NATIONWIDE EVALUATION OF CONCRETE PAVEMENTS - ILLINOIS DEMONSTRATION

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This paper describes the COncrete Pavement Evaluation System (COPES). This computerized system is capable of efficiently collecting, processing and evaluating large amounts of pavement data to improve the design, construction, materials, and maintenance of concrete pavements. The COPES data bank also provides extensive information that can be used for many pavement management purposes. Both historical data (e.g., design, traffic, construction, maintenance, climate, materials, . . .) and field data (e.g., distress, serviceability, . . .) are obtained for each pavement section included in COPES. Jointed plain, jointed reinforced and continuously reinforced pavements can all be included in COPES. The user can retrieve pavement information rapidly and easily using a remote computer terminal, and can perform many analyses and evaluations of the data. COPES was demonstrated on over 400 miles (644 km) of Interstate pavement in Illinois. Brief results from the Illinois demonstration included in this paper show that much valuable information can be obtained through the evaluation of in-service concrete pavements on a state level, and indicates the great potential value for evaluating pavements on a nationwide level. This would permit the development of broad based recommendations to be used by individual states, AASHTO and FHWA for improving concrete pavement technology.

A system for state and nationwide evaluation of concrete pavements has been developed. The system was developed under the National Cooperative Highway Research Program Project 1-19 at the University of Illinois. The overall objective of the COncrete Pavement Evaluation System (or COPES) is to provide a system to periodically collect, store and retrieve, and evaluate data from all types of in-service concrete pavements (see Figure 1).

COPES can be used for a wide variety of purposes including: improvement of design, construction and materials, maintenance and rehabilitation procedures; provision of a data base for planning rehabilitation needs and assisting in their design; and generation of reports useful for administration and other purposes. The initiation of the Federal RRR program increases the need for a continuous evaluation system from which reports can be generated about the condition of a pavement network. COPES is designed to meet these objectives at both a state and eventually a national level after collection of data from a number of states.

This paper briefly describes COPES and presents a few results on distress and serviceability prediction obtained from field testing in one state. Detailed information can be obtained from the NCHRP Project 1-19 final report (1).

Description of Copes

Data Collection

COPES is developed to include the three conventional pavement types: jointed plain concrete pavement (JPCP), jointed reinforced concrete pavement (JRCP), and continuously reinforced concrete pavement (CRCP). The procedures specify what data to collect and how to collect the data.

First, the concrete pavement network is divided into "uniform sections." A uniform section has uniform characteristics along its length including structural design, joints, reinforcement, truck traffic, subgrade conditions, etc. Generally, the entire construction project length will be a uniform section.

Next the collection of historical and field data begins. The historical data includes over 325 variables relative to project identification; location, environment, structural design, joint design, reinforcing steel, concrete, base, subgrade, shoulder, drainage, serviceability, roughness, skid resistance, traffic, maintenance and rehabilitation. The historical data are recorded on 13 sheets that are specifically prepared for direct keypunching onto computer cards or other medium. The historical data can normally be obtained directly from the state department of transportation original construction plans, standards, specifications, construction and materials reports, traffic studies, climatic records, and other sources.

The field data collection procedures describe how to obtain all needed data from a given highway construction project during a single visit to the project by a 2-3 person survey team.

The survey procedure provides for the efficient collection of all existing distress data on 11 data

sheets. A comprehensive distress identification manual (1) has been developed to provide for standardized uniform data collection. The manual describes each distress type and its general mechanism, defines levels of severity, describes measurement methods, and provides many typical photographs. COPES relies heavily on the use of existing pavement distress to conduct the many analyses and evaluations subsequently described.

The following survey time estimate shows that data can be collected relatively efficiently by a trained survey team:

Good Pavement Condition - 1/2 hr/mile (1/3 hr/km) (2 lanes)

Fair Pavement Condition - 3/4 hr/mile (1/2 hr/km) (2 lanes)

Poor Pavement Condition - 1 hr/mile (2/3 hr/km) (2 lanes)

No expensive equipment is needed to conduct the field survey. Only items such as a hand odometer, measuring tape, ruler, and faultmeter are required.

Data Storage and Retrieval

Large amounts of data must be collected and processed by COPES for a typical state highway network, and especially for nationwide evaluation over many states. Thus, the use of automatic data processing (ADP) is essential for successful operation. The system for data management used in COPES is the Scientific Information Retrieval (or SIR) (2) that provides efficient storage and retrieval of large amounts of data and many other capabilities. The statistical analyses of the data can be performed using the SPSS (Statistical Package for the Social Sciences) (3) or the Bio-Med Computer Package (BMDP) (4).

Data retrieval and analysis is easily accomplished using SIR by either batch mode (e.g., card decks) or interactive mode using a computer terminal. The terminal can be located in the user's office and connected to the computer by means of telephone lines. The user sitting at a computer terminal can input and execute a set of SIR commands, retrieve data files in any desired format, conduct many kinds of analyses on the data, etc.

Data Analysis and Evaluation

The evaluation procedures analyze the extensive field survey data and the historical data to provide information that is useful to several areas of a highway agency. These evaluations are categorized as follows:

1. Network facility data summary - a summary of what has been constructed and when (e.g., mileage of various design types, distribution of age of pavements, traffic loads, climate, subgrade soils, drainage, materials, maintenance and rehabilitation).
2. Condition data summary - includes all distress types, amount and severity, patching, roughness, serviceability, skid resistance, rates of deterioration.
3. Distress prediction and causation - identification of factors causing distress, development of models for prediction of distress, and selected analyses such as determining the amount of pavement deterioration caused by truck traffic and the amount caused by climate.
4. Design - evaluation of the adequacy of existing design procedures for foundation, subbase, drainage, joints, reinforcement, slab thickness, and shoulders; and pavement life studies.
5. Construction and materials - an evaluation of construction for slab, joints, shoulder, subbase, and foundation; and the materials used therein. The effect of quality control of construction on performance is one aspect that can be evaluated.
6. Maintenance - evaluation of the effectiveness of maintenance efforts (such as patch performance), or conversely, the effects of not applying maintenance on the amount and rate of deterioration.
7. Rehabilitation needs - the overall data contained in COPES provides an excellent basis to assist in determining the existing and future rehabilitation needs of the highway network. Most of the data to determine rehabilitation needs are contained in the COPES data bank.
8. Nationwide evaluation - data from many states can be combined and analyzed to provide a nationwide evaluation.
9. Research needs - can be determined based upon the most serious types of pavement deterioration and other information obtained from the COPES data bank.
10. Other - as COPES is used, there will likely be many additional uses of the system discovered.

Illinois Demonstration

COPES was demonstrated in Illinois using over 400 miles (644 km) of jointed reinforced concrete pavement (JRCP) located on Interstate highways. Only a brief summary of distress and serviceability prediction, design evaluation, and determining future rehabilitation needs from one state are described herein. Since the results given herein are based on data from only one state, they may not be applicable elsewhere.

Data Sources

Three different data sources were used in the Illinois demonstration.

Data Set A - 123 regular construction projects (containing 142 uniform sections) which represents nearly all of the JRCP constructed on the Interstate system between 1957 and 1973. These pavements have 100 ft. (30 m) joint spacing, a 10 in. (254 mm) slab, and granular base courses. All of this data were collected in 1979 by the project staff with the assistance of IDOT.

Data Set B - 20 sections constructed on I-80 in 1962. They include stabilized and non-stabilized subbases, 8-10 in. (203-254 mm) slabs, and 40-100 ft. (12-30 m) joint spacing. Performance data were obtained from 1962 through 1974 by IDOT (5).

Data Set C - 22 sections originally part of the AASHO Road Test that were left in service on I-80 from 1962 to 1974. These pavements ranged in slab thickness from 8 to 12.5 in. (203-318 mm). The data were collected by IDOT over this time period.

Distress Prediction and Causation

The Illinois data provides an excellent source from which to develop equations that predict the occurrence of distress in JRCP. These equations are useful for (1) explaining the causes of distress, (2) improving design procedures, and (3) pavement management purposes such as estimating future maintenance costs and pavement life. These equations should only be considered as tentative and applicable only to Illinois.

Twenty-one different distress types were identified, and the occurrence of some of these distresses

at medium to high severity levels have led to serious roughness problems and maintenance requirements. The major distress types that affect the rideability of these pavements are given in order of significance: mean joint faulting, transverse joint deterioration, transverse cracking deterioration, longitudinal joint spalling, corner breaks, longitudinal cracking, depressions and swells. These results show what has long been known by experienced pavement engineers, that concrete pavement performance could be improved greatly if transverse joint faulting and deterioration could be reduced. The deterioration of transverse cracks in the slab is also a very significant distress affecting performance.

As an example, three prediction equations are presented herein for transverse cracking, joint faulting, and joint deterioration. Equations could be developed for many other distress types.

Transverse Crack Deterioration (Data Sets A, B, and C)

These cracks are hairline when they occur and steel reinforcement is provided to keep the crack tight so that good aggregate interlock will exist. However, due to a variety of causes, many of these cracks deteriorate over time into working spalled and faulted cracks which result in roughness and potential blowup locations. The medium and high severity transverse cracks were one of the three most significant distresses causing loss of serviceability.

Multiple regression methods were used to develop the following predictive equation: transverse cracking of medium to high severity in units of no./mile was the dependent variable with age (0-22 years), equivalent single 18-kip axle loads (ESAL) (0-18 million), slab thickness (8-12.5 ins.), joint spacing (40-100 ft.), reinforcement content (.09-.17 in.^{2}/ft. width), and subbase type (granular and stabilized) the independent variables.

$$TC = AGE*ESAL \left[-1.500 + \frac{1.113}{H*ASTEEL} + \frac{4.584}{L} + \frac{1.129}{STAB + 1}\right] \quad (1)$$

where

TC: Transverse cracks of medium or high severity, no./mile

AGE: Age of the pavement, years

ESAL: Equivalent 18-kip single-axle loads, millions

ASTEEL: Area of longitudinal reinforcing steel, in.^{2}/ft. width of lane

L: Joint spacing, ft.

STAB: 1, if stabilized subbase (asphalt or cement) or 0, if granular subbase

H: Slab thickness, ins.

Statistics: R^2 = 0.52 (Sig. at < .01 level)

Std. error = 39 cks/mi.

n = 622 sections

Equation 1 was evaluated through sensitivity analysis to ascertain its reasonableness. Figures 2 and 3 illustrate the relative influence of several variables. Percent reinforcement has a very great effect on the amount of deteriorated transverse cracks, particularly below 0.12 percent. Increased slab thickness also has a large influence on decreasing crack deterioration.

One of the most significant variables was subbase type. The stabilized subbase reduced the amount of deteriorated cracks by a large amount. This reduction may be caused in part by the reduction in deflection and pumping, and thus less flexing at cracks reducing the wearout due to repeated truck loads. Further analysis shows that both asphalt stabilized and cement stabilized subbase provide approximately the same structural benefits.

Transverse Joint Faulting Prediction. Data sets A, B and C were used in stepwise multiple regression analyses to develop a predictive equation for transverse joint faulting. JRCP exhibits no faulting when newly constructed. Faulting then occurs with time and traffic as the transverse joints lose their load transfer efficiency through pumping and deterioration of the concrete surrounding the dowel bars. Thus the principal variables believed to influence the rate of increase of transverse joint faulting include traffic load repetition and the dowel bar bearing stress. Friberg's procedure was used for estimating dowel bearing stress as a function of dowel bar diameter, slab thickness, transverse joint spacing, joint opening and foundation support. Stepwise multiple regression analysis resulted in the following predictive model:

$$\ell n\,(F + 1) = \ell n\,(ESAL + 1)\,[-9.130 \times 10^{-2} + 1.394 \times 10^{-4} * BSTRESS] \quad (2)$$

where

F: Transverse joint faulting of adjacent slabs, inches

ESAL: Cumulative applied 18-kip equivalent single-axle loads in the given lane, millions

BSTRESS: Maximum bearing stress of the dowel bar nearest the slab edge as determined by Friberg's method for an 18-kip (80 kn) single axle load

Statistics: R^2 = is not meaningful since the equation was forced through the origin (Sig. at < .01 level)

Std. Error = 0.09 ins.

n = 284 cases

Figure 4 illustrates the effects of using several different dowel bar sizes in a given slab. As the dowel bar diameter increases, the bearing stress and resulting transverse joint faulting decreases greatly. This effect is quite large for dowel bars less than 1 1/4 inch (32 mm) diameter. An 8" (203 mm) slab with 1 inch (25 mm) diameter dowels, 40 ft. (12 m) joints, a granular subbase and one-half million 18-kip equivalent single-axle loads applied annually will exhibit an average transverse joint fault of approximately .53 inches (13 mm), while a similar pavement with 1 1/4 inch (32 mm) diameter dowels will average .25 inches (6 mm), or about half as much.

Joint Deterioration Prediction. Joint deterioration is a very broad term that encompasses several different types of distress including blowups, load transfer-associated distress, transverse joint spalling, etc. Also, patches placed at transverse joints indicate that these joints were severly distressed at one time. For the purposes of this study, joint deterioration was computed as the sum of the average number of permanent patches placed at joints and the average number of medium and high severity transverse joint spalls per 100 transverse joints. Furthermore, separate models were developed for pavements that exhibited and those that did not exhibit "D" cracking

(durability cracking).

Data Set A was used in stepwise multiple regression analyses to develop a predictive equation for joint deterioration. These analyses resulted in the following model for non-"D" cracked pavements:

$$\ln(DETER + 1) = \ln(ESAL + 1) * [AGE * (4.042 \times 10^{-3} + 2.074 \times 10^{-3} * FTCYCLE) + 8.032 \times 10^{-3} * TEMPDIF * JTSEAL * INCOMP] - 2.577 \times 10^{-2} \quad (3)$$

where:

DETER: Number of deteriorated joints per 100 joints;

ESAL: Accumulated 18-kip (80 kN) equivalent single-axle loads, in millions;

AGE: Age of the pavement, in years;

FTCYCLE: Average number of annual freeze-thaw cycles at the pavement site;

JTSEAL: 0, if joint seal damage is low or absent, and 1, if joint seal damage is of medium or high severity;

INCOMP: 0, if incompressible materials are not visable in the transverse joints, and 1, if incompressible materials are visable in the transverse joints;

TEMPDIF: The difference between the highest average monthly temperature and the lowest average monthly temperature, °C.

Statistics: R^2 = 0.393 (Sig. at < .01 level)

Std. Error = 0.9 Jts./100 Jts.

n = 159 cases

A series of sensitivity analyses were performed to evaluate the reasonableness of this equation. Figures 5 through 7 show the results of some of these analyses and illustrate the relative influence of several variables on joint deterioration.

Figure 5 illustrates the individual and combined effects of traffic loadings and age. Note that age may also be viewed as cumulative cycles of several types of climatic action. The most obvious feature of the graph is that increased rates of traffic loading increase the number of deteriorated joints, particularly at older ages. Figure 6 illustrates the potential benefits of maintaining well-sealed, incompressible-free transverse joints. Figure 7 shows the predicted effects of freeze-thaw action on joint deterioration. Clearly a pavement exposed to large numbers of freeze-thaw cycles will tend to deteriorate much more rapidly than a similarly designed and trafficked pavement in a milder climate.

Data Set A was also used in stepwise multiple regression analyses to develop the following model for joint deterioration of "D" cracked pavements:

$$\ln(DETER + 1) = AGE * [\ln(ESAL + 1) * (5.504 \times 10^{-3} + 2.206 \times 10^{-5} * \frac{TEMPDIF * PPTN}{(DRAIN + 1)}) + 9.721 \times 10^{-4} * FTCYCLE] + 7.667 \times 10^{-2} \quad (4)$$

where:

DETER: Number of deteriorated transverse joints per 100 transverse joints;

AGE: Age of the pavement in years;

ESAL: Accumulated 18-kip equivalent single axle loads, in millions;

TEMPDIF: The difference between the maximum average monthly temperature and the minimum average monthly temperature at the pavement;

PPTN: Average annual precipitation at the pavement site, in cm.;

DRAIN: 0, if no longitudinal underdrains are present; and 1, if longitudinal underdrains are present;

FTCYCLE: Number of average annual freeze-thaw cycles at the pavement site.

Statistics: R^2 = 0.574 (Sig. at < .01 level)

Std. Error = 1.1 Jts./100 Jts.

n = 113 cases

Sensitivity analyses were performed on this equation to evaluate its reasonableness.

Figure 8 illustrates the individual and combined effects of traffic and age. As in the case of non-"D" cracked sections it is obvious that the cumulative effects of traffic on the amount of joint deterioration are most notable. A comparison between this figure and Figure 5 reveals that the same levels of traffic on a pavement susceptible to "D" cracking results in a much greater level of joint deterioration which occurs more rapidly than on a pavement that is not susceptible to "D" cracking. Age (exposure to environmental effects) also plays a greater role in this type of pavement.

Other analyses indicates that installing longitudinal drains along "D" cracked concrete pavement reduces the amount of joint deterioration. The removal of excess water from the pavement is important in that it helps to minimize concrete damage caused by freeze-thaw action. Also, a substantial increase in the average amount of annual precipitation will result in higher levels of joint deterioration.

Design Evaluation

A serviceability prediction equation was developed based on actual field data from the in-service pavements. Most Illinois pavements exhibit a psi of 4 to 5 when newly constructed. The PSI then decreases with time and traffic as distress caused by climate and traffic develops. The major variables believed to influence the loss of PSI for JRCP include traffic, joint spacing and design, slab thickness, reinforcement, foundation support, slab materials, and climatic factors (moisture, temperature, deicing salts, etc.).

Data from sets A, B and C were used in multiple regression analyses to develop a predictive equation for PSI as a function of age (0-22 years), equivalent 18-kip single axle loads (0-18 million), slab thickness (8-12.5 inches) (203-318 mm), joint spacing (40-100 ft.) (12-30 m), amount of longitudinal reinforcement (.09-.17 in^2/ft. of lane width) (193-367 mm^2/m), and subbase type (granular and stabilized). The following equation was obtained after extensive stepwise regression analysis:

$$PSI = 4.58 + \ln (ESAL + 1) [Age (-7.634 \times 10^{-2} + 3.688 \times 10^{-2} * H * ASTEEL) + 3.113 \times 10^{-1} * STAB - 4.094 * 10^{-3} * L] \quad (5)$$

where

PSI: Present Serviceability Index
ESAL: Cumulative applied 18-kip equivalent single-axle loads in the given lane, millions
Age: Age of the pavement, years
H: Slab thickness, inches
ASTEEL: Area of longitudinal reinforcing steel, in^2/ft. of lane width
STAB: 1, if stabilized subbase (asphalt- or cement-stabilized), or 0, if granular subbase
L: Joint spacing, feet
Statistics: $R^2 = 0.72$ (Sig. at < .01 level)
Std. Error = 0.37
n = 344 cases

Sensitivity analyses were performed to evaluate the reasonableness of this equation. Figure 9 indicates that when all other variables are held constant an increase in slab thickness will result in an increased PSI at any given pavement age.

Figure 10 illustrates the effects of varying the amount of traffic carried over a given period of time. It is clear that the more heavily trafficked pavements (e.g., 1-2 million ESAL/yr) reach terminal serviceability much more quickly than pavements carrying more moderate to low traffic.

Figure 11 indicates that stabilized subbases (either asphalt- or cement-stabilized) result in better pavement performance than untreated granular subbases. (A 42 percent increase for the given example - 16.5 to 23.5 years.) There was no significant difference in asphalt or cement treated subbase performance. This increase in life may be due to less pumping and smaller pavement deflections with the stabilized bases.

The effect of joint spacing on the PSI is detailed in Figure 12. The figure indicates as the joint spacing decreases, the rate of loss of PSI decreases for values of joint spacing in the data range of 40 to 100 ft. (12-30 m) (a 30 percent increase in life to a PSI = 2.5). Thus, shorter joint spacing is beneficial to performance.

Many design cost trade-off analyses can be conducted using this equation, such as the relative cost effectiveness of increasing steel content, slab thickness, stabilizing the subbase, and shortening the joint spacing.

Another important application of such a predictive equation is to illustrate the relative effects of climate and traffic on pavement deterioration. Since loss of PSI is an indication of overall pavement damage, Eq. 5 can be rearranged as follows:

$$DAMAGE = \ell n\ (ESAL + 1) * [Age * (-7.634 \times 10^{-2} + 3.688 \times 10^{-2} * H * ASTEEL) + 3.113 \times 10^{-1} * STAB - 4.094 \times 10^{-3} * L] \quad (6)$$

where
DAMAGE: 4.58 - PSI, the loss of PSI from the initial PSI of 4.58.

This equation can be used to prepare a variety of graphs illustrating the relative influence of traffic and age (or climate) on the loss of serviceability (or DAMAGE). A loss of 1.0 unit of serviceability, or DAMAGE = 1.0, occurs at several combinations of Age and ESAL, for example:

AGE	ESAL (millions)
5	21.0
10	7.0
15	3.7
20	2.5
25	1.9

The DAMAGE contours are not symetrical indicating that at older ages the DAMAGE increases much more rapidly than at younger ages. At age 5 years the JRCP can carry well over 20 million ESAL's to a serviceability of say 3.0, but at an age of 20 years, it can only carry about 5 million. This general phenomenon could be due to the destructive effect of climate over many years in causing deteriorated joints, corrosion of dowels and reinforcement, and loss of support from pumping.

An expansion of these results are given in the 3-dimensional plot given in Figure 13 for the same JRCP. Here the effects of age, traffic and their combined influence can be observed. The resulting DAMAGE surface shows that the combined effects of traffic and age (climatic factors and their effects on materials and material properties) are far greater than the effects of either age or traffic alone.

These are only a few of the ways that such an equation might be used to improve or evaluate the design adequacy of a given system of pavements. As the COPES data base is expanded to include pavements from additional states, more widely applicable equations can be developed which will result in more reliable pavement designs nationwide.

Reinforcement Evaluation

The standard reinforcement design procedure based upon the "subgrade drag" theory does not consider such factors as repeated traffic loads, pumping (resulting in high deflections), joint lockup, and corrosion. Thus it might be expected that the amount of reinforcement required to "drag the slab over the subgrade" without opening the cracks may be insufficient to prevent crack breakdown in a harsh climate, with heavy traffic, and extensive pumping such as the Interstate JRCP in Illinois.

The standard reinforcement design for the Illinois JRCP provides 0.17 in^2/ft. (360 $\frac{mm}{m}$) width of slab. Using Eq. 1 and computing the expected amount of transverse cracks to spall and rupture for the standard 10 in. (254 mm) JRCP gives the following over a range of traffic during 20 years:

ESAL (millions)	No. Medium-High Transverse Cracks per Mile
5	33 (1 crack/160 ft.)(1 crack/49 m)
12	79 (1 crack/67 ft.)(1 crack/20 m)
20	132 (1 crack/40 ft.)(1 crack/12 m)

If, for example, the designer decided that a limiting amount of crack deterioration was one per 100 ft. (one per 30 m), the steel required for ESAL traffic levels greater than about 8 million should be increased above the existing design. One half of the JRCP projects had greater than 7 million ESAL's. Thus, explaining why a large percentage of cracks (e.g., 30%) were deteriorated. A new reinforcement design nomograph could be developed utilizing Eq. 1 for whatever level of crack deterioration was deemed acceptable.

Joint Design Evaluation

Since a large amount of the overall JRCP deterioration occurred at the joints, it is obvious that improvements are needed. The various predictive equations have shown that overall joint performance could be improved by (1) reduced joint spacing, (2) increased dowel bar diameter, and (3) methods to reduce pumping at joints such as underdrains and stabilized subbases.

Rehabilitation Needs

Data in COPES along with the predictive models for serviceability and distress provide an excellent source of information to determine present and future rehabilitation needs and assist with general pavement management. An example application of COPES is developed utilizing the 400 mile (644 km) JRCP Interstate highway network in Illinois.

Pavement serviceability is used in this example as an indicator of rehabilitation needs. However, any other index could be developed such as a composite distress index. The 0 to 5 PSR scale is divided into the three classifications of good (5 - 3.5), fair (3.5 - 2.5), and poor (2.5 - 0), similar to the 1976 National Highway Inventory and Performance Study (NHIPS) (6). When the PSR is less than 2.5, an Interstate highway is considered to require rehabilitation. In fact, many Interstate highways are rehabilitated at an even higher level of serviceability, particularly in urban areas. Using the serviceability predictive Equation 4, past and future performance predictions were developed for each uniform section. Figure 14 shows six histograms of JRCP pavement condition over the 400 mile (644 km) Interstate highway network. In 1970, the overall pavement age was 8 years (ranging from 0 to 13), and nearly 80 percent was in the "good" category. None of the miles were in the "poor" category. However by 1990 where the mean age is 28 years (20 - 33) the overall condition distribution is predicted to have deteriorated to where a majority of the pavements are in the "poor" category. Of course this distribution assumes that no projects are rehabilitated during this time. If they are, the PSR would immediately increase to the "good" rating and the distribution would be altered.

The preceeding analysis has concentrated primarily on the age of the pavements and when they need rehabilitation. It must be noted however, that overall the level of traffic on many of these Interstate pavements is very high. The accumulated ESAL at the various ages in the outer lane is as follows:

Year	Mean Age	Mean* ESAL, 10^6	Range ESAL, 10^6	% Miles Rated Poor
1970	8	2.3	0.3-8.0	0
1974	12	4.2	0.8-11.3	3
1978	16	6.7	1.6-14.6	8
1982	20	9.1	2.4-17.9	22
1986	24	11.6	3.3-21.9	38
1990	28	14.1	4.2-26.2	55

*Accumulated in outer lane

Thus, the mean pavement life of this 400 mile Interstate network is expected to be approximately 27 years (when 50% fall below 2.5 serviceability).

An average ESAL's used for design of a 10 inch (254 mm) JRCP slab is approximately 9 million using the AASHTO Interim Guide. This occurred at about an average age of 20 years for these pavements, but only about 22 percent of the mileage was < 2.5 PSR.

The capability to estimate future pavement performance, and consequently future rehabilitation needs, permits an agency to estimate funding levels required to maintain a certain overall level of "condition" over the network. It also allows the agency to show what will happen to a pavement network for various levels of funding.

Conclusions

Valuable information can be obtained through the evaluation of in-service concrete pavements to improve design, construction, material quality, and maintenance procedures. The information is also very useful in pavement management for determining the condition of an overall pavement network and its existing and future rehabilitation needs.

Many uses and evaluations can be made from the COPES data bank on state and national levels such as the following: network facility summary, network condition data summary, distress prediction and causation, design evaluation and improvement, construction and materials evaluation and improvement, maintenance needs and evaluation, rehabilitation needs, research needs, and others.

References

1. M. I. Darter, M. B. Snyder and R. E. Smith, "Development of System for Nationwide Evaluation of Portland Cement Concrete Pavements," Final Report NCHRP Project 1-19, University of Illinois, 1980.
2. B. N. Robinson, G. D. Anderson, E. Cohen, and W. F. Gazdzik, "Scientific Information Retrieval (SIR) User's Manual," (Second Edition) SIR, Inc., P. O. Box 1404, Evanston, Illinois, 60204: 1979.
3. N. H. Nie, C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent, "Statistical Package for the Social Sciences (SPSS)," (Second Edition), New York, New York: McGraw-Hill Book Company, 1975.
4. BMDP Biomedical Computer Programs, P-Series, University of California Press, 1979.
5. L. J. McKenzie, R. J. Little, and P. G. Dierstein, "Behavior of Contraction Joints in the Rehabilitated AASHO Road Test," Report No. FHWA-IL-PR-75, Illinois DOT, 1977.
6. "The Status of the Nations Highways: Conditions and Performance," Report of the Sec. of Transportation to the United States Congress, September 1977.

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Disclaimer

The opinions and conclusions expressed or implied

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Figure 1.

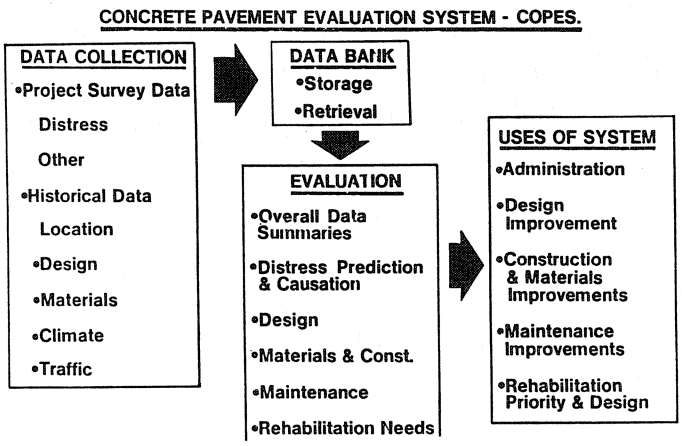


Figure 2. Percent reinforcement vs. deteriorated transverse cracks with varying slab thicknesses using eq. 1.

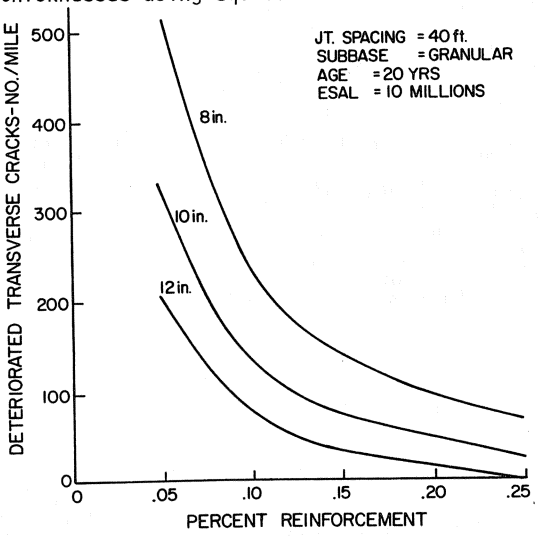


Figure 3. Percent reinforcement vs. deteriorated transverse cracks using eq. 1.

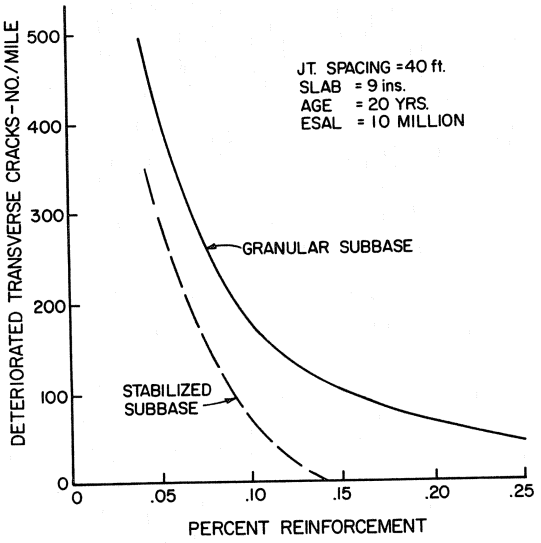


Figure 4. Age vs. faulting with varying dowel bar size using eq. 2.

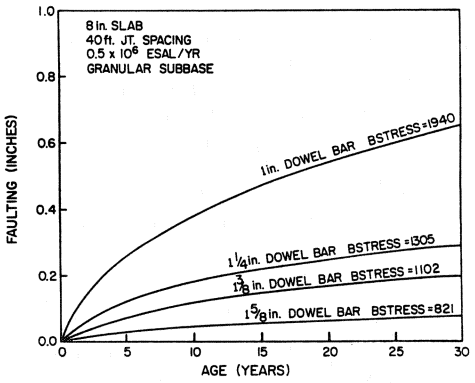


Figure 5. Number of deteriorated joints per 100 joints vs. age with varying ESAL/yr. using eq. 3.

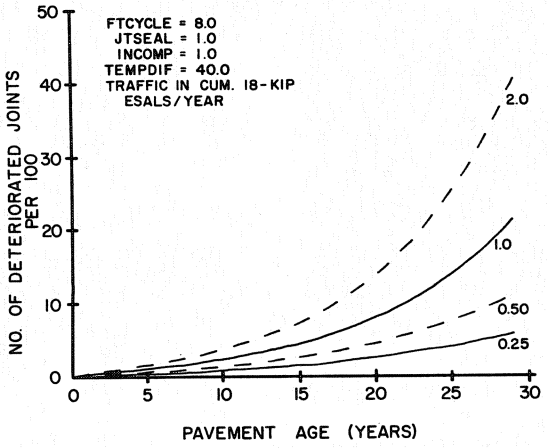


Figure 6. Number of deteriorated joints per 100 joints vs. age with varying joint conditions using eq. 3.

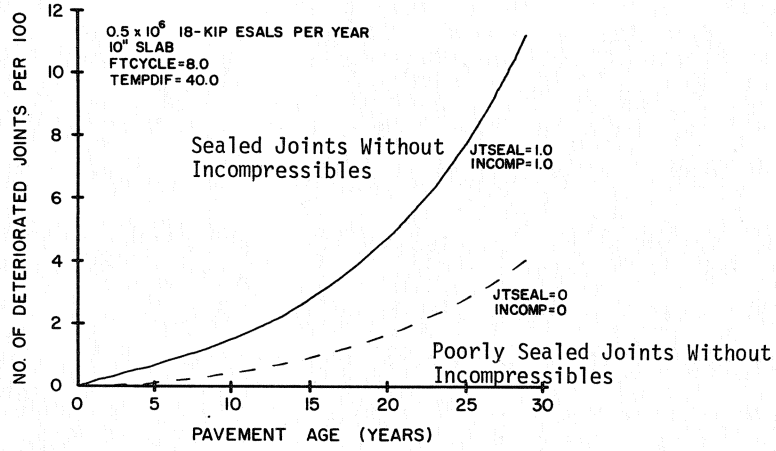


Figure 7. Number of deteriorated joints per 100 joints vs. age with varying annual freeze-thaw cycles using eq. 3.

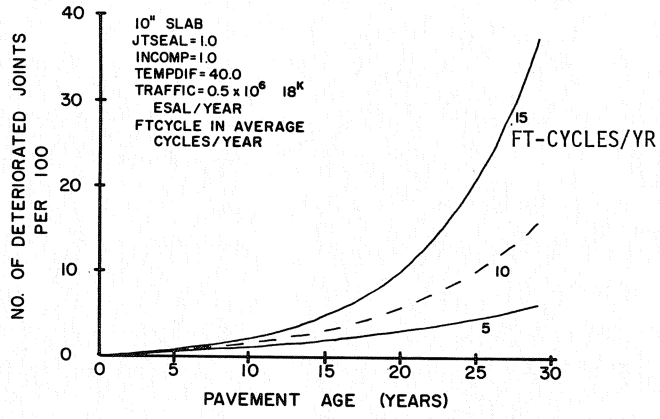


Figure 8. Number of deteriorated joints per 100 joints vs. age with varying ESAL/yr. using eq. 4.

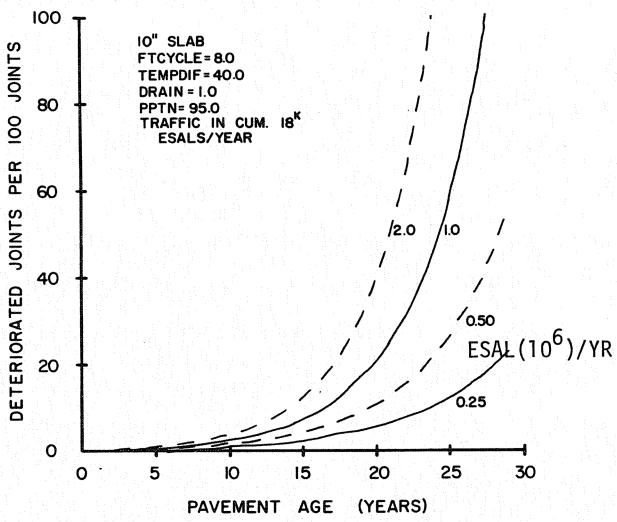


Figure 9. Age vs. psi with varying slab thicknesses using eq. 5.

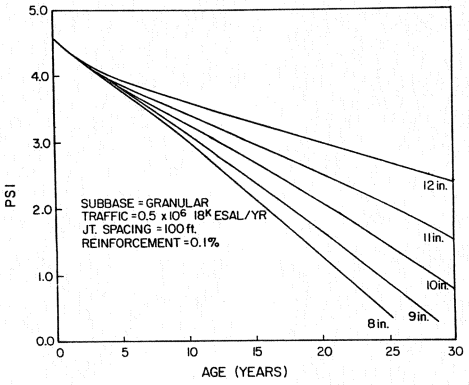


Figure 12. Age vs. psi with different slab lengths using eq. 5.

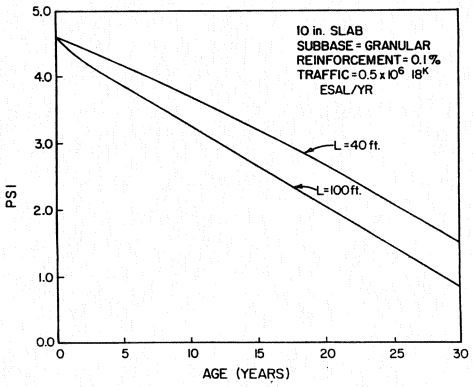


Figure 10. Age vs. psi with varying ESAL/yr. using eq. 5.

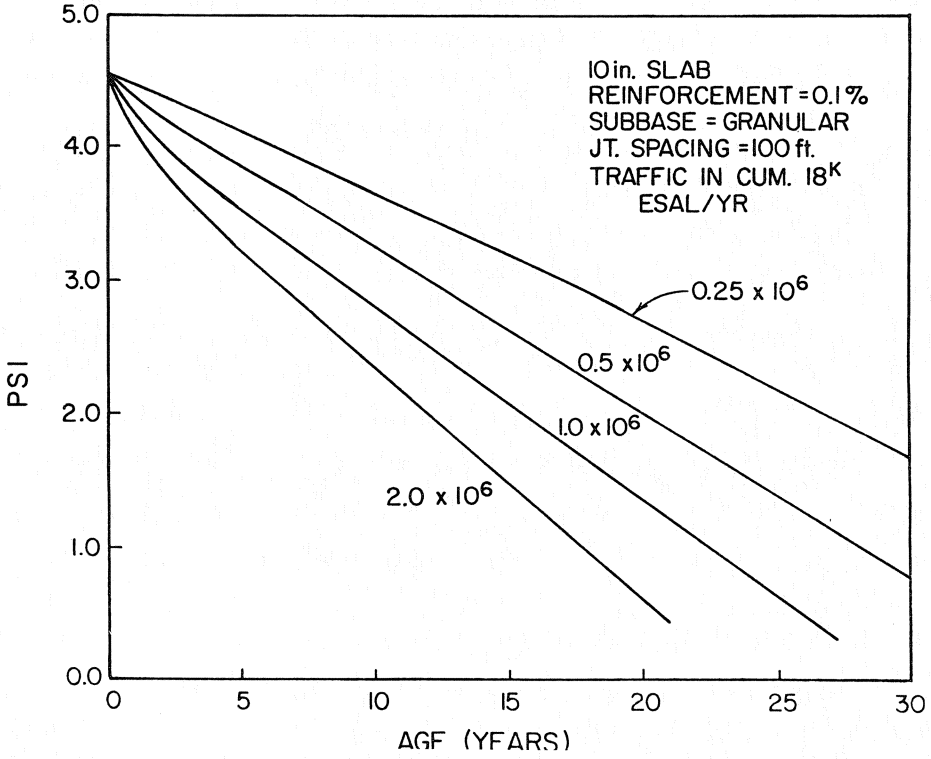


Figure 11. Age vs. psi for granular and stabilized subbases using eq. 5.

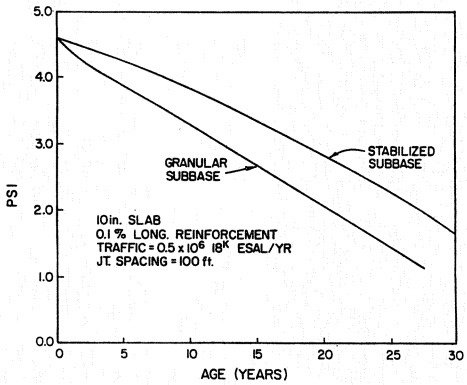


Figure 13. 3 - Dimensional plot of age vs. cumulative ESAL vs. damage (4.58 - psi) from eq. 6.

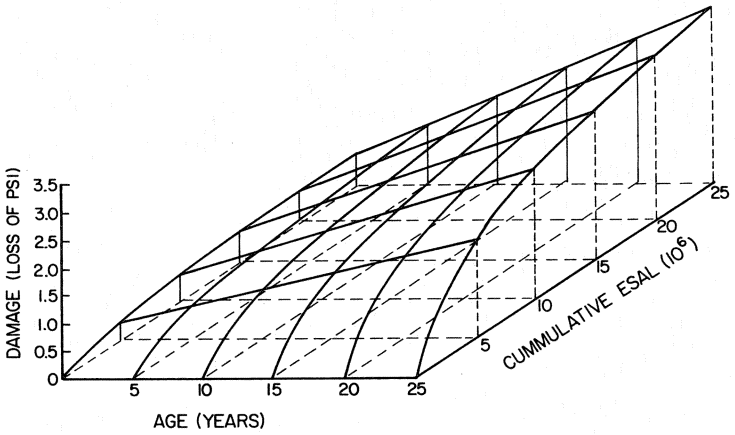


Figure 14. Histograms of psr of Illinois JRCP sections from the years 1970 - 1990 estimated using eq. 5.

