After three years of service, only 35 percent of the transverse cracks had reflected through the bonded overlay. The bonded overlay, after 3 years of service, appears to be performing well.

ANNOTATED BIBLIOGRAPHY FOR 1993

1. **TITLE:** Performance of Bare and Resurfaced JRCP and CRCP on the Illinois Interstate Highway System -- 1991 Update - Interim Report

AUTHORS/AGENCY/COUNTRY: Hall, K.T.; Darter, M.I.; Rexroad, W.M./United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA-IL-UI-244 UILU-ENG-93-2005 Res Rept 532-1/ October 1993

NUMBER OF PAGES: 96 p

APPLICABLE CATEGORY: Evaluation, Rehabilitation

SUMMARY: Two previous studies on the survival of bare and asphalt-overlaid concrete pavements on the Illinois Interstate Highway System were updated to reflect the performance of the pavements through 1991. The Illinois Interstate Highway System consists of about 2816 km (1,750 mi) of 254 mm (10 in) jointed reinforced concrete pavement (JRCP) and CRCP ranging in thickness from 178 to 254 mm (7 to 10 in). As of 1991, about 60 percent of these pavements had been overlaid with asphalt concrete

(AC), ranging in thickness from 38 to 152 mm (1.5 to 6.0 in). Data for the survival analysis were retrieved from the Illinois Pavement Feedback System database. Both inservice life and accumulated 80 kN (18 kip) ESAL's at rehabilitation were estimated for bare pavements categorized by type, thickness, and D-cracking susceptibility, and for overlaid pavements categorized by overlay thickness, overlaid pavement type, and D-cracking susceptibility. The results show the effects of D-cracking, traffic level, pavement type, pavement thickness, and overlay thickness on performance of bare and resurfaced concrete pavements.

2. **TITLE:** Recycling Old PCC Pavement - Performance Evaluation of FAI 57 Inlays - Final Report

AUTHORS/AGENCY/COUNTRY: Schutzbach, A.M./Illinois Department of Transportation/United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: FHWA/IL/PR-113 Physical Res Rept No. 113/February 1993

NUMBER OF PAGES: 55 p

APPLICABLE CATEGORY: Evaluation, Rehabilitation

SUMMARY: This report details the construction and performance monitoring efforts of two demonstration projects proposed in an experimental features work plan entitled "Recycling Old PCC Pavement." The objectives of this experimental feature were to evaluate the viability of recycling old PCC pavements into new inlays and to determine the subsequent performance of the recycled pavements. Two demonstration projects were undertaken to make this evaluation. On one project, an old, badly faulted, JRC pavement containing high quality aggregates was recycled into a new CRC inlay. On the second project, a deteriorated CRC pavement containing D-cracking susceptible aggregates was recycled into a full-depth AC inlay. Inlays were constructed because the existing shoulders were in good condition. Both demonstration projects were constructed in a 2-year phase, beginning in 1986. The construction of both projects was monitored. Performance monitoring of the recycled pavement began in 1987, and included friction testing, ride quality testing, visual distress surveys, and deflection testing with a FWD. After 5 to 6 years in service, no major maintenance has been required and both pavements are performing well.

3. **TITLE:** Preliminary Distress and Performance Prediction Models for Concrete Pavements in Texas - Interim Report

AUTHORS/AGENCY/COUNTRY: Singh, N.; Dossey, T.; Weissmann, J.; Hudson, W.R./ United States

SOURCE: National Technical Information Service

REPORT NUMBER/DATE: TX-94+1908-1 Res Rept 1908-1 CTR 7-1908-1/August 1993

NUMBER OF PAGES: 156 p

APPLICABLE CATEGORY: Design, Evaluation

SUMMARY: This document presents the results of a study to develop and test distress and performance prediction models for rigid pavements (CRC, JRC, and JPC pavements) in Texas. These models were developed for the Texas Department of Transportation (TxDOT) for possible incorporation into their Texas Pavement Management Information System (PMIS). Data for testing the models were obtained from data bases maintained by TxDOT and the Center for Transportation Research (CTR) at the University of Texas at Austin. The data base maintained by TxDOT is part of the Department's Pavement Evaluation System (PES). Additional maintenance and rehabilitation (M&R) data were obtained from TxDOT district offices. The modeling process consisted of first identifying the prevalent distress manifestations for rigid pavements in Texas. The available data sources were then studied to determine whether data were available to test models for the prevalent distress manifestations identified. A survey was conducted to collect M&R data from TxDOT district offices. These M&R data were merged with the PES condition evaluation data in order to separate the condition data into M&R categories. Four M&R categories were defined: preventative, light, moderate, and heavy. A study was also performed to determine the compatibility between the PES and CTR data bases. Condition data from the PES and CTR databases were analyzed using the statistical analysis software, SAS. Scatter charts of distress levels versus pavement age were plotted to identify any trends in distress level with pavement age. Distress data from the CTR data base for non-overlaid CRC pavement sections displayed little variance and a reasonable trend with pavement age. Hence the prediction models developed using these data are reliable and robust.

The data available for asphalt-overlaid CRC pavement and JCP sections, and for non-overlaid JCP sections from the CTR and PES data bases, were sparse and less detailed. Except for the non-overlaid JCP data, the remaining data showed no definite correlation between distress level and pavement age. Therefore, the models developed for overlaid CRC pavement and JCP sections, and for non-overlaid JCP sections, are less reliable. Although the models presented in this study make only a small contribution to network-level pavement management, they do serve as a starting point for further development by helping to identify data requirements for developing future statistically significant models.

4. **TITLE:** The Construction and Performance of Concrete Pavements Reinforced with Flexarm

AUTHORS/AGENCY/COUNTRY: Peshkin, D.G; Darter, M.I.; Aunis, J./United States

SOURCE: Proceedings, 5th International Conference on Concrete Pavement Design and Rehabilitation

REPORT NUMBER/DATE: April 1993

NUMBER OF PAGES: 9 p

APPLICABLE CATEGORY: Design

SUMMARY: Paper provides information on the development of Flexarm steel reinforcement for CRC pavement construction in France. Flexarm steel is a flat ribbon, 2.03 mm (0.08 in) thick by 39.9 mm (1.57 in) wide, that is dented to provide a deformed surface. The flat surfaces are heat galvanized. The performance of two CRC pavements constructed using Flexarm was evaluated and is reported. Flexarm was used in the amount of 0.30 percent. The Flexarm sections exhibited crack spacing that was "longer than usual and some of the cracks were spalling and had opened slightly." The galvanized steel was also identified as a possible item of concern, for use of Flexarm in the U.S.

5. **TITLE:** Long Term Performance of Uncontrolled Longitudinal Cracking and Failed Longitudinal Joints in CRCP

AUTHORS/AGENCY/COUNTRY: Moody, E.D.; McCullough, B.F./United States

SOURCE: Proceedings, 5th International Conference on Concrete Pavement Design and Rehabilitation

REPORT NUMBER/DATE: April 1993

NUMBER OF PAGES: 7 p

APPLICABLE CATEGORY: Design

SUMMARY: The paper presents a summary of procedures used to repair uncontrolled longitudinal cracking and failed longitudinal joints at several CRC pavement projects in Texas. The repairs included widening the crack and filling it with polymer concrete and use of stitching technique for failed longitudinal joints. The repairs were reported to have performed well after several years.

6. **TITLE:** Prediction of CRCP Terminal Movements

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Moody, E.D./United States

SOURCE: Proceedings, 5th International Conference on Concrete Pavement Design and Rehabilitation

REPORT NUMBER/DATE: April 1993

NUMBER OF PAGES: 10 p

APPLICABLE CATEGORY: Design

SUMMARY: A study was conducted to determine information about CRC pavement terminal movement. A mechanistic model, PSCP2, was used to analyze free end movement and to predict the amount of terminal movements. Field measurements were also

conducted at SH-225 in Houston, Texas. Study showed that the maximum length of CRC pavement moving is 381 m (1,250 ft) CRC pavement with limestone aggregate concrete has approximately two-thirds the end movement of CRC pavement with siliceous river gravel concrete. Also, winter placement generates about 25 percent less end movement than summer placement and friction is a significant factor affecting end movement of CRC pavement.

7. **TITLE:** Cracking and Corrosion in CRCP

AUTHORS/AGENCY/COUNTRY: K. Verhoeven

SOURCE: Proceedings, 5th International Conference on Concrete Pavement Design and Rehabilitation

REPORT NUMBER/DATE: April 1993

NUMBER OF PAGES: 9 p

APPLICABLE CATEGORY: Design, Evaluation

SUMMARY: The Belgian experience with CRC pavement was reported. Initially, 0.85 percent steel was used in conjunction with lean concrete base and a bituminous base course over the LCB. Because of small crack spacing and a rougher ride, the reinforcement percentage was reduced to 0.67 percent in the late 1970's. Also the use of the bituminous base course was eliminated. The performance of inservice 20 test sections was evaluated and is reported. The sections with 0.85 percent steel and small crack spacing were performing well. The sections with 0.67 percent steel placed directly on the LCB has a wide range of crack spacing possibly because of the CRC pavement adhesion to the LCB. Corrosion of the steel was found to be normal.

8. **TITLE:** Analysis of CRCP Under Moisture, Temperature, and Creep Effects

AUTHORS/AGENCY/COUNTRY: Kadiyala, S.M.; Zollinger, D.G./United States

SOURCE: Proceedings, 5th International Conference on Concrete Pavement Design and Rehabilitation

REPORT NUMBER/DATE: April 1993

NUMBER OF PAGES: 24 p

APPLICABLE CATEGORY: Design

SUMMARY: A numerical procedure is presented for studying the effects of steel reinforcement and environmental parameters on the early age behavior of CRC pavement. Both thermal and shrinkage strains are determined. Finite element technique was used for the theoretical modeling. Comparisons were made with Vetter's analysis procedures for determining steel stress.

9. **TITLE:** Concrete Pavement Design and Construction Practices by the Texas DOT

AUTHORS/AGENCY/COUNTRY: A.J. Wimsatt/United States

SOURCE: Proceedings, 5th International Conference on Concrete Pavement Design and Rehabilitation

REPORT NUMBER/DATE: April 1993

NUMBER OF PAGES: 24 p

APPLICABLE CATEGORY: Design, Construction

SUMMARY: Paper presents a summary of practices of Texas DOT for concrete pavement design and construction. The practices for CRC pavement are also presented. CRC pavement is the most widely used concrete pavement type in Texas. Texas DOT specified steel reinforcement as a function of slab thickness and ranges from 0.43 percent for 203-mm (8-in) thick CRC pavement to 0.61 percent for 305-mm (12-in) thick CRC pavement.

10. **TITLE:** Development of Load Transfer Coefficients for Use with the AASHTO Guide Based on Field Measurement

AUTHORS/AGENCY/COUNTRY: McCullough, B.F.; Moody, E.D./United States

SOURCE: Proceedings, 5th International Conference on Concrete Pavement Design and Rehabilitation

REPORT NUMBER/DATE: April 1993

NUMBER OF PAGES: 16 p

APPLICABLE CATEGORY: Design

SUMMARY: The paper documents the development of appropriate load transfer coefficients for the design of CRC pavement in Texas. Findings are based on theoretical analysis (using finite element method) and field testing. Field testing indicated that concrete shoulders reduced edge deflections. Recommendations were made for J-values for Texas conditions.

11. **TITLE:** Distress Identification Manual for Long Term Pavement Performance Project

AUTHORS/AGENCY/COUNTRY: Strategic Highway Research Program/United States

SOURCE: Strategic Highway Research Program

REPORT NUMBER/DATE: 1993

NUMBER OF PAGES: 147 p

APPLICABLE CATEGORY: Evaluation

SUMMARY: The Distress Identification Manual (DIM) was developed to provide a consistent, uniform basis for collecting distress data for SHRP's LTPP program. The manual is divided into three sections - asphalt concrete surfaced pavements, jointed portland cement concrete pavements, and continuously reinforced concrete pavements. Each distress is clearly described with photographs, and severity levels are explained.

12. **TITLE:** AASHTO Guide for Design of Pavement Structures - 1993

AUTHORS/AGENCY/COUNTRY: AASHTO/United States

SOURCE: Association of American State Highway and Transportation Officials

REPORT NUMBER/DATE: 1993

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: This is a revised version of the 1986 AASHTO Guide. The primary revisions were made in Part III - Pavement Design Procedures for Rehabilitation of Existing Pavements. The design procedures for new construction are essentially the same as those originally presented in the 1986 Guide. The Guide contains a thickness design procedure for concrete pavements (applicable to both jointed and CRC pavement) and a procedure for estimating the amount of longitudinal steel for CRC pavement. Also, overlay design procedures are presented and are applicable to existing CRC pavement.

13. **TITLE:** Design of CRCP for Highways (Program CRC-HIGHWAY PAVE)

AUTHORS/AGENCY/COUNTRY: B.F. McCullough/United States

SOURCE: Concrete Reinforcing Steel Institute

REPORT NUMBER/DATE: June 1993

NUMBER OF PAGES:

APPLICABLE CATEGORY: Design

SUMMARY: A revised design procedure for CRC pavement for highways is presented. This procedure uses the computer program CRC-HIGHWAY PAVE which is based on more rigorous analytical procedures developed at the University of Texas at Austin. The procedure also checks for longitudinal cracking, in addition to developing a set of solutions for steel content based on anticipated crack spacing, crack width, and steel stress.

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1. **TITLE:** The Bond Strength of a Reinforcing Unit for CRCP and its Importance in CRCP Design Procedures

   AUTHORS/AGENCY/COUNTRY: G. Guerin; D. Peshkin; V. Gillet/United States

   SOURCE: Unpublished Report, SOLLAC, France

   REPORT NUMBER/DATE: 1994

   NUMBER OF PAGES: 24 p

   APPLICABLE CATEGORY: Design

   SUMMARY: A new procedure for performing steel pull-out tests was developed and is compared with conventional procedures. Testing was done using Flexarm reinforcing strips.

2. **TITLE:** Image-Based Expert System Approach to Distress Detection on CRCP

   AUTHORS/AGENCY/COUNTRY: S. Tsao, et al.

   SOURCE: Journal of Transportation Engineering, ASCE

   REPORT NUMBER/DATE: Vol 120, No. 1/January/February 1994

   NUMBER OF PAGES: 14 p

   APPLICABLE CATEGORY: Evaluation

   SUMMARY: The paper discusses an image-based expert system to provide an automated evaluation of CRC pavement distresses.

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