TRUNK

PAVEMENT RECYCLING GUIDELINES FOR LOCAL GOVERNMENTS

Reference Manual

APPENDICES

DISCLAIMER

Many competent men and women serve the paving industry; however, in this manual only masculine pronouns are used in reference to engineers, technicians and other personnel. This convention is intended to avoid awkwardness in style and in no way reflects sexual bias on the part of the authors.

All reasonable care has been taken in the preparation of this Manual. However, the Federal Highway Administration can accept no responsibility for the consequences of any inaccuracy or omission. The Federal Highway Administration does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered necessary to the object of this publication.

** These appendices were inadvertently omitted from the printing of the manual.

Technical Report Documentation Page

1. Report No. FHWA-TS-87-230	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PAVEMENT RECYCLING GUIDELINES FOR LOCAL GOVERNMENTS - REFERENCE MANUAL Appendices **		5. Report Date September, 1987
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address ARE Inc - Engineering Consultants 6811 Kenilworth Avenue, #216 Riverdale, Maryland 20737		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFH61-85-C-00118
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Highway Administration Washington, D.C. 20590		13. Type of Report and Period Covered FINAL
		14. Sponsoring Agency Code HHO-12
15. Supplementary Notes		

16. Abstract

Recycling processes can be categorized according to material type - asphalt surface recycling, cold-mix asphalt recycling, hot-mix asphalt recycling, and portland cement concrete recycling; or according to procedural type - surface recycling, in-place recycling and central plant recycling. If the project can be restored by making corrections to the surface, with a minimum of new materials, surface recycling will prove satisfactory. If substantial corrections are required, in-place or central plant mixed procedures should be used. Methods of mix design and structural design for pavements containing recycled materials are generally similar to those used for designing mixes containing all virgin materials. The major difference is that variability in the properties of the recycled materials needs to be taken into consideration. This necessitates more frequent sampling and testing than with conventional mixtures and greater engineering judgment on the part of the designer. Cost is the traditional criterion for selection between various rehabilitation alternatives. The alternative with the least cost, including initial and maintenance, is usually selected by the designer. In the case of recycling, the relative cost savings will depend on the costs and availability of other types of treatment, as well as those of the recycling option selected.

17. Key Words Pavement Recycling, Asphalt Pavements, Concrete Pavements, Recycled Mixtures, Pavement Design, Overlay Design	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 178	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

PAVEMENT RECYCLING GUIDELINES FOR LOCAL GOVERNMENTS

Reference Manual

APPENDICES

Prepared for:
U.S. Department of Transportation
Federal Highway Administration

APPENDIX A

PAVEMENT MANAGEMENT SYSTEM*

INTRODUCTION

County and city officials have a responsibility to the public to provide the best roads possible within available funds. A concept called pavement management has evolved over the past 20 years to combine all of the activities involved in providing and managing pavements. The objective of pavement management is to use reliable and consistent information and facts to develop decision criteria in an organized framework to produce a cost effective pavement program. Without a pavement management system (PMS), the engineer will probably depend on rules of thumb such as:

- "My budget should equal last year's budget plus an arbitrary percentage increase."

- "Establish a maintenance program based on periodic timing, such as crack sealing every other year, seal coats every four years, and overlays every twelve years."

- "Respond to emergency demands and citizen complaints as they arise."

- "Use political considerations to establish programs and budgets."

Such criteria are not satisfactory even if sufficient funds are available or the roads are in good condition. However, if the roads are in bad shape and getting worse, or funding is less than required to meet demands, then there is a clear motive to use a more systematic and organized approach in the decision making process.

Some of the benefits that can be gained by approaching the management of roads in a more systematic manner include:

- Organization of information gathering and storage methods, allows information to be shared with others in the organization, between agencies, and with the public.

- Facts and data let decision makers know the impact of their decisions when developing long range plans and annual budgets, thus reducing a reliance on guess work and political pressure.

---

* Adapted with permission from a paper by R.F. Carmichael III and F. N. Finn presented at the ASCE Specialty Conference on Solutions for Pavement Rehabilitation Problems (Atlanta, May 1986).

- Response can be made to the public with factual knowledge of the situation, plans for correcting the problem, and how individual roads fit into the overall operation of the road network.

- The greatest benefits can be achieved for the available money.

- Performance or the time history of roadway condition, can be predicted along with maintenance activities and costs.

- The consequences of past maintenance and rehabilitation decisions can be predicted.

Pavement management is an encompassing process which includes all those activities involved in providing roads. These are initial information acquisition, planning and programming of maintenance, rehabilitation and new construction, designing details of individual projects, and periodic monitoring of existing pavements. Pavement management identifies the best strategies and prioritizes them for implementation.

A pavement management system is simply that combination of analysis procedures, detailed forms, measurements, tools (such as computer programs), decision criteria, etc. which provide street managers with systematic and optimum plans or methods for managing their roads.

Pavement management activities are characterized by the administrative level at which they occur. The <u>project level</u> is characterized by predominantly technical management concerns, such as detailed engineering design decisions regarding individual projects. The models utilized at this level require detailed information on individual sections of a road. The <u>network level</u> primarily involves planning decisions for large groups of projects or an entire road network.

The degree of sophistication or completeness of a pavement management system can range from a simple data base to full optimization. Between these two extremes there are a range of possibilities. The amount of sophistication required in the pavement management system will, to a large extent, be influenced by the objectives set for the system.

For personnel in cities and counties, there is generally one primary requirement, i.e., <u>the system should be simple to maintain and operate</u>. It should be noted, however, that the definition of simple may be different from one agency to another, depending on the size of the agency and the resources available to support a PMS. Many cities and counties have indicated that "user-friendly menu-driven" software was a desirable attribute of a PMS. Such a system provides interactive use for data entry, editing and retrieval of information rapidly, easily and at remote terminals by users at various levels of management. After the requirement for simplicity and "user friendly" preferences, agency priorities will vary somewhat.

It has been suggested that three activities are of primary importance: 1) a procedure to objectively quantify pavement condition, 2) a list of the most cost effective maintenance treatments, and 3) a means of matching treatments to problems. However, only the larger jurisdictions (over 250 miles of roads) will normally be interested in a system that optimizes treatments.

As discussed in the previous section, it is important to remember that pavement management systems usually consist of two subsystems: one for the network and one for the project. The network level subsystem must deal with the pavement network as a whole and usually is concerned primarily with maintenance and rehabilitation decisions while the project level subsystem deals with new construction or reconstruction decisions. Considerably more information can be obtained at the project level since only a limited number of projects will be scheduled in one planning and/or construction season. It is important to keep these two subsystems in perspective in considering the implementation of a PMS.

DATA BASE APPROACH

Figure A-1 illustrates the various levels of a PMS which can be produced starting with a data base of information. The five components of the data base are: 1) construction history, 2) inventory, 3) traffic, 4) surface friction, and 5) pavement condition.

It is not necessary to include all of the files indicated above, and some agencies may want to add additional files for maintenance history, signing, drainage, shoulders, etc.

The key information for most city and county systems will be contained in the traffic, construction history and condition rating files. Depending on what information is contained in the construction history file, a record of maintenance may also be useful.

The condition file can be used to evaluate the overall "health" of the pavement network by a simple tabulation of condition. In addition, each street segment can be ranked according to the extent of a particular distress type. For example, the ranking may be based on fatigue (alligator) cracking for which severity ranges from 1 to 3 (with 3 being the worst) and extent ranges from 1 to 4, according to the percent of the length affected (4 being the greatest extent). Thus, if fatigue cracking is considered to be the most critical condition rated, the first sections listed would be given first consideration for corrective action. Other statistical information could easily be produced from this type of information.

Interpreting Data

The interpreting program referred to in Figure A-1 translates the information into a combined rating for each section using condition data in the data base. This is accomplished by applying weighting values to the extent and severity of each distress category. This technique is used in a number of systems such as that developed for the counties in the State of Washington (Ref. 1); the APWA PAVER System (Ref. 2); Ventura, California (Ref. 3); and others.

Some pavement management systems can combine roughness, pavement distress, structural capacity, skid number and structural evaluation

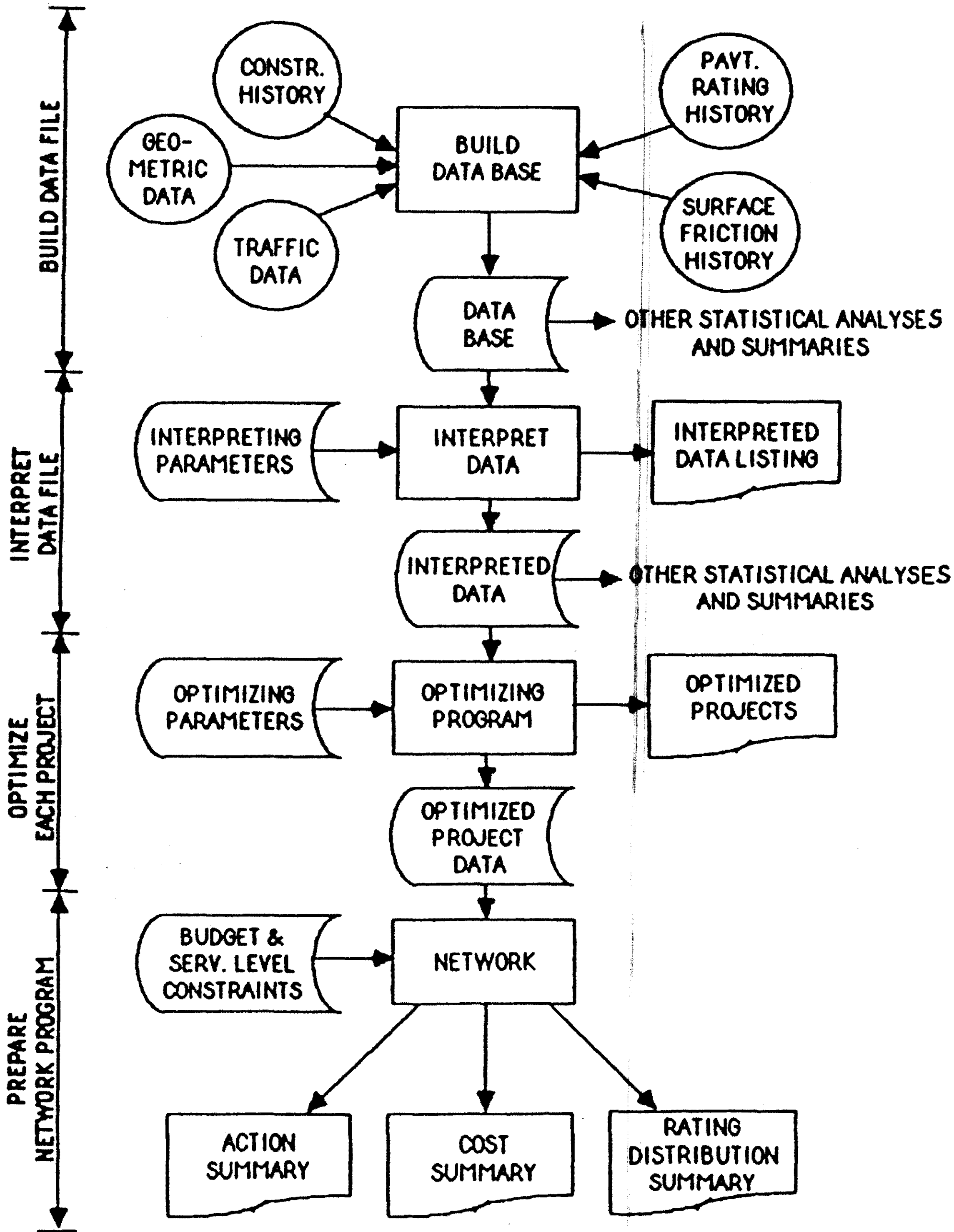


Figure A-1. Conceptual flow chart of WSPMS operations (Ref. 1).

(nondestructive deflection tests). Increasing the number of considerations does increase the difficulty in assigning proper weighting factors; however, it has been done when considered necessary.

The combined index can be used in a number of ways: 1) to establish priorities, 2) to summarize overall condition of pavements in the network, i.e., "health" of system, 3) to develop performance curves (predictions) over time, and 4) to provide performance trends based on budget level.

Priorities are necessary in order to determine which projects to rehabilitate when there are funding constraints. However, before priorities can be established, it is necessary to identify which segments need rehabilitation or maintenance. Various systems have been devised for assigning particular rehabilitation methods as a function of pavement condition. For example, the APWA PAVER System uses the pavement condition index (PCI) to establish threshold values which can be used to select projects needing improvement. Figure A-2 illustrates the PCI criteria as applied by one user of the system (Ref. 4).

Procedures developed for San Francisco and Palo Alto, California (Ref. 5) illustrate yet another technique for establishing threshold values for maintenance or rehabilitation. This technique is illustrated in Figure A-3. Using this method, deduct values are assigned to each type of distress considered important with regard to the need for treatment. Depending on the condition and traffic (TI), an action is recommended as noted. If more than one deficiency is noted, a selection logic is used to pick the action which will correct all recorded deficiencies below the threshold value as shown in Figure A-4.

Thus, priorities can be established without prediction models or optimization. This method is relatively simple; however, it relies almost entirely on engineering judgment and experience to identify threshold values and the "best" action or treatment. In many cases, this is all that is needed. If agencies wish to proceed further, the next class of systems must include some type of pediction models.

SUMMARY OF CITY AND COUNTY SYSTEMS

Figure A-5 can be used to summarize systems that can be applied to cities and counties.

The data bank is the heart of the system. Exactly what is in the data bank will depend on the system requirements. As a minimum, information concerning the condition of pavements in the network will be necessary.

Based on the condition, it will be necessary to establish a set of actions considered appropriate for each condition state, i.e., single or multiple variable indices.

The best treatment from the feasible set must be determined. The treatment may be obtained from a consensus of knowledgeable people, usually within the agency personnel. This "best" action can also be determined by use of prediction models and optimization procedures.

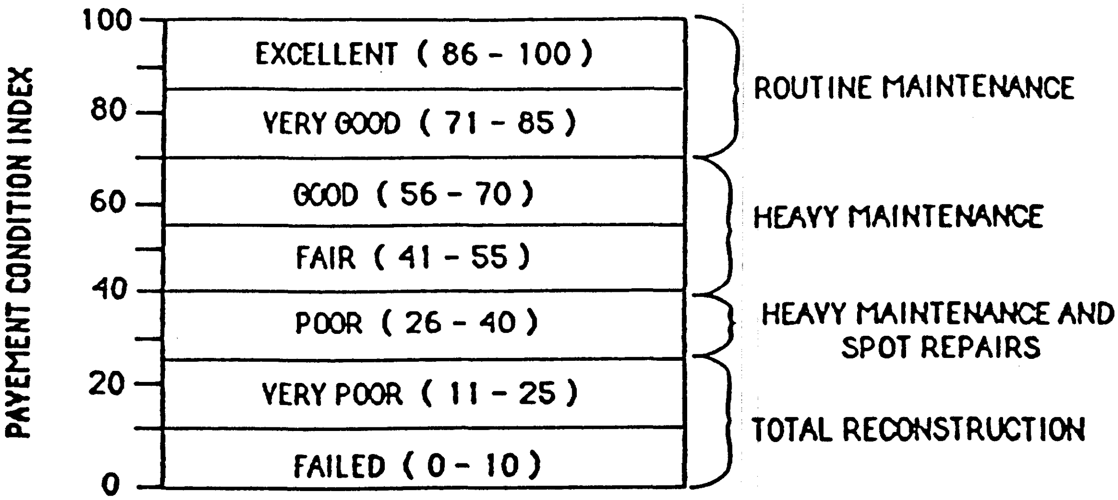


Figure A-2. Pavement condition index showing condition rating and type of repair required (Ref. 4).

AREA CRACKING

SEVERITY	Deduct Values Extent (% of Area) N/O	1-25	26-50	>50	TREATMENT Deduct Values	TI 5	6	7	8
Acceptable	0	5	10	15	< 19	*DN	DN	DN	DN
Tolerable	0	13	19	26	19-23	DN	P	P	M&F
Unacceptable	0	23	30	40	26-30	OL	M&F	M&F	MF&O
					40	M&F	M&F	MF&O	RES

*DN-Do Nothing, M&F- Mill and Fill, P-Patch, MF&O-Mill, Fill and Overlay, OL-Overlay, and RES-Restore or Reconstruct

Figure A-3. Deduct values for pavement distress and recommended treatments (Ref. 5).

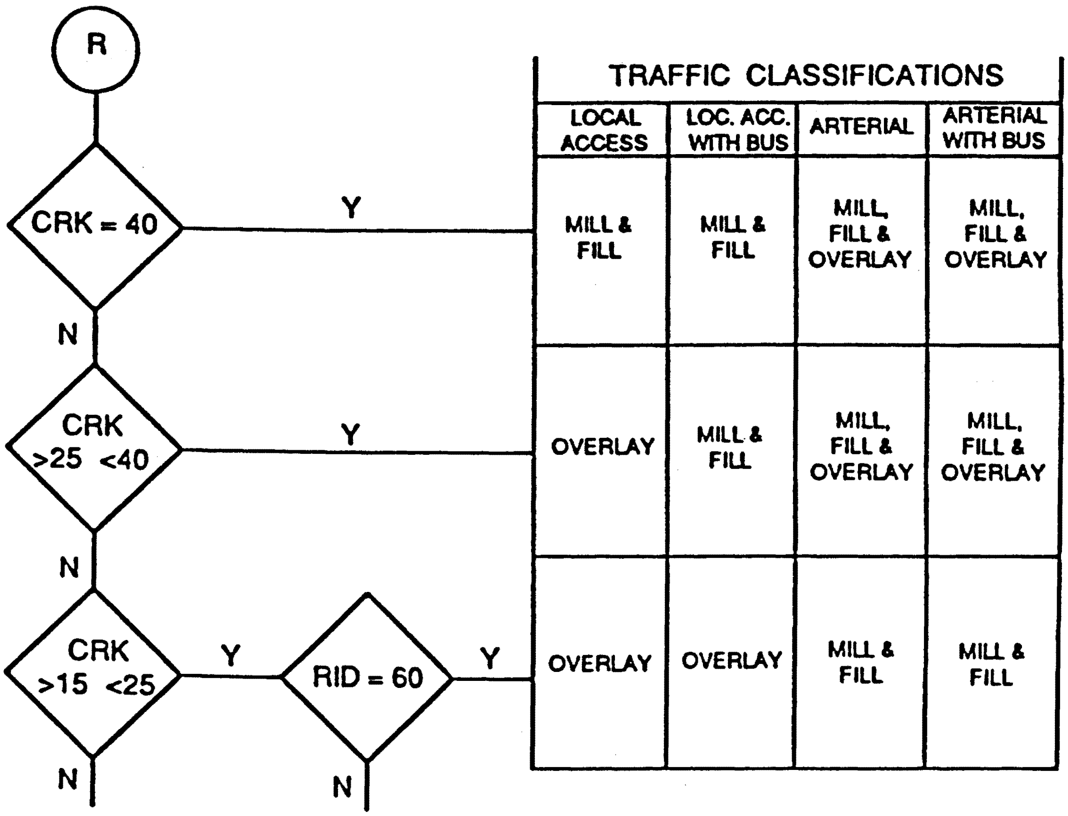


Figure A-4. Rehabilitation selection logic (Ref. 5).

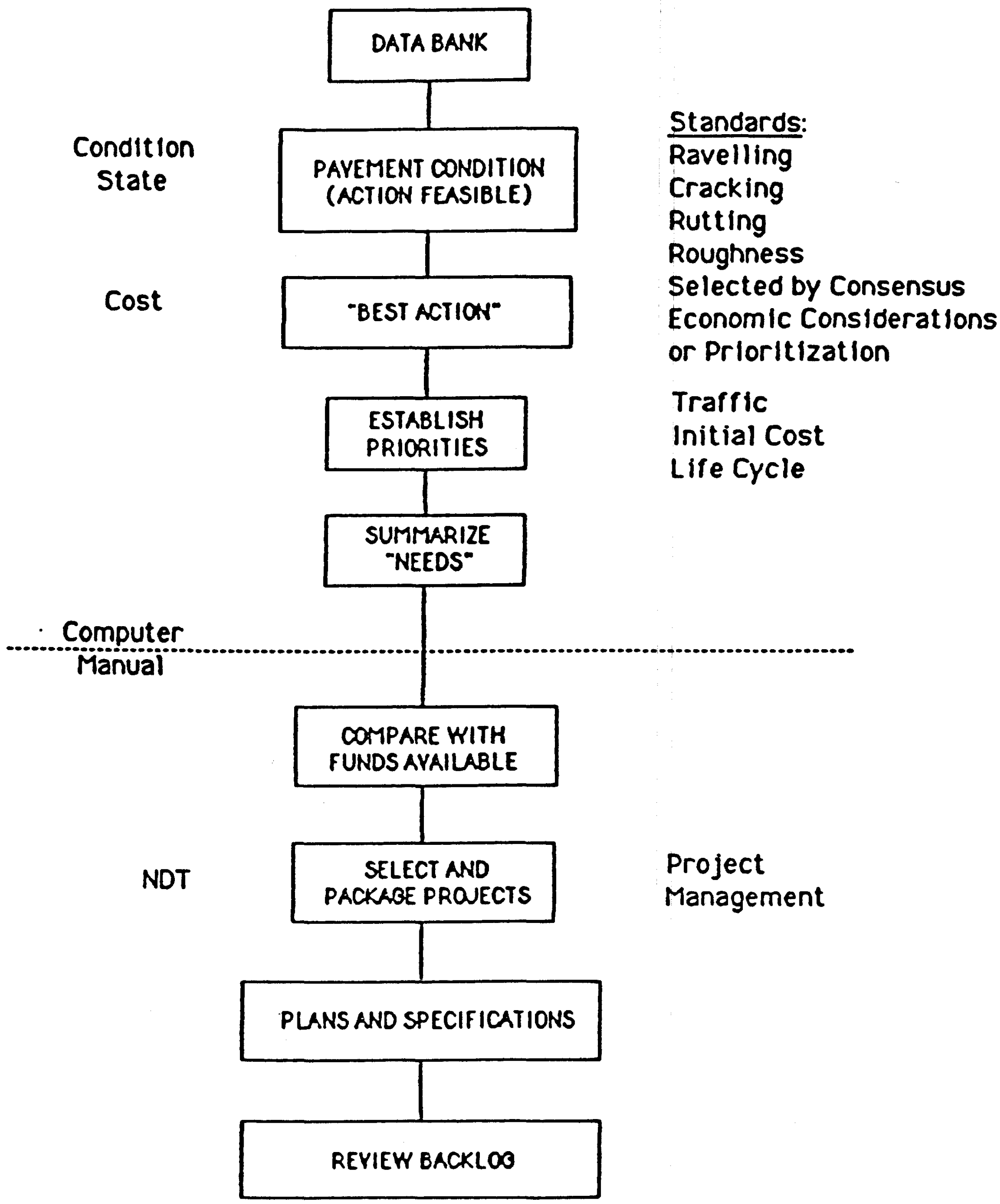


Figure A-5. Basic components of PMS for local governments

Priorities can be developed based on ranking procedures, benefit-cost ratios, maximizing performance or condition of the network, minimizing cost or such other methods as may be developed using performance, benefits and cost as primary considerations.

In most cases, the needs will exceed the means (funds available). Priorities can be used to select sections for corrective action. Some sections will have to be deferred to future years.

A careful evaluation of each section will be essential in order to be sure that the information in the network data base is correct and that there are no site specific conditions which would alter the plan developed by the network branch of the system.

Finally, plans and specifications are prepared for implementation of the program. A feedback is an important part of the PMS. Such as, what is happening to the overall condition of the pavement network? Is it improving? Deteriorating? Or remaining status quo? This review of the backlog of needs will be useful in requesting funds to maintain the pavement network at a desired level.

PLANNING A PMS

There are a number of factors to be considered in planning the development of a PMS. Some of the more important factors include: 1) availability of resources, 2) information requirements, 3) level of sophistication (completeness), 4) data management, 5) reporting, and 6) administration.

Resource Requirements

Resources can be divided into three categories: (a) personnel, (b) equipment, and (c) funds. The resource requirements can be divided into two levels: those needed for development and those required for operation of the system.

Due to a shortage of personnel with the proper training or background, most agencies have called on consultants to assist in the development of a PMS. There have been exceptions, but even these agencies have relied on published descriptions of systems developed by other agencies. When consultants are retained, it is always a joint effort, with the agency providing the kind of assistance for which it can be most helpful.

Cities and counties, for the most part, have not purchased equipment to be used in the field, i.e., road meters, deflection testing devices, skid testing, road loggers, etc. Again, there are some exceptions in the case of deflection testing equipment; however, by far, the majority of agencies rely on commercial companies to provide measurement equipment services.

Computer equipment is generally always available for use by the agency. Some cities and counties have mainframe computers "in-house," while others have micro-computers assigned within the department which can be used to operate the PMS. In this way, the department can maintain direct control of the system, update data in a timely fashion, produce reports when and of the type necessary and can interact with the data base as necessary for editing and retrieval.

Funding is always a problem for cities and counties, both for development and operation of the PMS. The cost of developing a PMS can range from as little as $10,000 to as much as $300,000 or more (not counting data acquisition), depending on the level of sophistication required. In planning the PMS, a realistic estimate of the amount of funds available is very important.

Information Requirements

The three main types of data files considered by agencies include: 1) design and construction, 2) maintenance history, and 3) pavement condition.

Design and construction can include information relative to parameters related to construction or reconstruction such as dates, traffic, soil support, materials and layer thicknesses.

Maintenance history can include information relative to what was done to maintain a segment as well as its timing and cost. Overlays, surface treatments, base repairs and crack sealing are specific examples of maintenance activities. Historical information of this kind is useful to the engineer when packaging projects.

Pavement condition information can vary depending on local experience. Typical types of information for flexible pavements include: 1) surface type, 2) transverse cracking, 3) fatigue (alligator cracking), 4) deformation (ruts and corrugations), 5) edge deterioration (cracking, shoulder drop off), 6) block cracking, 7) patching, 8) utility cuts, 9) ride, and 10) raveling.

For rigid and composite pavements, many of the distress types are common with flexible pavements. However, due to the nature of these pavements some additions and deletions are required. Some of the additional items include: 1) joint distress, 2) faulting, 3) joint seal damage, and 4) D cracking.

The agency should not attempt to collect more information than is necessary. This slows down the condition survey, reduces reliability of information, and requires increased computer storage and programming.

DEVELOPING A PMS

At the local level of government there are several key elements to successful pavement management and these are as follows: 1) keep data collection simple and practical, 2) use computerized data storage and analysis techniques, 3) develop methods particularly tailored to the individual city or county organizational, technical, and budget constraints, 4) involve all the important departments within the agency organization, and 5) plan a stepwise development of the PMS system.

Evaluation of Existing Management Pracitces

Every agency, whether it is a city, county, or state, accomplishes some form of pavement management. Engineering staffs and public works managers have, in the past, developed pavement rehabilitation programs, pavement construction programs, and selected particular streets for maintenance and rehabilitation based upon experience. Most cities and counties have a standard system for classifying their streets based upon the level of traffic and use. The first step in the development of a PMS should be an examination of existing practices.

Formulation of Goals and Objectives

It is often the case that a local government agency that successfully develops a PMS also has a "PMS committee," which is formed with representatives from each of the key departments including construction, design, maintenance, traffic and administration. An early formulation of goals and objectives by such a group will avoid such problems as having some part of the system developed and finding that it does not meet the needs of a particular department.

Training of Field Personnel for Condition Surveys

Training agency staffs for condition surveys is a very feasible and practical approach. City or county field crews can then collect network-wide information every two or three years. There will be differences in pavement ratings since the human factor is involved; however, an acceptable level of consistency generally can be achieved after several practice ratings. It is also a quick and inexpensive way to obtain the data necessary to make maintenance and rehabilitation decisions at the network level. Another important consideration is that using agency personnel for condition surveys gives them additional input into the management and administrative decision making process.

Establishing the Data Base and Street Inventory

One of the most fundamental elements of a PMS is a computerized street inventory of data base system. The development of high speed and low cost computers in the last decade has made this alternative more practical and efficient than using hand manipulated records. Not only can the street inventory contained on a computerized data base be very useful in sorting out the quantities of rehabilitation and maintenance work that the city has, but also the quantities of pavement in the different condition categories. If a set of existing information already exists in the city or county, it may be the basis for a good beginning, or it may be more feasible to develop such data from scratch, thus including all the elements specified in the PMS goals and objectives. The establishment of the data base is probably the most important initial first step in the development of a PMS system. Once the data are collected and a system established to continue this collection, procedures can be established to estimate needs, to prioritize maintenance, to develop schedules, and to derive other important PMS outputs.

Development of Predictive Models and Optimization Strategies

Once the data have been collected, the information can be analyzed to determine if predictive models can be developed to estimate the pavement life being obtained by different types of new construction and different rehabilitation and maintenance actions for different levels of traffic and soil types. With such predictive models more precise optimization strategies can be developed, such that maintenance and rehabilitation priorities are more clearly and precisely defined. It is best to develop the predictive models and optimization strategies based upon the experience and the condition of pavements in a specific city rather than to rely upon predictive models that are based upon experiences elsewhere.

FEASIBILITY OF STRUCTURAL TESTING

Structural testing of city streets and county roads can be rapidly performed with a number of deflection testing devices. Although it is feasible to collect deflection data on a network level basis, it is not cost effective. Deflection measurements are generally more useful at the project level, since if the street is not rehabilitated in the year of measurement, the measurements must be repeated later to be valid.

By structurally testing an individual street along its length the engineer can locate weak areas, determine the overall general deflection level of the street, and possibly develop different design sections thereby saving money in the process.

ROUGHNESS TESTING

In general, roughness or pavement ride quality measurements are very useful on high speed roads because data can rapidly be collected to relate the relative condition of all sections. At the municipal level such information is useful only on primary arterial or collector streets where the speeds are at or above 45 miles per hour. Local streets, with low speeds and low traffic rates, usually provide a quality of ride which is acceptable. If the street has severe potholing or other such problems which create poor ride, these problems can be estimated in the visual condition survey.

REFERENCES

1. Kulkarni, R., F. Finn and A. Lamont, Feasibility Study of a Pavement Management System for Washington Counties, Prepared for Thurston County, Washington, 1984.

2. Salmon, M., "PAVER Saves a Million Dollars," APWA Reporter, Chicago, December 1985.

3. City of Ventura, California, Manual for Ventura Pavement Management System, May 1983.

4. Roberts, J.H., "Implementation Issues of a Pavement Management System for Corps of Engineers District," Proceedings, North American Pavement Management Conference, Toronto, Canada, 1985.

5. Finn, F.N., D.A. Hornby and R. Kulkarni, A Pavement Management System for the City and County of San Francisco, July 1983.

APPENDIX B

FIELD EVALUATION OF PAVEMENTS

INTRODUCTION

Most local governments are not equipped for measuring or monitoring pavement condition, or for extensive structural evaluation; and frequently they do not have all of the traffic and materials data needed for a thorough evaluation. Evaluation procedures that are relatively simple and that can be done using a minimum amount of equipment and manpower are needed. The procedures that are based on visual inspection of pavement condition fall in this category, and are used in this report.

Table B-1 (Ref. 1) shows the major pavement rehabilitation techniques used today. Before selecting a maintenance or rehabilitation technique, however, it is necessary to determine the condition of the pavement by identifying the prevailing distress conditions if a cost-effective solution is to be selected. In most cases more than one alternative maintenance or rehabilitation procedure can be used effectively. To determine the best solution, estimates of cost and expected life of the alternatives need to be obtained for all of the candidate pavements under consideration. If this is done reasonably well, the candidate pavement sections can be ranked according to the most cost-effective method, and the best overall plan for the local system as a whole can be obtained.

CONDITION SURVEYS

Several systems for evaluating the distress condition of pavements have been developed and used by various agencies (Refs. 2, 3, 4, 5, 6). A simple procedure developed by The Asphalt Institute (Refs. 2, 3,) for rating low-volume roads that is applicable to most road and street systems at the local government level.

For those individuals or agencies with the responsibility of maintaining low-volume roads and streets, deciding which roads should get first attention is often difficult. One factor complicating the decision is the variety of types of pavement distress; some serious, others rather insignificant. The Asphalt Institute system utilizes the experience of an engineer, maintenance superintendent, or foreman to assign a numerical value to each type of pavement defect, taking into account both the extent of distress and its relative seriousness. The sum of these numerical values provides a fairly accurate, though subjective, index of the general condition of the road. The index can be useful in setting maintenance priorities.

When using rating systems, attention must be given to maintaining consistency of ratings, particularly if more than one rating team is involved. This is done by holding training sessions for raters, using actual pavements sections and photographs or color slides, and by using automated equipment where possible. Trained operators should be used for automated equipment and the equipment should be calibrated frequently.

TABLE B-1 Major Rehabilitation Concepts (Ref. 1)

Rehabilitation Methods Other Than Overlay	
1.	Full Depth Pavement Repair
2.	Partial Depth Pavement Repair
3.	Joint and Crack Sealing
4.	Subsealing of Concrete Pavements
5.	Grinding or Milling of Pavements
6.	Subdrainage Design
7.	Pressure Relief
8.	Restoration of Joint Load Transfer
9.	Surface Treatments
Rehabilitation Methods With Overlay	
1.	Flexible Overlay on Existing Flexible Pavement
2.	Flexible Overlay on Existing Rigid Pavement
3.	Rigid Overlay on Existing Flexible Pavement
4.	Rigid Overlay on Existing Rigid Pavement
Special Rehabilitation Concepts	
1.	Recycling Asphalt and Concrete Pavements
2.	Break and Seat Concrete Pavements

Obtaining data in a timely manner may be a problem. However, the use of data records collected over a period of several years with a computerized analysis procedure to estimate future conditions for programming purposes will help reduce this problem.

Condition Rating for Asphalt (Flexible) Pavements

Figures B-1 and B-2 describe a simple rating system for asphalt roads that has been used successfully by local agencies, sometimes with minor modifications. The rating system is intended for agencies or organizations not having the benefit of specialized highway engineering experience and without access to conventional testing facilities. It is designed to apply to relatively low-volume roads and streets-those that carry fewer than 1,000 cars and 50 trucks per day.

An effective way of inspecting a pavement is first to drive slowly over the road to get an overall impression of its conditions. Then, to make a thorough inspection on foot, making rough notes on the type and extent of distress as one goes along. When the inspection is completed, the rating form is filled out. It may be useful to drive again slowly over the pavement after filling out the rating form. Since the system is based on personal judgment, better results are obtained when two or more experienced individuals independently rate the pavements and average the results.

As mentioned earlier, some defects affect the performance of a pavement more than others. Under this rating system, the less serious problems are assigned values between 0 and 5. Defects of a more serious nature (those directly related to the strength of the pavement) are rated on a scale of 1 to 10. A rating of 0 means that the pavement is free of that particular type of distress. Figures B-3 through B-14 should be helpful in identifying the different types of defects.

When assigning a rating to a particular defect, it is important to consider both its extent and severity. For example, a rating of 10 for "rutting" would indicate that it occurs on much or all of the road, and that the ruts are probably deep enough to be a safety hazard, especially during rain, and an impediment to traffic at all times. On the other hand, a rating of 1 for "corrugations" would indicate that corrugations, although evident, are not numerous and that at present the distortions are not very large.

After each defect is rated, the individual ratings are added. This sum is then subtracted from 100, and the result is simply called the "condition rating."

There are two ways that the condition rating can be used:

First, as a relative measurement it provides a rational method for ranking roads and streets according to their condition.

Second, as an absolute measure the condition rating provides a general indicator of the type and degree of repair work necessary. As a very general rule, if the condition rating is between 80 and 100, normal maintenance operations such as crack filling, pothole repair, or perhaps a seal coat are usually all that is required. If the condition rating falls below 80, it

ASPHALT PAVEMENT RATING FORM

STREET OR ROUTE ____________ CITY OR COUNTY ____________

LENGTH OF PROJECT ____________ WIDTH ____________

PAVEMENT TYPE ____________ DATE ____________

(Note: A rating of "0" indicates defect does not occur)

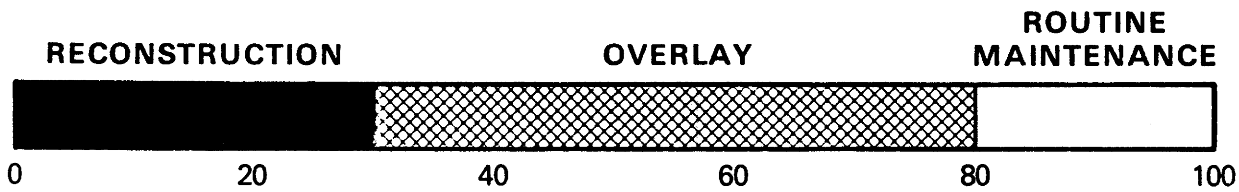
DEFECTS		RATING
Transverse Cracks	0-5	______
Longitudinal Cracks	0-5	______
Alligator Cracks	0-10	______
Shrinkage Cracks	0-5	______
Rutting	0-10	______
Corrugations	0-5	______
Raveling	0-5	______
Shoving or Pushing	0-10	______
Pot Holes	0-10	______
Excess Asphalt	0-10	______
Polished Aggregate	0-5	______
Deficient Drainage	0-10	______
Overall Riding Quality (0 is excellent; 10 is very poor)	0-10	______
	Sum of Defects	______

Condition Rating = 100 - Sum of Defects

= 100 - ____________

Condition Rating = [ ]

Figure B-1 **Asphalt pavement rating form.**



CONDITION RATING AS A GENERAL INDICATOR OF TYPE OF MAINTENANCE

Figure B-2

Figure B-3

SHOVING — Lateral displacement of paving material due to the action of traffic, generally resulting in the bulging of the surface.

Caused by lack of stability in asphalt layers.

Requires removal of affected area, followed by deep patching.

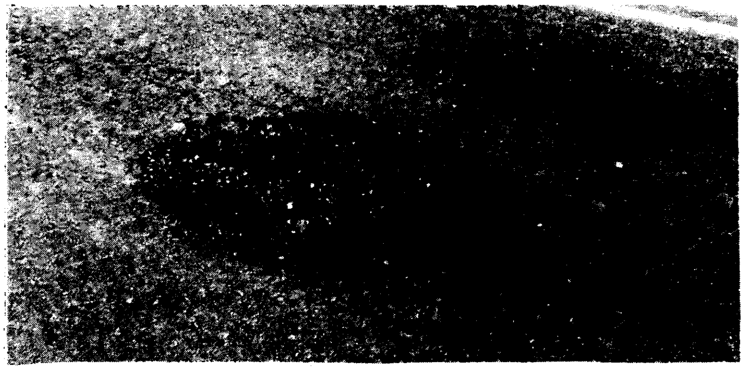
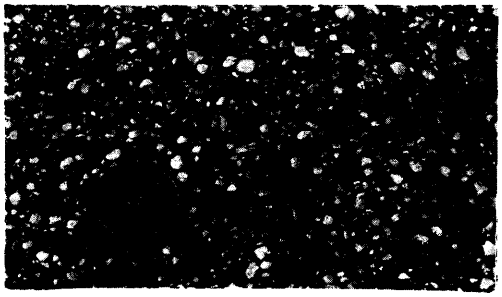


Figure B-4

POT HOLES — Bowl-shaped holes of varying sizes in the pavement, often the result of progressive deterioration of other defects such as alligator cracking.

Usually caused by a combination of weaknesses in the pavement resulting from such as too little asphalt, too thin an asphalt surface, too many fines, too few fines, or poor drainage, and traffic.

Requires deep patching.



POLISHED AGGREGATE — Aggregates in the surface of a pavement that have been polished smooth.

Caused by naturally smooth uncrushed gravels and crushed rock that wears down quickly under action of traffic.

Requires covering the surface with a skid resistant treatment.

Figure B-6

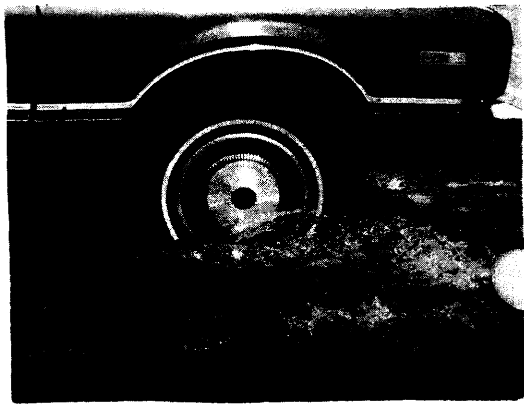
Figure B-5

EXCESS ASPHALT (BLEEDING) — Free asphalt on the surface of the pavement.

Caused by too much asphalt in one or more of the pavement courses.

In many cases, bleeding can be corrected by repeated applications of hot sand, hot slag screenings or hot rock screenings to blot up the excess asphalt. Sometimes, when bleeding is light, a plant-mixed surface treatment or an aggregate seal coat, using absorptive aggregate, is the only treatment needed. In rare instances of heavily over-asphalted surfaces, the surfaces should be completely removed.

Figure B-7



DEFICIENT DRAINAGE — Drainage problems may be considered in two categories: surface and subsurface. Proper surface drainage efficiently removes runoff from the pavement and the nearby ground. Standing water on the pavement or in the side ditches indicates surface drainage deficiency.

Proper subsurface drainage keeps groundwater away from the pavement structure. Two indicators of deficient subsurface drainage are, in the absence of precipitation, water in a side ditch, or alligator cracking with moisture in the cracks.

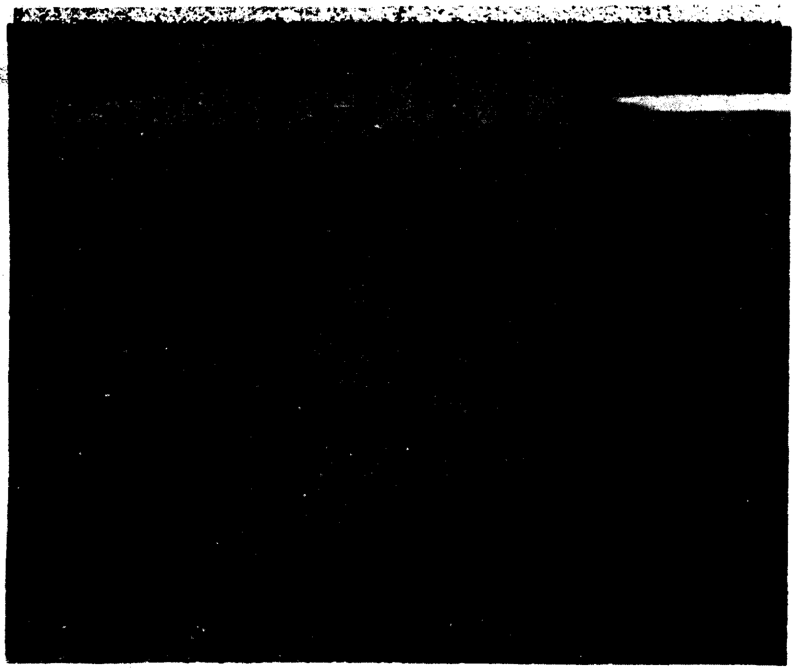
For information on alleviation of drainage problems, the reader is referred to *Drainage of Asphalt Pavement Structures*, MS-15, The Asphalt Institute.

Figure B-8

TRANSVERSE CRACK — A crack that follows a course approximately at right angles to the pavement centerline.

This frequently is caused by movement in the pavement beneath the asphalt layer (reflection cracking). Can also result from stresses induced by low-temperature contraction of the pavement.

Requires filling with asphalt emulsion slurry. This is usually (but not necessarily) followed by a seal coat or overlay over the entire surface.



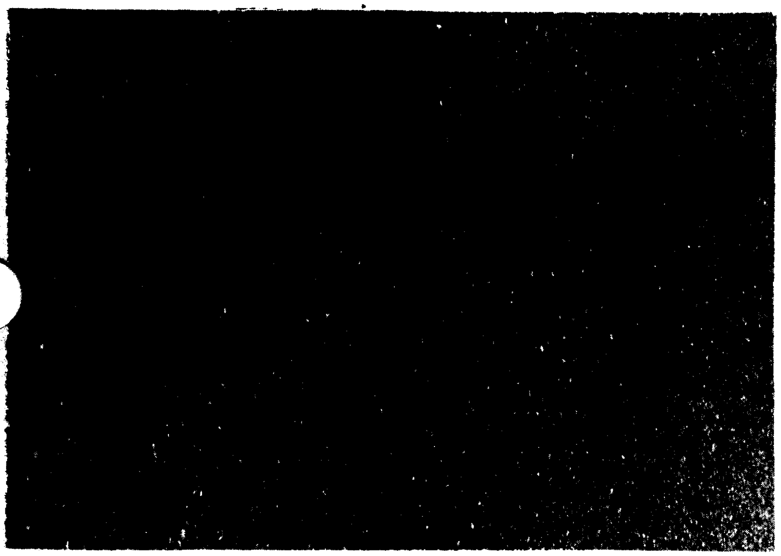


Figure B-9

LONGITUDINAL CRACK — A crack that follows a course approximately parallel to the centerline.

This usually results from a weak joint between paving lanes. These cracks can also result from earth movements, particularly on embankments. Two closely-spaced longitudinal cracks in a wheel path usually indicate bending stress induced by rutting. Longitudinal cracks can also occur as a result of movement in the pavement beneath the asphalt layer (reflection cracking).

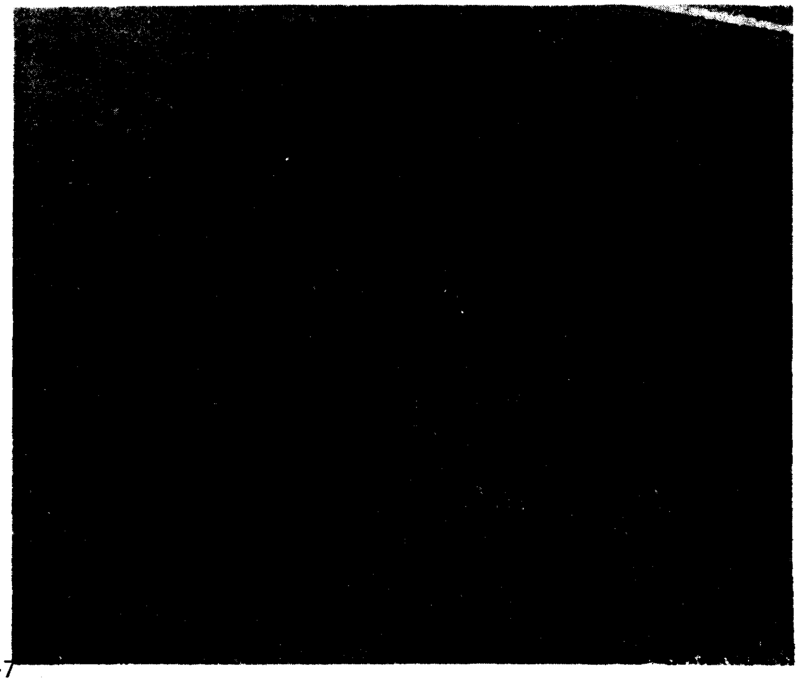
For repair, see "Transverse Crack."

Figure B-10

ALLIGATOR CRACKS — Interconnected cracks forming a series of small polygons, the pattern resembling an alligator's skin.

Caused by excessive deflection of the surface over unstable subgrade or lower courses of the pavement. The unstable support usually is the result of saturated granular bases or subgrade.

Requires deep patching.



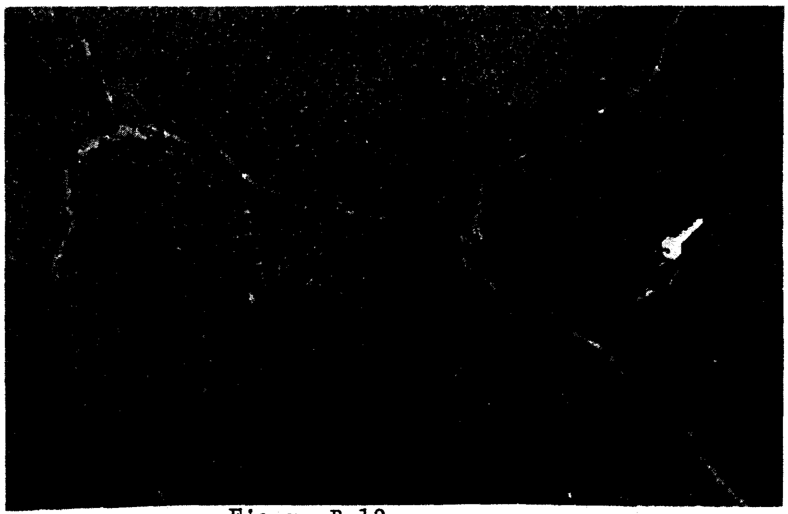


Figure B-11

SHRINKAGE CRACKS — Interconnected cracks forming a series of large polygons, usually having sharp angles at the corners.

Caused by volume change in the asphalt mix or in the base or subgrade.

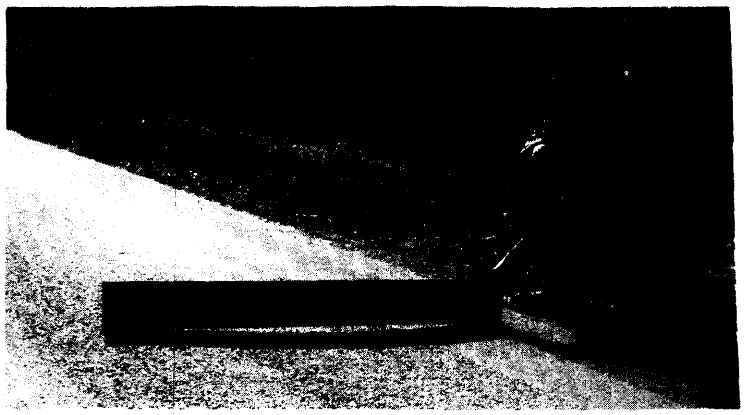
Requires crack filling with asphalt emulsion slurry followed by a surface treatment or a slurry seal over the entire surface.

Figure B-12

RUTTING — Longitudinal depressions that form under traffic in the wheel paths and have a minimum length of approximately 6 m (20 ft).

Caused by consolidation or lateral movement under traffic in one or more of the underlying courses, or by displacement in the asphalt surface layer itself.

Ruts should be filled with hot plant-mixed material to restore proper cross section. This should be followed by a thin overlay.



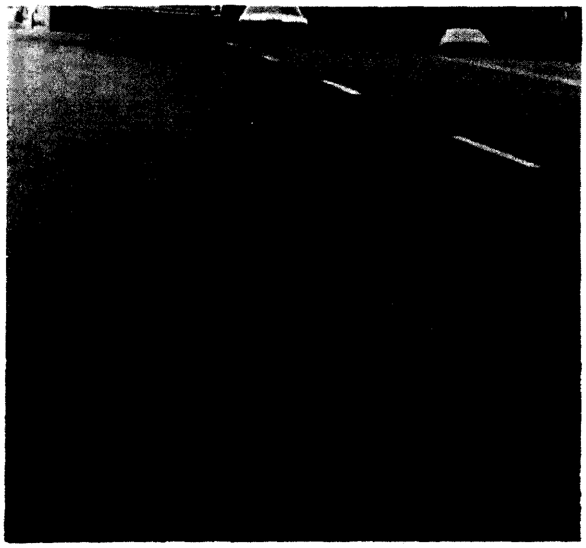


Figure B-13

CORRUGATIONS — Transverse undulations at regular intervals in the surface of the pavement consisting of alternate closely-spaced valleys and crests.

Caused by lack of stability in asphalt layers. Requires repair before resurfacing. If the corrugated pavement has an aggregate base with a thin surface treatment, a satisfactory corrective measure is to scarify the surface, mix it with the base, and recompact the mixture before resurfacing. If the pavement has more than 50mm (2 in.) of asphalt surfacing and base, shallow corrugations can be removed with a pavement planing machine, better known as a "heater-planer." This is followed with a seal coat or overlay.

Figure B-14

RAVELING — The progressive disintegration from the surface downward, or edges inward by the dislodgement of aggregate particles.

Caused by lack of compaction during construction, construction during wet or cold weather, dirty or disintegrating aggregate, too little asphalt in the mix, or overheating of the asphalt mix.

Usually requires a seal coat.

is likely that an overlay or recycling with or without an overlay will be necessary. If the condition rating is below 30, chances are that major reconstruction is necessary. The scale given in Figure B-2 illustrates the use of the rating system as a general indicator of the type of maintenance to be done.

More elaborate systems in use provide for more detailed forms of recording type and degree of distress. The province of Ontario (Canada) (Ref. 7) has developed guides for relating pavement condition index, a word description of pavement conditions, and estimates of years in the future at which overlays or reconstruction will be needed. The guide for asphalt (flexible) pavements is shown in Figure B-15. In using the system a pavement rating is first determined using a condition evaluation form, Figure B-16, to obtain an assessment of the condition of the pavement. Although not done in this case, an index could be calculated by assigning weights to each category of distress shown on the ratings forms, as was done for The Asphalt Institute system (Figure B-1). Distress weighting values to be used with Figure B-16 will be found in Reference 7.

Condition Ratings for Portland Cement Concrete Pavements

Figure B-17 and B-18 give a simple system for recording the condition of concrete pavements that is relatively easy to use (Ref. 5). Each type of distress is given a score that depends on the amount and severity of distress. Figure B-17 shows the inventory form on which the pavement condition is noted. Figure B-18 is used to assign deduct points to the different distress conditions. Deduct points are added and deducted from 100 to obtain a score. The score describes the condition of the pavement, and can be used to rank different pavement sections in order of condition. Experience can be used to prepare a scale similar to the one for asphalt pavements shown in Figure B-2. For example, experience might show that a pavement with a score of 80 or more would be assigned routine maintenance, while a score of 50 or less might indicate a need for major maintenance, an overlay or another rehabilitation treatment.

Figures B-19 and B-20 show guides for a system used in Ontario (Canada) that are comparisons to those shown in Figures B-15 and B-16 for flexible pavements. Details will be found in Reference 7. Some of the distress types referred to are described below.

Joint Seal Damage. Joint seal damage is any condition which enables incompressible materials to infiltrate into the joints from the surface, or allows significant infiltration of water. The accumulation of incompressible materials within the joints restricts in-slab expansion and may result in buckling, shattering or spalling. A pliable joint filler bonded to the edges of the slabs protects the joints from accumulating the incompressible materials and also reduces the amount of water seeping into the pavement structure. Typical types of joint seal damage are: (1) stripping of joint sealant; (2) extrusion of joint sealant; (3) weed growth; (4) hardening of the filler (oxidation); (5) loss of bond to the slab edges; and (6) lack or absence of sealant in the joint.

A Guide for the Estimation of
Pavement Condition Rating and Priority for Flexible Pavements*

Reconstruct or recycle within 2 years.	0-20	Pavement is in poor to very poor condition with extensive severe cracking, alligatoring and channeling. Ridability is poor and the surface is very rough and uneven.
Reconstruct or recycle within 2 - 3 years.	20-30	Pavement is in poor condition with moderate alligatoring and extensive severe cracking and channeling. Ridability is poor and the surface is very rough and uneven.
Overlay, recycle or reconstruct 3 - 4 years.	30-40	Pavement is in poor to fair condition with frequent moderate alligatoring and extensive moderate cracking and channeling. Ridability is poor to fair and surface is moderately rough and uneven.
Reconstruct in 4 - 5 years or resurface within 2 years with extensive leveling.	40-50	Pavement is in poor to fair condition with frequent moderate cracking and channeling, and intermittent moderate alligatoring. Ridability is poor to fair and surface is moderately rough and uneven.
Resurface within 3 years.	50-65	Pavement is in fair condition with intermittent moderate and frequent slight cracking, and with intermittent slight or moderate alligatoring and channeling. Ridability is fair and surface is slightly rough and uneven.
Resurface in 3 - 5 years.	65-80	Pavement is in fairly good condition with frequent slight cracking, slight or very slight channeling and a few areas of slight alligatoring. Ridability is fairly good with intermittent rough and uneven sections.
Normal maintenance only.	80-100	Pavement is in good condition with frequent very slight or slight cracking. Ridability is good with a few slightly rough and uneven sections.
No maintenance required.	90-100	Pavement is in excellent condition with few cracks. Ridability is excellent with few areas of slight distortion.

*Adapted from Transportation Research Board Record No. 700

Figure B-15-A guide for the estimation of pavement condition rating and priority for flexible pavements

Riding Comfort Rating (At 80 km/h)	Excellent	Good	Fair	Poor	Very Poor

Pavement Distress Manifestations			Severity of Pavement Distress: 1 Very Slight	2 Slight	3 Moderate	4 Severe	5 Very Severe	Density of Pavement Distress (Extent of Occurrence): 6 Few 10 %	7 Intermittent 10 20 %	8 Frequent 20 50 %	9 Extensive 50 80 %	10 Throughout 80 100 %	Characteristics of Pavement Distresses: Reflection Cracking	Pavement Edge Crack: Progressive (12 in. from edge) (0.3 m)	Pavement Edge Crack: Non Progressive (12 in. from edge) (0.3 m)	Transverse Crack Spacing m	Alligator Cracking: Alligator Block Size mm	Alligator Cracking: Distortion of Alligator Areas mm
Surface Defects		1 Coarse Aggregate Loss																
		2 Ravelling																
		3 Flushing																
Surface Deformation		4 Rippling																
		5 Shoving																
		6 Wheel Track Rutting																
		7 Distortion																
Cracking	Longitudinal Wheel Track	8 Single																
		9 Multiple																
		10 Alligator																
	Midland	11 Single																
		12 Multiple																
	Center Line	13 Single																
		14 Multiple																
		15 Alligator																
	Meander	16 Single																
		17 Multiple																
	Pavement Edge	18 Single																
		19 Multiple																
		20 Alligator																
	Transverse	21 Partial																
		22 Half																
		23 Full																
		24 Multiple																
		25 Alligator																
	26 Random																	
	27 Slippage																	
	28																	
	29																	
Maintenance Patching		Spray																
		Skin																
		Hot Mix																
Additional Remarks																		

Figure B-16 -Flexible pavement condition evaluation form

(Chart courtesy William A. Phang, Ontario (Canada) Ministry of Transportation and Communications)

Total Distress Points ___

Street Name ______________________ Section No. ________

From ______________________ To ______________________

RIDING QUALITY (Check one) 1 ☐ 2 ☐ 3 ☐ 4 ☐

Types of Distress	Degree of Distress	Percentage of Area		
		1-15%	16-30%	31%+
SPALLING ___ Score	Slight			
	Moderate			
	Severe			
SURFACE DETERIORATION ___ Score	Slight			
	Moderate			
	Severe			
LONGITUDINAL CRACKING ___ Score	Slight			
	Moderate			
	Severe			
TRANSVERSE CRACKING ___ Score	Slight			
	Moderate			
	Severe			
PATCHING ___ Score	Slight			
	Moderate			
	Severe			
JOINTS	Sealed ☐			
	Partially Sealed ☐			
	Not Sealed ☐			

JOINT SPACING
Less than 20' ___
More than 20' ___

Figure B-17 Inventory Data From B (Rigid Pavements)

Total Distress Points ____

Street Name ______________________ Section No. ____________

From ______________________ To ______________________

Types of Distress	Degree of Distress	Percentage of Area		
		1-15%	16-30%	31%+
SPALLING	Slight	5	10	15
____ Score	Moderate	10	15	20
	Severe	20	40	60
SURFACE DETERIORATION	Slight	5	10	20
____ Score	Moderate	10	20	30
	Severe	20	40	60
LONGITUDINAL CRACKING	Slight	5	10	15
____ Score	Moderate	10	15	20
	Severe	15	20	25

Types of Distress	Degree of Distress	1-15%		16-30%		31%+	
		<20	>20	<20	>20	<20	>20
TRANSVERSE CRACKING	Slight	5	0	10	5	20	10
____ Score	Moderate	10	5	20	10	30	20
	Severe	15	10	30	15	40	30

Types of Distress	Degree of Distress	1-15%	16-30%	31%+
PATCHING	Slight	0	2	5
____ Score	Moderate	5	7	10
	Severe	7	15	20

JOINTS	Sealed	☐
	Partially Sealed	☐
(For Information Only)	Not Sealed	☐

Figure B-18 Scoring Key B (Rigid Pavements)

A Guide for the Estimation of
Pavement Condition Rating and Priority for Rigid Pavements

Reconstruct with structural overlay within 2 years.	0-20	Pavement is in very poor condition with severe cracking and faulting. Frequent badly broken and tilted slabs. Ridability is very poor. Extremely rough and uneven throughout.
Reconstruct with structural overlay in 2 - 3 years.	20-40	Pavement is in poor condition with severe cracking and faulting. Intermittent badly broken or tilted slabs. Ridability is poor. Very rough and uneven throughout.
Cut relief joints if necessary. Resurface and underseal within 2 years.	40-50	Pavement is in fair to poor condition with moderate to severe faulting cracks and joints. Ridability is fair to poor and the surface is moderately rough and uneven throughout. Occasional blow ups may occur. Surface moderately polished by traffic.
Cut relief joints if necessary. Resurface and underseal in 2 - 5 years.	50-75	Pavement is in fair condition with moderate faulting at cracks and joints. Ridability is fair and the surface is slightly to moderately rough and uneven throughout. Occasional blow ups may occur. Surface moderately polished by traffic.
Grooving or resurfacing to restore skid resistance if necessary. Otherwise normal maintenance only.	75-90	Pavement is in fair to good condition with slight faulting at cracks & joints Ridability is fair to good with intermittent slightly rough sections. Surface slightly polished by traffic.
Normal maintenance only. Repair joint seals as necessary.	90-100	Pavement is in good condition with little cracking between joints. Intermittent slight faulting at joints. Ridability is good. Skid resistance is satisfactory.

Figure B-19-A guide for the estimation of pavement condition rating and priority for rigid pavements

Riding Comfort Rating (At 80 km/h)	Excellent	Good	Fair	Poor	Very Poor

Pavement Distress Manifestations			Severity of Pavement Distress: Very Slight	Slight	Moderate	Severe	Very Severe	Density of Pavement Distress (% of Occurrence): Few <10%	Intermittent 10 20 %	Frequent 20 50 %	Extensive 50 80 %	Throughout 80 100 %	Characteristics of Pavement Distress: Reflection Crack	Transverse Crack Spacing (m)	Joint or Crack With Pumping	Joint or Crack With Debris
Surface Defects	Polishing															
	Loss of Coarse Aggregates															
	Pot Hole															
	Scaling															
	Raveling															
Surface Deformation	Faulting															
	Settlement															
Joint Deficiencies	Joint Creeping															
	Joint Sealant Loss															
	Joint Spalling															
	Joint Failures (Blow Up Etc.)															
Cracking	Longitudinal															
	Meandering															
	Corner															
	D															
	Transverse	Single														
		Multiple														
	Diagonal															
	Edge Crescent															
	Miscellaneous Cracks															
Miscellaneous Distresses	Lane Separation															
	Slab Warping															
	Wheel Track Wear															
	Others															
Maintenance	Full Width Joint Repair															
	Full Depth Relief Joint															
	Precast Slab															
	Cold Mix Patching															
	Full Width HL Patch															
Additional Remarks																

Figure B-20 Rigid pavement condition evaluation form

(Chart courtesy William A. Phang, Ontario (Canada) Ministry of Transportation and Communications)

Corner Break. A corner break is a crack that intersects the joints at a distance of less than 6 ft on either side measured from the corner of the slab. A corner break differs from a corner spall in that the crack extends vertically through the entire slab thickness while a corner spall intersects the joint at an angle. Load repetition combined with loss of support, poor load transfer across joints, and thermal curling and moisture warping stress usually cause corner breaks.

Spalling. Spalling of cracks and joints is the cracking, breaking or chipping of the slab edges within 2 ft of the joint. A joint spall usually does not extend vertically through the whole slab thickness, but extends to intersect the joint at an angle. Spalling usually results from (a) excessive stresses at the joint or crack caused by infiltration of incompressible materials and subsequent expansion or traffic loading; (b) disintegration of the concrete; (c) weak concrete at the joint (caused by over-working) combined with traffic loads; or (d) poorly designed or constructed load transfer device.

Faulting of Transverse Joints. Faulting is the difference of elevation across a joint or crack. Faulting is caused in part by a buildup of loose materials under the approach slab near the joint or crack as well as depression of the leave slab. The buildup of eroded or infiltrated materials is caused by pumping (free moisture under pressure) due to heavy loadings. The warp and/or curl upward of the slab near the joint or crack due to moisture and/or temperature gradient contributes to the pumping condition. Lack of load transfer contributes greatly to faulting.

"D" Cracking. "D" Cracking is a series of closely spaced crescent-shaped hairline cracks that appear at a PCC pavement slab surface adjacent and roughly parallel to transverse and longitudinal joints, transverse and longitudinal cracks, and the free edges of pavement slabs. The fine surface cracks often curve around the intersection of longitudinal joints/cracks and transverse joints/cracks. These surface cracks often contain calcium hydroxide residue which causes a dark coloring of the crack and its immediate surrounding area. This may eventually lead to disintegration of the concrete within 1-2 ft or more of the joint crack, particularly in the wheelpaths. "D" Cracking is caused by freeze-thaw expansive pressures of certain types of coarse aggregates.

Blow-Up. Blow-ups occur in hot weather at a transverse joint or crack which will not permit expansion of the concrete slabs. The insufficient expansion width of joints is usually a result of the infiltration of incompressible materials into the joint space. When compressive expansion pressure cannot be relieved, a localized upward movement of the slab edges (buckling) or shattering occurs in the vicinity of the joint. Blow-ups can also occur at utility cut patches and drainage inlets. Blow-ups are accelerated due to a spalling away of the slab at the bottom creating reduced joint contact area. The presence of "D" cracking also weakens the concrete near the joint, resulting in increased spalling and blow-up potential.

Edge Punchout (for continuously reinforced concrete pavement (CRCP)). An edge punchout is first characterized by a loss of aggregate interlock at one or two closely spaced cracks (i.e., usually less than 48 in. apart) near the edge joint. The crack or cracks begin to fault and spall slightly which causes the portion of the slab between the closely spaced cracks to act essentially as a cantilever beam. As heavy truck load applications continue, a short longitudinal crack forms between the two transverse cracks about 24-60 in. from the pavement edge. Eventually the transverse cracks break down further, the steel ruptures and the pieces of concrete punch downward under load into the subbase and subgrade. There is usually evidence of pumping near edge punchouts and sometimes extensive pumping. The distressed area will expand in size to adjoining cracks and develop into a very large area if not repaired. The edge punchout is the major structural distress of CRCP.

Longitudinal Cracks. Longitudinal cracks occur generally parallel to the centerline of the pavement. They are often caused by improper construction of longitudinal joints or by a combination of heavy-load repetition, loss of foundation support, and thermal and moisture gradient stresses.

Transverse and Diagonal Cracks. These cracks are usually caused by a combination of heavy-load repetition, thermal and moisture gradient stresses, and drying shrinkage stresses. Medium or high severity cracks are working cracks and are considered major structural distresses. (Note: hairline cracks that are less then 6 ft long are not rated.)

Raveling. This is loss of fine aggregate from the matrix. This is a different form of scaling, and visually the characteristics are not the same. Scaling is spotty whereas raveling is continuous over the affected pavement surface. In appearance it is very similar to the raveling of an asphalt pavement surface and generally appears to be worse in the two-wheel tracks. Therefore, to differentiate between these two forms of scaling, this shall be named raveling. Possible causes include: (1) Poor quality fine aggregates; (2) Lack of bond between mortar and coarse aggregates; (3) Effect of freeze-thaw and/or de-icing chemicals on non-air-entrained concrete; (4) Frost action on concrete not fully cured or weak; (5) Traffic action of special nature such as studded tires.

Patches. A patch on a rigid pavement may be PCC or asphalt concrete. Patches are rated for several reasons. A patch is an indication that a pavement problem had existed in the past, and the cause may still be present. Patches are also rated in order to explain why some distresses may have disappeared since a previous survey.

REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO), Proposed AASHTO Guide for Design of Pavement Structures, Draft, Washington, D.C., March 1985.

2. Asphalt Institute, The, Asphalt Overlays for Highway and Street Rehabilitation, Manual Series No. 17 (MS-17), College Park, Maryland, June 1983.

3. Asphalt Institute, The, A Pavement Rating System for Low-Volume Asphalt Roads, Information Series No. 169 (IS-169), College Park, Maryland, November 1977.

4. Hicks, R.G., "Collection and Use of Pavement Condition Data," NCHRP Synthesis of Highway Practice 76, Transportation Research Board, Washington, D.C., July 1981.

5. Carmichael, R.F., "Conducting Effective Pavement Condition Surveys For Pavement Management," Austin Research Engineers Report, ARE Inc., Austin, Texas, September 1984.

6. Carmichael, R.F., and J.B. O'Grady, "Pavement Management: One City's Experience," Transportation Research Record 938, Transportation Research Board, Washington, D.C. 1983.

7. Phang, W.A., "Pavement-Condition Ratings and Rehabilitation Needs," Transportation Research Record 700, Transportation Research Board, Washington, D.C., 1979.

APPENDIX C

PAVEMENT AND OVERLAY DESIGN

INTRODUCTION

When recycled material is used in a pavement structure there are no special changes required in the design methods. The recycled material is viewed as simply "another source" of material and design properties for recycled materials are found in an identical manner as for new or virgin materials. However, from a practical viewpoint, the designer will normally find it more difficult to properly and accurately evaluate design properties with recycled materials (Ref. 1). The decision to use a design procedure for new construction or to use an overlay design will depend on whether or not any of the original pavement structure remains prior to the placing of the recycled layer. With overlays, it is also important to establish the true structural capacity of the existing pavement in those cases where a portion of the pavement is removed by grinding, milling, etc., prior to the overlay. In other words, when partial reconstruction, grinding or milling operations are used in conjunction with an overlay, changes in the remaining life of the existing pavement should be taken into consideration since a portion of the pavement's structural capacity has been removed.

The following section summarizes several of the procedures that are currently available for designing new pavements and overlays for both flexible and rigid pavements. These methods have generally been developed using empirical data, mechanistic theory or a combination of the two. Those that are based on empirical data attempt to relate design to observed pavement performance. However, because of the varying degree of empiricism that has developed from each individual agency's correlation to its own design method, it is not uncommon to obtain different design thicknesses from different design methods for identical input factors. A great deal of this difference can be attributed to the lack of a precise and quantitative description as to what constitutes a highway pavement failure. The remainder stems from the fact that because of the empirical nature of most designs, differences originally existed in test methods, evaluation of environmental effects, as well as the various ways of handling traffic. After the initial performance-design correlations were established, inertia made it exceedingly difficult to make major changes in the design approach (Ref. 2).

In recent years a number of mechanistic-empirical (or analytically based) design procedures have been developed for both asphalt concrete and portland cement concrete pavements. Examples of these are listed in Table C-1; included are procedures for overlay as well as new (original) design. Mechanistic procedures make use of one of the following representations of the pavement structure to estimate appropriate measures for performance:

(1) multi-layered elastic solid
(2) multi-layered visco-elastic solid
(3) elastic plate on dense liquid subgrade
(4) finite element idealizations of (1) and (3).

TABLE C-1 Examples of Mechanistic-Empirical (Analytically Based) Design Procedures (Ref. 3)

PAVEMENT TYPE	DESIGN PROCEDURE
Asphalt Concrete - New	The Asphalt Institute NCHRP 1-10B Shell Research U.S. Army Corps of Engineers FHWA Premium Pavements - ARE, Inc.
Asphalt Concrete - Overlays	Shell Research FHWA - ARE, Inc. FHWA - Resource International Inc. (OAF) Kentucky Department of Highways
Portland Cement Concrete - New	Portland Cement Association FHWA Zero Maintenance - Univ. of Illinois FHWA - RII U.S. Army Corps of Engineers
Portland Cement Concrete - Overlays	FHWA - ARE, Inc. FHWA - RII (OAR)

Stresses or strains are calculated for specific pavement layers and related to the ability of the pavement structure to resist various forms of distress such as fatigue cracking, permanent deformation, faulting and joint deterioration. Distress criteria must be developed for each of the distress types to be predicted by the procedure. For example, for fatigue cracking the distress criterion for rigid pavements is based on the maximum tensile stress in the slab and for flexible pavements is based on the maximum tensile strain in the asphalt concrete. It has been recognized that pavement performance will likely be influenced by a number of factors which will not be precisely modeled by mechanistic methods. It is therefore usually necessary to calibrate the models and establish distress criteria based on observations of performance, i.e., empirical correlations. These methods are thus referred to as mechanistic-empirical design procedures. Inputs for the analysis include the fundamental properties of the materials such as stiffness modulus and Poisson's ratio, traffic loadings and environmental effects.

Most current methods of design for flexible pavements make no direct use of mechanistic-design procedures. There are a few exceptions; for example, the Kentucky Department of Highways, The Asphalt Institute, and Shell International all have developed such procedures for general application to a variety of design considerations. Most methods for structural design of rigid pavements now include mechanistic design concepts. The method of the Portland Cement Association for fatigue of concrete is a representative example (Ref. 1).

FLEXIBLE PAVEMENT DESIGN FOR NEW CONSTRUCTION OR RECONSTRUCTION

AASHTO (Ref. 1)

The primary example of an empirically derived design method is that recommended by the American Association of State Highway and Transportation Officials (AASHTO). It is based upon the results of the extensive AASHO Road Test conducted in Ottawa, Illinois in the late 1950's and early 1960's. The AASHO (now AASHTO) Committee on Design first published an Interim Design Guide in 1961, issued a revised edition in 1972 based upon review and research of the original version, revised Chapter III of the Guide in 1981 and recently published a revision to the entire Guide to reflect changes in design methodologies developed since 1972 and to incorporate a new section on rehabilitation.

The AASHTO design method introduces a road user definition of pavement failure rather than one based upon strict structural failure concepts (e.g., cracking, deformation). Simply stated, the function of any road is to safely and smoothly carry vehicular traffic from one point to another. In order to quantify such a functional description, several important concepts were introduced. The first concept is that of serviceability, defined as the ability of a pavement to serve the traffic for which it was designed. Peformance is the ability of a pavement to satisfactorily serve traffic over a period of time. At the AASHO Road Test, performance was determined by the serviceability at the time of construction as well as at various times after construction for all pavements. Initially, the manner in which these periodic ratings of serviceability were obtained was by the mean rating of a selected panel of people who rated each pavement on an arbitrary scale of 0 to 5 with 5 being an excellent pavement. This measure of serviceability, using ratings, is defined as the Present Serviceability Rating (PSR). Additionally, a statistical analysis was made to correlate PSR to various physical measurements of the pavement. This prediction of PSR from these physical measurements is defined as the Present Serviceability Index (PSI). The correlation equation developed at the AASHO Road Test for flexible pavements is:

$$PSI = 5.03 - 1.91 \log (1 + SV) - 1.38\, RD\{ -0.01\, (C + P)^{1/2}.$$

where SV = slope variance, a measure of longitudinal roughness

RD = average rut depth

C + P = area of class 2 and 3 cracking plus patching per 1000 ft.

The AASHO design equations for flexible pavement design were based upon an analysis of the effect of structural design (including component thicknesses and material type) and loading (magnitude and frequency of axle loads) upon the performance of the flexible pavement test sections (Ref. 2).

Figure C-1 shows the flexible pavement design equation developed from the original AASHO Road Test data plus the recommended nomograph for determining the design structural number (SN) required for specific conditions, including:

(1) the estimated future traffic, w_{18}, for the performance period
(2) the reliability, R, which assumes all input is at average value
(3) the overall standard deviation, S_o
(4) the effective resilient modulus of roadbed material, M_R

(5) the design serviceability loss, $\Delta PSI = P_o - P_t$.

These input design factors are additions to or modifications of design factors for previous editions of the Design Guide.

<u>Traffic</u>. To use the AASHTO design procedure, mixed traffic must be converted to an equivalent number of 18 - kip single-axle loads (ESALs). The prediction of traffic for design purpose must rely on information from past traffic, modified by factors for growth or other expected changes. Most States, in cooperation with FHWA, accumulate past traffic information in the form of truck weight study data W4 tables. Truck distribution information by truck class (i.e., single and multiple units and by axles) is available from W2 tables. Typical information includes: (1) axle weight distributions in 2000 lb. intervals, (2) ESALs for all trucks weighed, (3) ESALs per 1000 trucks weighed, (4) ESALs for all trucks counted, and (5) percent distribution of ESALs by truck class.

If the number of equivalent axle loads represents the total for all lanes and both directions of travel, this number must be distributed by direction and by lanes for design purposes.

<u>Reliability</u>. This is included in the method to incorporate some degree of certainty into the design process to insure that the various design alternatives will last the analysis period. The reliability design factor

NOMOGRAPH SOLVES:

$$\log_{10}W_{18} = Z_R*S_o + 9.36*\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32*\log_{10}M_R - 8.07$$

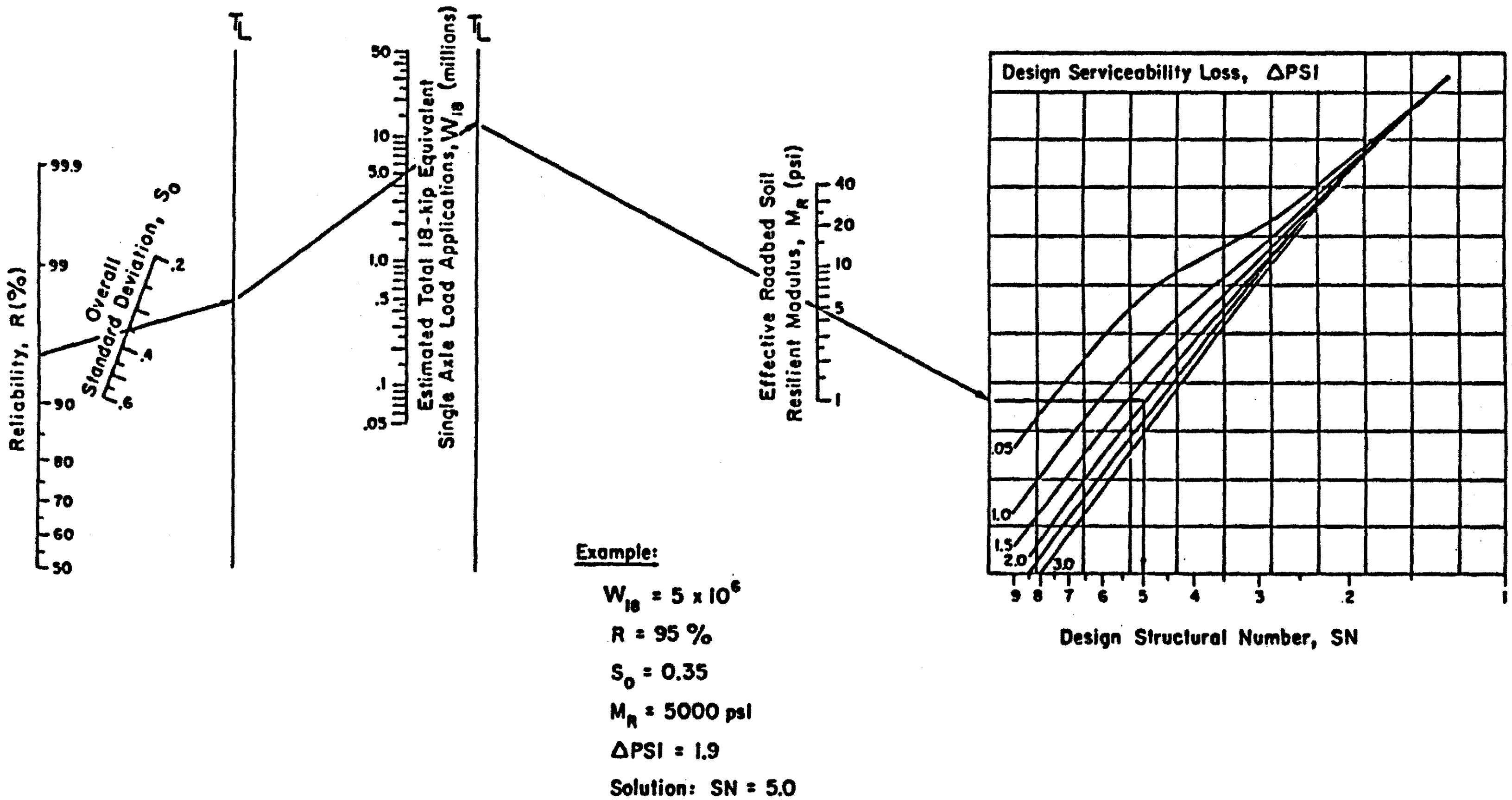


Figure C-1. Design chart for flexible pavements based on using mean values for each input.

accounts for chance variations in both traffic prediction (w_{18}) and the performance prediction (W_{18}), and therefore provides a predetermined level of assurance (R%) that pavement sections will survive the period for which they were designed.

Generally, as the volume of traffic, difficulty of diverting traffic, and public expectation of availability increases, the risk of not performing to expectations must be lower. Thus, higher levels of reliability must be selected. Table C-2 presents recommended levels of reliability for various functional classifications. Note that the higher levels correspond to the facilities which receive the most use, while the lowest level, 50 percent, corresponds to local roads. It follows that the greater the value of reliability, the more pavement structure is required.

An overall standard deviation (S_o) is also a design input and is an indication of chance variation in the traffic prediction and chance variation in pavement performance. The value of S_o has been estimated to range between 0.40 and 0.50 for flexible pavements.

Effective Roadbed Soil Resilient Modulus. For roadbed materials, laboratory resilient modulus (M_R) tests (AASHTO T274) should be performed on representative samples in moisture conditions simulating those of the primary moisture season, or determined by correlations with soil properties, i.e. clay content, moisture, plasticity index, etc. The purpose of this is to quantify the relative damage a pavement is subjected to during each season of the year and treat it as part of the overall design. The seasonal data can be translated into an effective roadbed soil resilient modulus, which is a weighted value that gives the equivalent annual damage obtained by treating each season independently in the performance equation and summing the damage.

Design Serviceability Loss. The primary measure of serviceability is the Present Serviceability Index (PSI) which ranges from 0 (impossible road) to 5 (perfect road). The basic design philosophy is the serviceability-performance concept which provides a means of designing a pavement for the minimum level of serviceability desired at the end of the performance period or after exposure to a specific total traffic volume. A terminal serviceability index (p_t) of 2.5 or higher is suggested for design of major highways and 2.0 for highways with lesser traffic volumes. The following equation may be applied to define the change in serviceability index basd on the actual initial serviceability, p_o, and the desired terminal serviceability, p_t:

$$\Delta PSI = p_o - p_t$$

Structural Design. The inputs for traffic reliability, roadbed resilient modulus and serviceability loss can be used with Figure C-1 to arrive at a structural number (SN) for the pavement. The following generalized equation provides the basis for converting SN into actual thicknesses of surface, base and subbase:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

where: a_1, a_2, a_3 = layer coefficients representative of surface, base, and subbase courses respectively.

Table C-2. Suggested levels of reliability for various functional classifications.

Functional Classification	Recommended Level of Reliability	
	Urban	Rural
Interstate and other freeways	85 - 99.9	80 - 99.9
Other Principle Arterials	80 - 99	75 - 95
Collectors	80 - 95	75 - 95
Local	50 - 80	50 - 80

Note: Results based on a survey of the AASHTO Pavement Design Task Force

D_1, D_2, D_3, = actual thicknesses (in inches) of surface, base, and subbase courses, respectively.

m_2, m_3 = drainage coefficients for untreated base and subbase layers, repectively.

The layer coefficients can be those that have traditionally been used in the original AASHTO flexible pavement design procedure or can be derived from appropriate laboratory tests such as CBR, resilient modulus, Marshall stability, etc. using the conversion charts contained in Reference 1. The layer coefficients are modified through the use of drainage coefficients based on the quality of drainage and the percent of time during the year that the pavement structure would normally be exposed to moisture levels approaching saturation.

The SN equation does not have a single unique solution: therefore, there are many combinations of layer thicknesses that are satisfactory. When selecting appropriate values for the layer thicknesses, it is necessary to consider their cost effectiveness along with construction and maintenance constraints. Recommended minimum thicknesses and a "layered design analysis" procedure for computing maximum allowable thicknesses are included in the revised Guide (Ref. 1).

National Crushed Stone Association (Ref. 4)

This empirical design procedure is based upon the U.S. Corps of Engineers CBR method of pavement design. The philosophy of the method is to provide adequate thickness and quality of material to prevent repetitive shear deformations within any layer. Additionally, the effects of frost action, if a pertinent variable, are minimized to an acceptable level. The analysis involves consideration of traffic, subgrade and material strength, frost effects, and an adequate compaction requirement to minimize permanent deformation due to densification under traffic.

Soil Support. The California Bearing Ratio (CBR) test can be used to evaluate the load carrying capacity of soils under non-frost conditions. The design CBR value is usually selected from the lower quartile of the range of test results (i.e., 75 percent of the test values are greater than the design CBR value). The method includes a correlation chart for converting strength values from other tests (R - Value and Texas Triaxial) or soil classifications to approximate values of CBR.

Traffic. Six Design Index (DI) categories (see Table C-3) are used to classify traffic based upon ranges in the average equivalent 18-kip single-axle loads (ESALs) per lane per day expected during the pavement's design life. The use of AASHTO load equivalencies is suggested if detailed traffic surveys are available. In the absence of such data, general groupings of vehicles are obtained from spot checks of traffic and placed in one of three categories: Group 1 denotes passenger cars, panel and pick-up trucks; Group 2 denotes two-axle trucks loaded, or larger vehicles empty or carrying light loads; and Group 3 denotes all vehicles having more than three loaded axles.

TABLE C-3 Design Index Categories for Traffic

Design Index	General Character	Daily EAL
DI-1	Light traffic (few vehicles heavier than passenger cars, no regular use by Group 2 or 3 vehicles)	5 or less
DI-2	Medium-light traffic (similar to DI-1, maximum 1000 VPD, including not over 5% Group 2, no regular use by Group 3 vehicles)	6-20
DI-3	Medium traffic (maximum 3000 VPD, including not over 10% Group 2 and 3, 1% Group 3 vehicles)	21-75
DI-4	Medium-heavy traffic (maximum 6000 VPD, including not over 15% Group 2 and 3, 1% Group 3 vehicles)	76-250
DI-5	Heavy traffic (maximum 6000 VPD, may include 25% Group 2 and 3, 10% Group 3 vehicles)	251-900
DI-6	Very heavy traffic (over 6000 VPD, may include over 25% Group 2 or 3 vehicles.	901-3000

These counts are multiplied by load equivalency factors (from Figure C-2), based on estimated axle loads for each group, to estimate total daily ESALs. This value is then adjusted for future growth and lane distribution as applicable to establish the proper DI category for design purposes.

Thickness Design. After traffic and soil support values have been estimated, the basic design thickness for normal or temperate climatic conditions can be obtained from Figure C-3. Even more simply, where CBR values have been estimated from other available data, Table C-4 may be used to choose an appropriate design thickness.

If all three necessary factors are present for frost action (source of water, slowly depressed air temperatures and frost-susceptible soils), the basic design thickness is checked to insure that it is adequate under such adverse conditions. The U.S. Army has classified the frost susceptibility of soils of various types in accordance with Table C-5. Reduced strength designs as functions of the F rating and traffic level (DI), are shown in Table C-6. The final design thickness is the maximum of the basic CBR structural design and the thickness established by reduced strength concepts for F-1 to F-3 soils or the depth of frost for F-4.

Table C-7 summarizes recommended asphalt concrete surface thickness as a function of traffic intensity. It is recommended that if the total required base and subbase thickness is less than 10 to 12 inches, the unbound granular material should be high quality crushed stone material.

Mechanistic-Empirical Design Procedures

While empirical methods are based exclusively on observations of pavement performance and correlations involving a large number of pavement variables, the mechanistic types of design involve a more fundamental or "analytical" approach in which stresses, strains and displacements for each pavement layer are calculated using mathematical models that predict pavement performance. Essentially the process involves the estimation of the potential for a particular distress mode (fatigue cracking, rutting, thermal cracking, etc.) to occur in the pavement for the specific traffic and environmental conditions associated with the site. Failure criteria for the various types of distress modes have been developed based on observations of pavement performance such as from the AASHO Road Test. Since it is necessary to calibrate the models by means of empirical correlations, most current mechanistic design procedures can more accurately be described as mechanistic-empirical.

Nearly all mechanistic design procedures will require some type of computer hardware and software to perform the detailed computations that are necessary. Most current procedures require a mainframe computer, though the capability for running most structural analysis programs on microcomputer should be available in the near future. In recent years a number of analytically based design procedures (and associated computer programs) have been developed for asphalt concrete pavement. These include (Ref. 5):

(1) Shell International Petroleum Company, Limited (BISTRO, BISAR)
(2) Chevron Research Company (CHEVRON)
(3) The Asphalt Institute (DAMA)

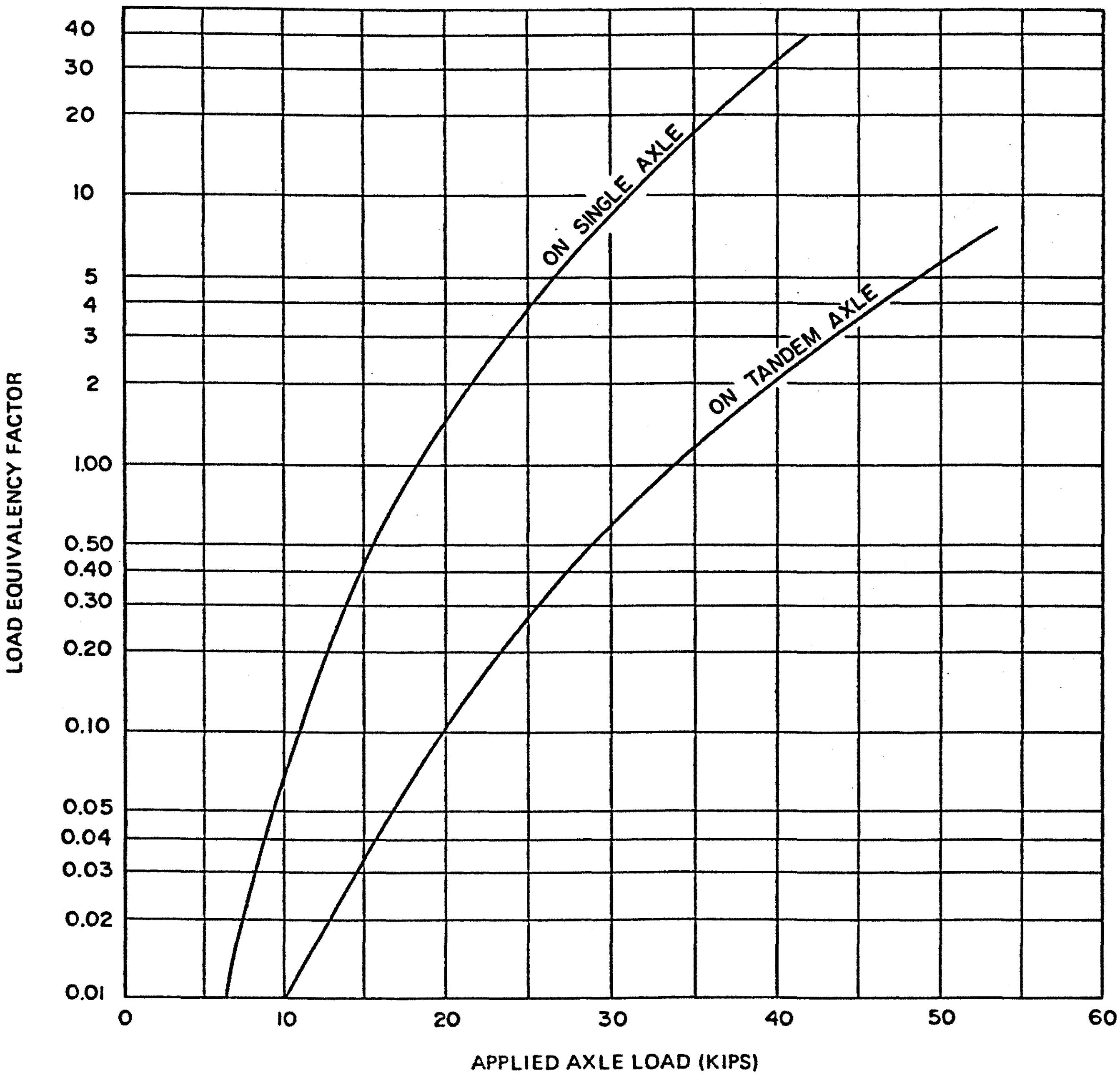


Figure C-2

RELATIONSHIP BETWEEN AXLE LOADS OF VARIOUS MAGNITUDES AND THE BASIC 18 KIP, SINGLE AXLE, DUAL TIRE LOAD.

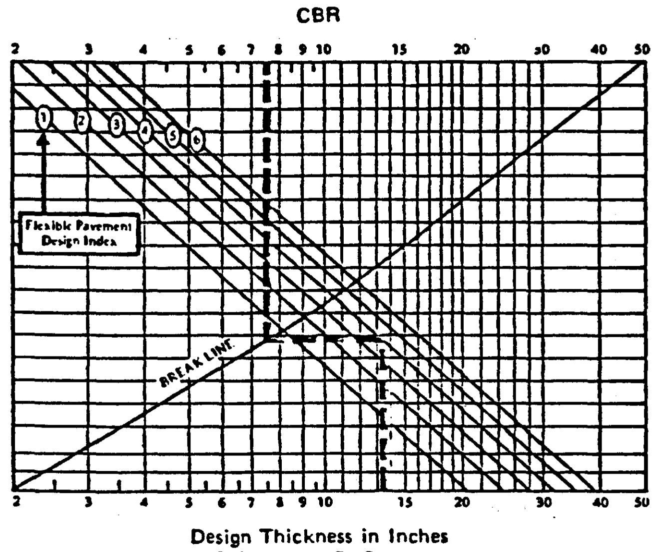


Figure C-3

THICKNESS DESIGN CHART
(From U.S. Army Engineers Manual TM 5-822-5, 1965, reproduced by permission)

Table C-4

Basic Design Thickness Table (Normal Climatic Conditions)

Subgrade Soil		Design Thickness (inches) for Indicated Traffic Intensity Categories					
Class	CBR	DI-1	DI-2	DI-3	DI-4	DI-5	DI-6
Excellent	15+	5	6	7	8	9	10
Good	10-14	7	8	9	10	11	12
Fair	6-9	9	11	12	14	15	17
Poor*	5 or less	Subgrade Improvement Recommended					

* Poor subgrade soil should be improved to "fair" or better by protecting them with available "select" materials or by stabilization. The depth or improvement required should be adequate to provide protection to unimproved soil beneath (determined from Figure 5).

Table C-5

Frost Group Classification

Frost Group	Percentage Finer than 0.02 mm	Unified Soil Classification*	Frost Susceptibility
F-1			
(a) Gravelly Soils	3-10	GW, GP, GW-GM, or GP-GM	Low
F-2			
(a) Gravelly Soils	10-20	GM, GW-GM or GP-GM	Low to
(b) Sands, Sand Clays	3-15	SW, SP, SM, SW-SM, or SP-SM	Medium
F-3			
(a) Gravelly Soils	over 20	GM or GC	
(b) Sands, coarse to medium	over 15	SM or SC	High
(c) Clays, PI 12	—	CL or CH	
F-4			
All silts, very fine silty sands, clays w/PI 12, etc.	over 15	ML, MH, SM, CL, CL-ML, CH and alternately banded deposits	Very High

*Reference ASTM Standard D 2587

Table C-6

Design Thickness, Frost Group Basis

Subgrade Soil Frost Group	Design Thicknesses (inches) For Indicated Traffic Intensity Categories					
	DI-1	DI-2	DI-3	DI-4	DI-5	DI-6
F-1	9	10	12	13	15	17
F-2	10	12	14	16	18	20
F-3	15	18	22	25	28	30
F-4	Subgrade Improvement Recommended					

Note: Design thicknesses may be conservative except where both adverse moisture conditions and deep freezes are common. F-4 soils should be upgraded to F-3 or better (as noted in Step 3) prior to construction. This operation should be extended to the full depth of frost penetration.

* Table devised from Figure 19, U.S. Army TM 5-818-2

Table C-7

Surfacing Thickness Recommendations

Traffic Intensity Category	Minimum Surfacing Required{
DI-1	1-inch (use surface treatments)
DI-2	2-inches
DI-3	2.5-inches
DI-4	3-inches
DI-5	3.5-inches}
DI-6	4-inches}

Notes 1: See definitions of Design Index (DI) categories, Page C-9

2: Minimum thicknesses required are predicted upon asumption that base course quality will be equal to that prescribed in Chapter V, Sections 1.00 and 2.00, and will be graded on compacted in accordance with Section 2.05. Minimum thickness requirements vary widely from state to state.

3: Where design surfacing thicknesses are in excess of 3-inches, considerable economy can often be realized by placing this thickness in two stages separated by one to perhaps five years.

(4) NCHRP Report 1-10B; Pavement Structural Subsystems (PDMAP, COLD)
(5) U.S. Federal Highway Administration (VESYS)
(6) U.S. Army Corps of Engineers, Waterways Experiment Station
(7) Kentucky Department of Highways
(8) University of California (ELSYM 5)
(9) University of Illinois (ILLI-PAVE)
(10) University of Nottingham, Great Britain
(11) Center for Road Research, Belgium
(12) National Institute for Transport and Road Research, South Africa

Inputs for these types of procedures generally include traffic, subgrade properties, environment, pavement material characteristics and uncertainty, i.e., variance on each of the inputs. In addition to being used for analysis of site specific cases, these procedures can also be used to develop design curves such as those developed by The Asphalt Institute, Shell International and the Kentucky Bureau of Highways. In such instances, the user is not required to do any analytical work in order to prepare design recommendations. A relatively simple step-by-step procedure can be specified for design which is very similar to the AASHTO procedures (Ref. 1).

RIGID PAVEMENT DESIGN FOR NEW CONSTRUCTION OR RECONSTRUCTION

AASHTO (Ref. 1)

The AASHTO design procedure for rigid pavements (including plain jointed concrete pavements, jointed reinforced concrete pavements and continuously reinforced concrete pavements) is similar to the AASHTO design of flexible pavements with regard to inputs for estimated future traffic, reliability (R), overall standard deviation (S_o) and design serviceability loss (PSI). Design inputs that are unique to rigid pavements include:

(1) Effective modulus of subgrade reaction (k-value)
(2) Concrete elastic modulus, E_c
(3) Concrete modulus of rupture, S_c
(4) Load transfer coefficient, J
(5) Drainage coefficient, C_d

The overall standard deviation is normally slightly lower for rigid pavements than for flexible pavements and the initial serviceability, p_o, is slightly higher for rigid pavements.

Effective Modulus of Subgrade Reaction. Like the effective roadbed soil resilient modulus for flexible pavement design, an effective modulus of subgrade reaction (k-value) is developed for rigid pavement design. The k-value is directly proportional to roadbed soil resilient modulus, the season lengths and seasonal moduli as developed for flexible pavements. In addition to the roadbed soil resilient modulus, the k-value will also be a function of:

(1) Subbase types - Different types of subbase have different strengths or modulus values. The consideration of a subbase type in estimating an effective k-value provides a basis for evaluating its costs-effectiveness as part of the design process.

(2) Subbase thickness (inches) - Potential design thicknesses for each subbase type should also be identified, so that its cost-effectiveness may be considered.

(3) Loss of support, LS - This factor, is used to correct the effective k-value based on potential erosion of the subbase material.

(4) Depth to rigid foundation (feet) - If bedrock lies within 10 feet of the surface of the subgrade for any significant length along the project, its effect on the overall k-value and the design slab thickness for that segment should be considered.

These factors can be input to a series of charts and tables in Reference 1 for establishing the final design k-value.

<u>Concrete Elastic Modulus</u>. The elastic modulus for any type of material may also be estimated using correlations developed by the state's department of transportation or by some other reputable agency. The following is a correlation recommended by the American Concrete Institute for normal weight portland cement concrete:

$$E_c = 57000\ (f'_c)^{0.5}$$

where

E_c = PCC elastic modulus (in psi),

f'_c = PCC compressive strength (in psi) as determined using AASHTO T 22, T 140, or ASTM C 39.

<u>Concrete Modulus of Rupture</u>. The modulus of rupture (flexural strength) of portland cement concrete (in psi) is required only for the design of a rigid pavement. The modulus of rupture required by the design procedure is the mean value determined after 28 days using third-point loading - AASHTO T 97 (ASTM C 78). If standard agency practice dictates the use of center-point loading, then a correlation should be made between the two tests.

<u>Load Transfer Coefficient</u>. The load transfer coefficient, J, is a factor used to account for the ability of a concrete pavement structure to transfer (distribute) load across discontinuities, such as joints or cracks. Load transfer devices, aggregate interlock, and the presence of tied concrete shoulders all have an effect on this value. Generally, the J-value for a given set of conditions (e.g., jointed concrete pavement with tied shoulders) increases as traffic loads increase since aggregate load transfer decreases with load repetitions. Table C-8 indicates ranges of load transfer coefficients for different conditions developed from experience and mechanistic stress analysis. As a general guide for the range of J-values, higher J's should be used with low k-values, high thermal coefficients, and large variations of temperature.

Table C-8 Recommended load transfer coefficient for various pavement types and design conditions.

Shoulder	Asphalt		Tied P.C.C.	
Load Transfer Devices	Yes	No	Yes	No
Pavement Type				
1. Plain Jointed and Jointed Reinforced	3.2	3.8 - 4.4	2.5 - 3.1	3.6 - 4.2
2. CRCP	2.9 - 3.2	N/A	2.3 - 2.9	N/A

Table C-9 Recommended values of drainage coefficient, C_d, for rigid pavement design.

Quality of Drainage	Percent of Time Pavement Structure is Exposed to Moisture Levels Approaching Saturation			
	Less Than 1%	1 - 5%	5 - 25%	Greater Than 25%
Excellent	1.25 - 1.20	1.20 - 1.15	1.15 - 1.10	1.10
Good	1.20 - 1.15	1.15 - 1.10	1.10 - 1.00	1.00
Fair	1.15 - 1.10	1.10 - 1.00	1.00 - 0.90	0.90
Poor	1.10 - 1.00	1.00 - 0.90	0.90 - 0.80	0.80
Very Poor	1.00 - 0.90	0.90 - 0.80	0.80 - 0.70	0.70

Drainage Coefficient. The treatment for the expected level of drainage for a rigid pavement is through the use of a drainage coefficient, C_d, in the performance equation. It has an effect similar to that of the load transfer coefficient, J. As a basis for comparison, the value for C_d for conditions at the AASHO Road Test is 1.0.

Table C-9 provides the recommended C_d values, depending on the quality of drainage and the percent of time during the year the pavement structure would normally be exposed to moisture levels approaching saturation. The latter is dependent on the average yearly rainfall and the prevailing drainage conditions.

Structural Design. Figure C-4 (in two segments) presents the AASHTO design nomograph used for determining the rigid pavement slab thickness, from which the designer can ultimately select the optimum combination of slab and subbase thicknesses based on economics and other agency policy requirements.

Portland Cement Association (Ref. 6)

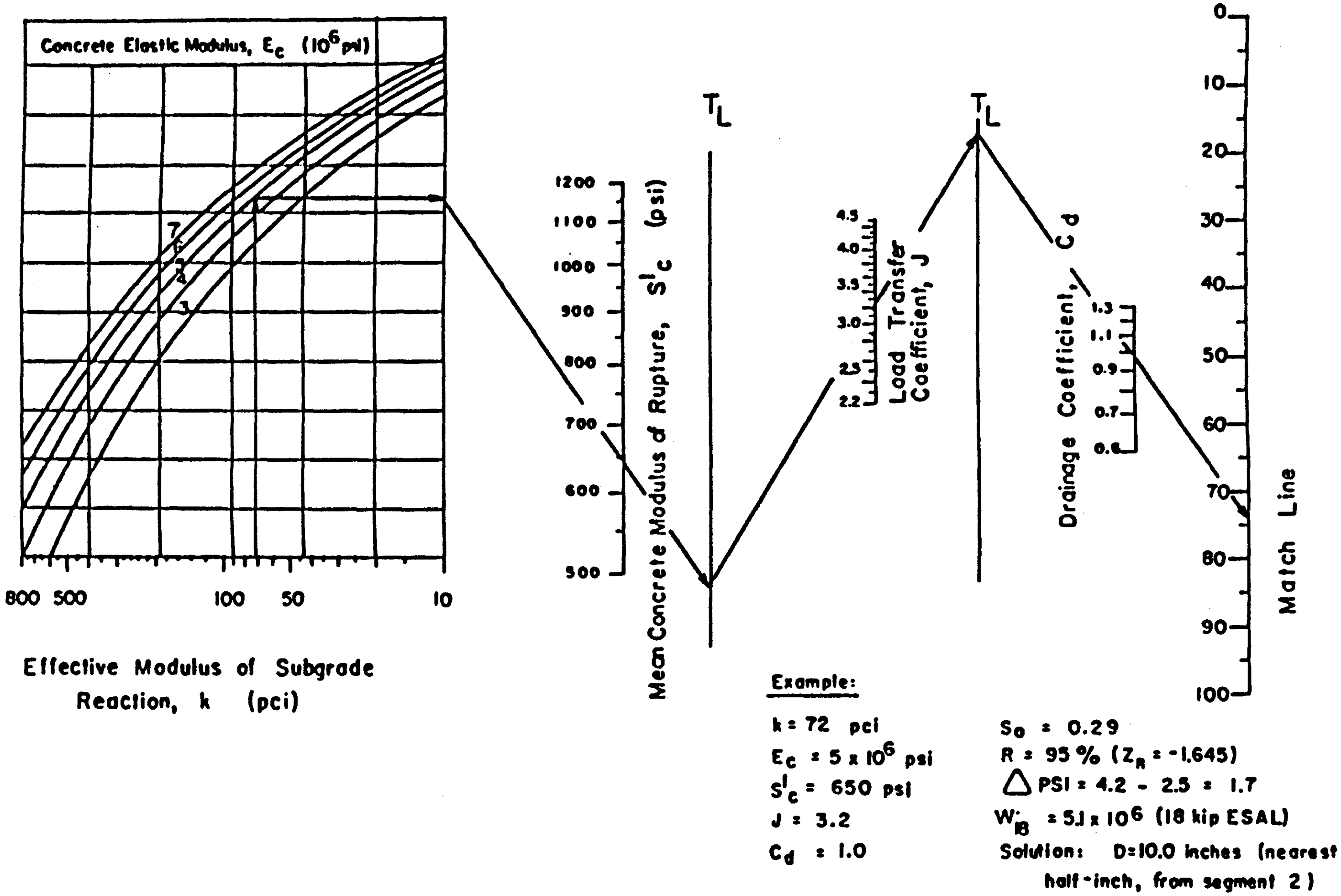
The Portland Cement Association (PCA) design procedures can be applied to plain, plain doweled, reinforced and continuously reinforced concrete pavements. The procedures include recognition of the following:

1. The degree of load transfer at transverse joints provided by the different pavement types.
2. The effect of using a concrete shoulder adjacent to the pavement; concrete shoulders reduce the flexural stresses and deflections caused by vehicle loads.
3. The effect of using a lean concrete (Econocrete) subbase, which reduces pavement stresses and deflections, provides considerable support when trucks pass over joints, and provides resistance to subbase erosion caused by repeated pavement deflections.
4. Two design criteria: (a) fatigue, to keep pavement stresses due to repeated loads within safe limits and thus prevent fatigue cracking; and (b) erosion, to limit the effects of pavement deflections at slab edges, joints, and corners and thus control the erosion of foundation and shoulder materials. The criterion for erosion is needed since some modes of pavement distress such as pumping, faulting, and shoulder distress are unrelated to fatigue.
5. Triple axles can be considered in design. While the conventional single-axle and tandem-axle configurations are still the predominant loads on highways, use of triple axles (tridems) is increasing. They are seen on some over-the-road trucks and on special roads used for hauling coal or other minerals. Tridems may be more damaging from an erosion criterion (deflection) than from a fatigue criterion.

Selection of an adequate thickness is dependent upon the choice of other design features - jointing system, type of subbase if needed, and shoulder type. With these additional design conditions, the thickness requirements of design alternatives, which influence cost, can be directly compared.

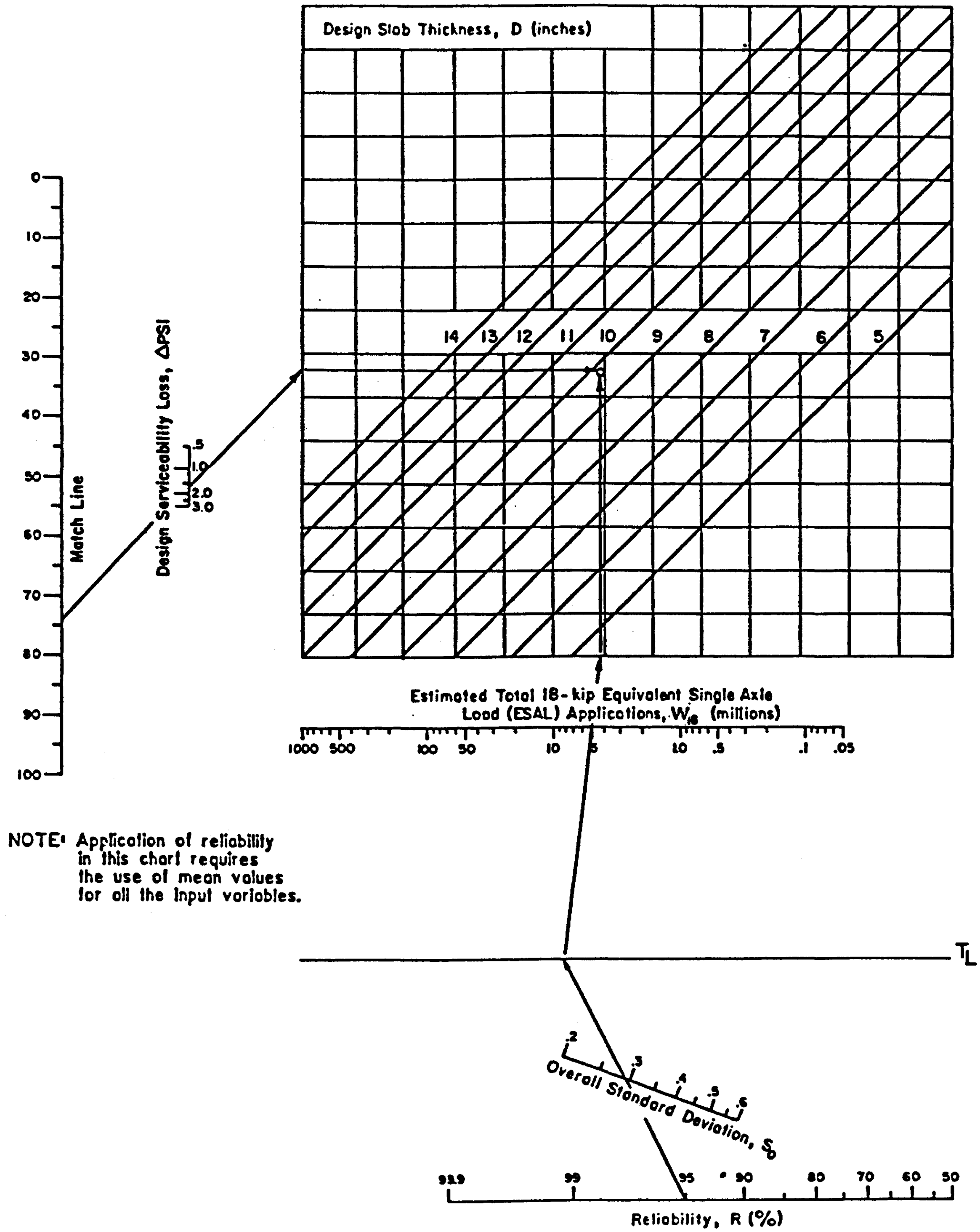
NOMOGRAPH SOLVES:

$$\log_{10}W_{18} = Z_R{*}S_o + 7.35{*}\log_{10}(D+1) - 0.06 + \frac{\log_{10}\left[\dfrac{\Delta PSI}{4.5-1.5}\right]}{1+\dfrac{1.624{*}10^7}{(D+1)^{8.46}}} + (4.22-0.32p_t){*}\log_{10}\left[\frac{S_c'{*}C_d\left[D^{0.75}-1.132\right]}{215.63{*}J\left[D^{0.75}-\dfrac{18.42}{(E_c/k)^{0.25}}\right]}\right]$$



Design chart for rigid pavement based on using mean values for each input variable (Segment 1).

Figure C-4



NOTE: Application of reliability in this chart requires the use of mean values for all the input variables.

Design chart for rigid pavements based on using mean values for each input variable (Segment 2).

Figure C-4

Figure C-5 is an example of a worksheet showing the format for completing design problems, which involves checking trial thicknesses for total fatigue and erosion damage. If either is greater than 100 percent, the design is inadequate and a thicker pavement is required. The analysis requires as input certain design factors as discussed below.

Type of Joint and Shoulder. The choice of which table or chart to use in Reference 6 for determining equivalent stress factors and allowable repetitions for both the fatigue and erosion analysis depends on type ofjoint (doweled joints/continuously reinforced pavements vs. aggregate-interlock joints) and type of shoulders (with or without concrete shoulders).

Concrete Flexural Strength (MR). As with the AASHTO method, the modulus of rupture (MR) at 28 days determined by the more conservative third-point method on 6 x 6 x 30 in. beams - AASHTO T 97 (ASTM C 78) - is used for the PCA design procedure.

Subgrade/Subbase Strength. The support given to concrete pavements by the subgrade, and the subbase where used, is defined in terms of the Westergaard modulus of subgrade reaction (k). It is equal to the load in pounds per square inch on a loaded area (a 30-in.-diameter plate) divided by the deflection in inches for that load. The k values are expressed as pounds per square inch per inch (psi/in.) or, more commonly, as pounds per cubic inch (pci). The k value can be determined by the plate loading test which is time consuming and expensive. Therefore, the k value is usually estimated by correlation to simpler tests such as the California Bearing Ratio (CBR) or R-value tests. Reference 6 contains tables for determining a "combined" k-value for design as a function of subgrade k-value plus type and thickness of subbase.

Traffic. The average daily truck traffic in both directions (ADTT) is needed in the design procedure. It is usually expressed as a percentage of average daily traffic (ADT) for all vehicles, which can be obtained from special traffic counts or from State, county or city traffic volume maps. Traffic growth during the design period (commonly 20 years) must be considered for computing total traffic for the entire design period.

Additionally, data on axle-load distribution of truck traffic are needed to compute the numbers of single and tandem axles (plus tridem axles if they are to use the facility) of various weights expected during the design period. These data can be obtained from special traffic studies, State highway department loadometer weight stations, or from methods based on categories of representative data for different types of pavement facilities (see Chapter 4 of Reference 6).

Load Safety Factor. In the design procedure, the axle loads determined as described above are multiplied by a load safety factor (LSF). The following load safety factors are recommended:

Figure C-5

Calculation of Pavement Thickness

Project *Design 1A, four-lane Interstate, rural*

Trial thickness *9.5* in.

Subbase-subgrade k *130* pci

Modulus of rupture, MR *650* psi

Load safety factor, LSF *1.2*

Doweled joints: yes *✓* no ____

Concrete shoulder: yes ____ no *✓*

Design period *20* years

4-in. untreated subbase

Axle load, kips	Multiplied by LSF *1.2*	Expected repetitions	Fatigue analysis: Allowable repetitions	Fatigue analysis: Fatigue, percent	Erosion analysis: Allowable repetitions	Erosion analysis: Damage, percent
1	2	3	4	5	6	7

8. Equivalent stress *206*

9. Stress ratio factor *0.317*

10. Erosion factor *2.59*

Single Axles

Axle load, kips	Multiplied by LSF	Expected repetitions	Allowable repetitions	Fatigue, percent	Allowable repetitions	Damage, percent
30	36.0	6,310	27,000	23.3	1,500,000	0.4
28	33.6	14,690	77,000	19.1	2,200,000	0.7
26	31.2	30,140	230,000	13.1	3,500,000	0.9
24	28.8	64,410	1,200,000	5.4	5,900,000	1.1
22	26.4	106,900	Unlimited	0	11,000,000	1.0
20	24.0	235,800	"	0	23,000,000	1.0
18	21.6	307,200	"	0	64,000,000	0.5
16	19.2	422,500			Unlimited	0
14	16.8	586,900			"	0
12	14.4	1,837,000			"	0

11. Equivalent stress *192*

12. Stress ratio factor *0.295*

13. Erosion factor *2.79*

Tandem Axles

Axle load, kips	Multiplied by LSF	Expected repetitions	Allowable repetitions	Fatigue, percent	Allowable repetitions	Damage, percent
52	62.4	21,320	1,100,000	1.9	920,000	2.3
48	57.6	42,870	Unlimited	0	1,500,000	2.9
44	52.8	124,900	"	0	2,500,000	5.0
40	48.0	372,900	"	0	4,600,000	8.1
36	43.2	885,800			9,500,000	9.3
32	38.4	930,700			24,000,000	3.9
28	33.6	1,656,000			92,000,000	1.8
24	28.8	984,900			Unlimited	0
20	24.0	1,227,000			"	0
16	19.2	1,356,000				
			Total	62.8	Total	38.9

For Interstate and other multilane projects where there will be uninterrupted traffic flow and high volumes of truck traffic, LSF = 1.2.

For highways and arterial streets where there will be moderate volumes of truck traffic, LSF = 1.1.

For roads, residential streets, and other streets that will carry small volumes of truck traffic, LSF = 1.0.

Lean Concrete Lower Course Design. The PCA method also includes a thickness design procedure for composite concrete pavements incorporating a lower layer of lean concrete, either as a subbase constructed separately or as a lower layer in monolithic construction. Lean concrete is stronger than conventional subbase materials and is considered to be nonerodable. Recognition of its superior structural properties can be taken by a reduction in thickness design requirements.

Analysis of composite concrete pavements is a special case where the conventional two-layer theory (single slab on a foundation) is not strictly applicable. The design procedure gives a thickness for a two-layer concrete pavement equivalent to a given thickness of normal concrete (as determined by the procedure described above). The equivalence is based on providing thickness for a two-layer concrete pavement that will have the same margin of safety for fatigue and erosion as a single-layer normal concrete pavement.

In the design charts, Figures C-6 and C-7, the required layer thicknesses depend on the flexural strengths of the two concrete materials as determined by AASHTO T 97 (ASTM C 78). The quality of lean concrete is often specified on the basis of compressive strength, which can be converted to an estimated flexural strength (modulus of rupture) for use in preliminary design calculations.

LOW VOLUME ROAD DESIGN (Ref. 1)

In many instances, recycled materials are used in pavement structures designed to carry low volumes of traffic. The revised AASHTO Design Guide contains procedures specifically aimed toward the design of low volume roads based on design charts (nomographs) and design catalogs.

The low volume road design chart procedures for flexible and rigid pavements are basically the same as those for highway pavement design. The primary difference in the design for low volume roads is the level of reliability that may be used. Because of their relative low usage and the associated low level of risk, the level of reliability recommended for low-volume road design is 50 percent. The user may, however, design for higher levels of 60 to 80 percent, depending on the actual projected level of traffic and the feasibility of rehabilitation, importance of corridor, etc.

If, in estimating an effective resilient modulus of the roadbed material (M_R) or an effective modulus of subgrade reaction (k), it is not possible to determine the lengths of the seasons or even the seasonal roadbed soil resilient moduli, alternate methods can be used. Reference 1 provides

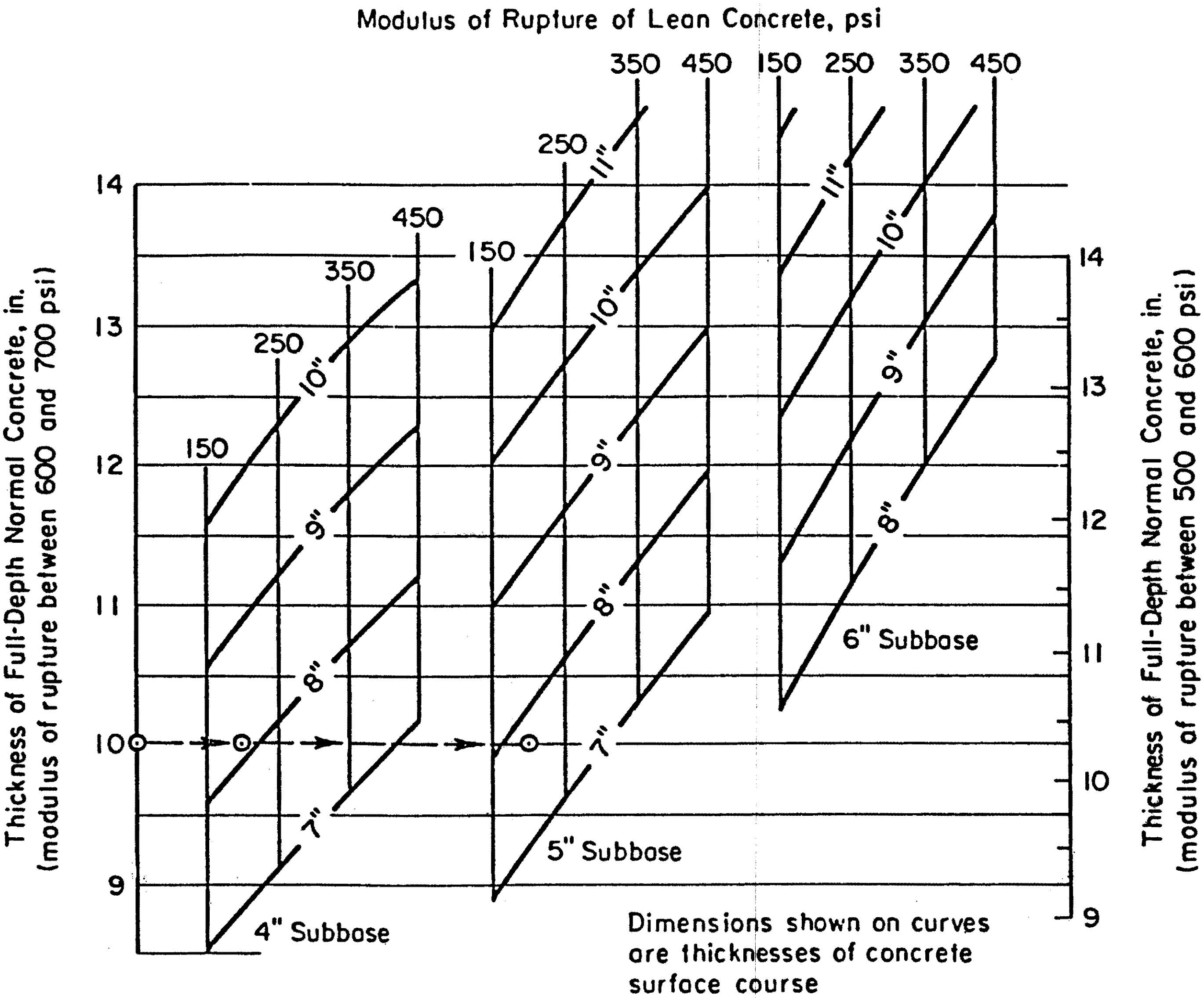


Figure C-6. Design chart for composite concrete pavement (lean concrete subbase).

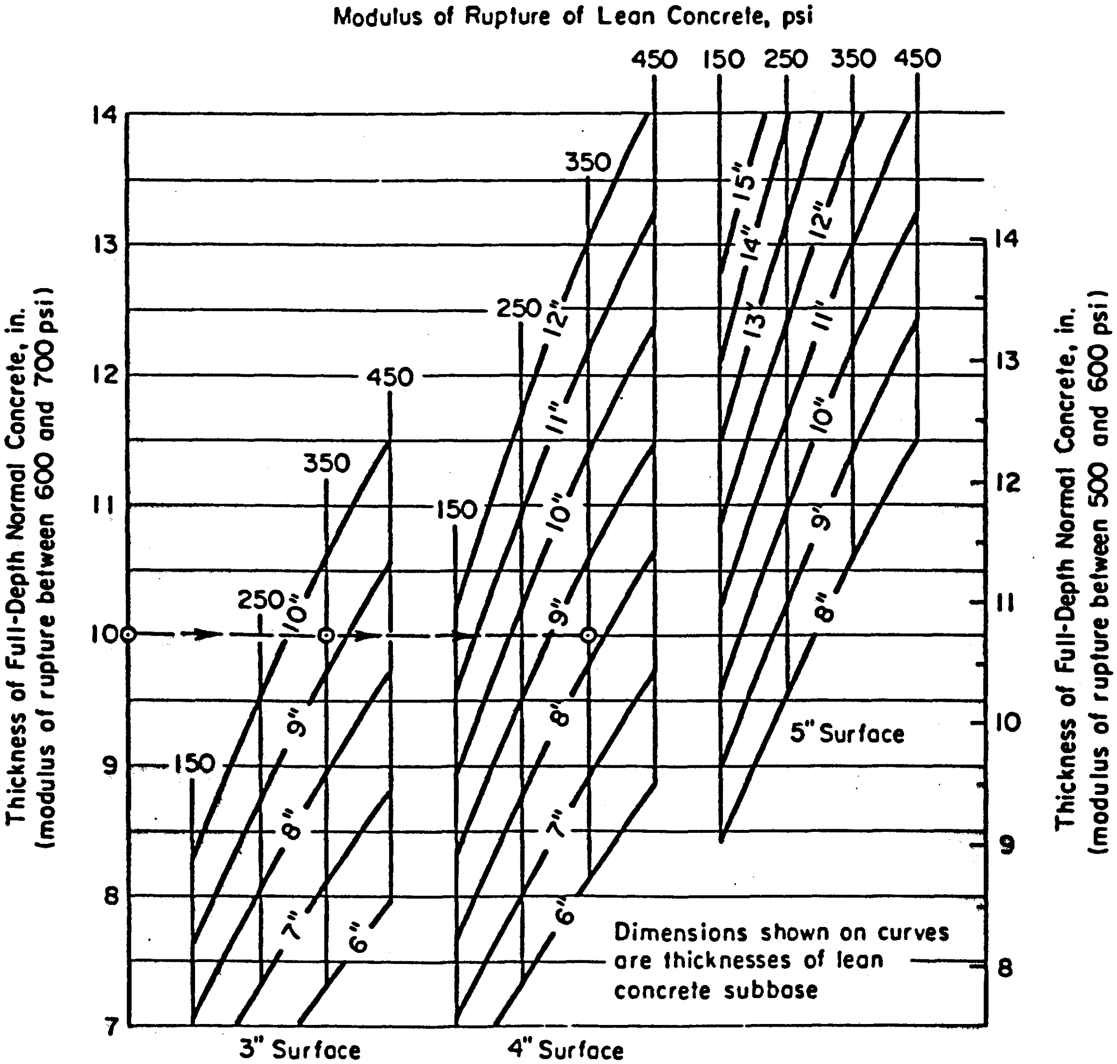


Figure C-7. Design chart for composite concrete pavement (monolithic with lean concrete lower layer).

tables for determining effective roadbed soil resilient modulus as a function of climatic region (six regions are designated for the U.S. as shown in Figure C-8), and general quality of the roadbed material.

A simpler procedure than using the design nomographs discussed in previous sections is to use the AASHTO design catalogs to identify reasonable pavement structural designs suitable for low-volume roads. These designs are based on a unique set of assumptions relative to design requirements and environmental conditions:

(1) All designs are based on the structural requirements for one performance period, regardless of the time interval. The range of traffic levels for the flexible and rigid pavement designs is between 50,000 and 1,000,000 18-kip ESAL applications.

(2) All designs presented are based on either a 50 or 75 percent level of reliability.

(3) The designs are for environmental conditions corresponding to all six of the U.S. climatic regions.

(4) The designs are for five qualitative levels of roadbed soil strength or support capability: Very Good, Good, Fair, Poor, and Very Poor.

(5) The terminal serviceability for the flexible and rigid pavement designs is 1.5.

Flexible Pavement Design Catalog. Tables C-10 and C-11 present a catalog of flexible pavement SN values (structural numbers) that may be used for the design of low volume roads when the more detailed design approach is not possible. Table C-10 is based on the 50 percent reliability level and Table C-11 is based on a 75 percent level. The range of SN values shown for each condition is based on a specific range of 18-kip ESAL applications at each traffic level:

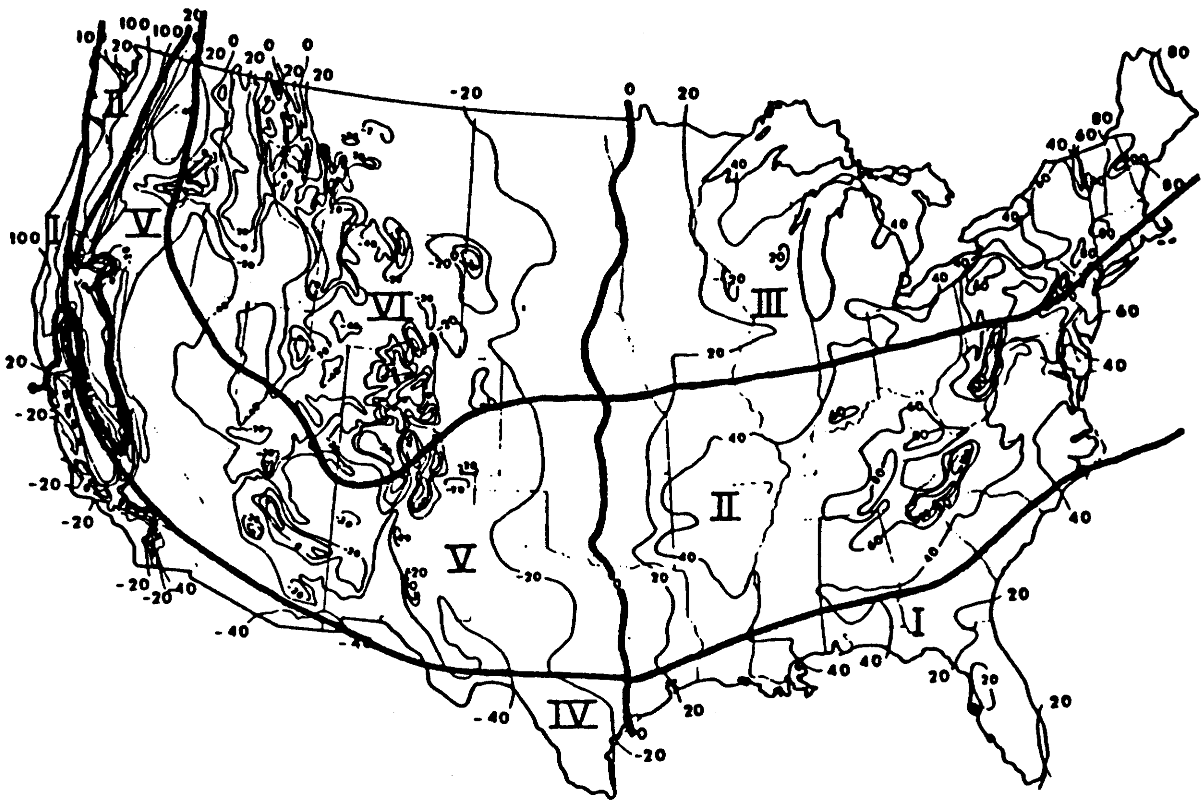
High	700,000	to	1,000,000
Medium	400,000	to	600,000
Low	50,000	to	300,000

Once a design structural number is selected, it is up to the user to identify an appropriate combination of flexible pavement layer thicknesses which will provide the desired load-carrying capacity. This may be accomplished using the criteria for layer coefficients (a_i values) and the general equation for structural number:

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3$$

a_1, a_2, a_3 = layer coefficient for surface, base, and subbase course materials, respectively, and

D_1, D_2, D_3 = Thickness (in inches) of surface, base, and subbase course, respectively.



REGION	CHARACTERISTICS
I	Wet, no freeze
II	Wet, freeze - thaw cycling
III	Wet, hard-freeze, spring thaw
IV	Dry, no freeze
V	Dry, freeze - thaw cycling
VI	Dry, hard freeze, spring thaw

Figure C-8. The Six Climatic Regions of the United States.

Table C-10 **Flexible pavement design catalog for low volume roads: recommended ranges of structural number (SN) for the six U.S. climatic regions, three levels of axle load traffic and five levels of roadbed soil quality. Inherent reliability: 50 percent.**

Relative Quality of Roadbed Soil	Traffic Level	U.S. Climatic Region					
		I	II	III	IV	V	VI
Very Good	High	2.3 - 2.5*	2.5 - 2.7	2.8 - 3.0	2.1 - 2.3	2.4 - 2.6	2.8 - 3.0
	Medium	2.1 - 2.3	2.3 - 2.5	2.5 - 2.7	1.9 - 2.1	2.2 - 2.4	2.5 - 2.7
	Low	1.5 - 2.0	1.7 - 2.2	1.9 - 2.4	1.4 - 1.8	1.6 - 2.1	1.9 - 2.4
Good	High	2.6 - 2.8	2.8 - 3.0	3.0 - 3.2	2.5 - 2.7	2.7 - 2.9	3.0 - 3.2
	Medium	2.4 - 2.6	2.6 - 2.8	2.8 - 3.0	2.2 - 2.4	2.5 - 2.7	2.7 - 2.9
	Low	1.7 - 2.3	1.9 - 2.4	2.0 - 2.7	1.6 - 2.1	1.8 - 2.4	2.0 - 2.6
Fair	High	2.9 - 3.1	3.0 - 3.2	3.1 - 3.3	2.8 - 3.0	2.9 - 3.1	3.1 - 3.3
	Medium	2.6 - 2.8	2.8 - 3.0	2.9 - 3.1	2.5 - 2.7	2.6 - 2.8	2.8 - 3.0
	Low	2.0 - 2.6	2.0 - 2.6	2.1 - 2.8	1.9 - 2.4	1.9 - 2.5	2.1 - 2.7
Poor	High	3.2 - 3.4	3.3 - 3.5	3.4 - 3.6	3.1 - 3.3	3.2 - 3.4	3.4 - 3.6
	Medium	3.0 - 3.2	3.0 - 3.2	3.1 - 3.4	2.8 - 3.0	2.9 - 3.2	3.1 - 3.3
	Low	2.2 - 2.8	2.2 - 2.9	2.3 - 3.0	2.1 - 2.7	2.2 - 2.8	2.3 - 3.0
Very Poor	High	3.5 - 3.7	3.5 - 3.7	3.5 - 3.7	3.3 - 3.5	3.4 - 3.6	3.5 - 3.7
	Medium	3.2 - 3.4	3.3 - 3.5	3.3 - 3.5	3.1 - 3.3	3.1 - 3.3	3.2 - 3.4
	Low	2.4 - 3.1	2.4 - 3.1	2.4 - 3.1	2.3 - 3.0	2.3 - 3.0	2.4 - 3.1

*Recommended range of structural number (SN).

Table C-11 **Flexible pavement design catalog for low volume roads: recommended ranges of structural number (SN) for six U.S. climatic regions, three levels of axle load traffic and five levels of roadbed soil quality. Inherent reliability: 75 percent.**

Relative Quality of Roadbed Soil	Traffic Level	U.S. Climatic Region					
		I	II	III	IV	V	VI
Very Good	High	2.6 - 2.7*	2.8 - 2.9	3.0 - 3.2	2.4 - 2.5	2.7 - 2.8	3.0 - 3.2
	Medium	2.3 - 2.5	2.5 - 2.7	2.7 - 3.0	2.1 - 2.3	2.4 - 2.6	2.7 - 3.0
	Low	1.6 - 2.1	1.8 - 2.3	2.0 - 2.6	1.5 - 2.0	1.7 - 2.2	2.0 - 2.6
Good	High	2.9 - 3.0	3.0 - 3.2	3.3 - 3.4	2.7 - 2.8	3.0 - 3.1	3.3 - 3.4
	Medium	2.6 - 2.8	2.7 - 3.0	3.0 - 3.2	2.4 - 2.6	2.6 - 2.9	2.9 - 3.2
	Low	1.9 - 2.4	2.0 - 2.6	2.2 - 2.8	1.8 - 2.3	2.0 - 2.5	2.2 - 2.8
Fair	High	3.2 - 3.3	3.3 - 3.4	3.4 - 3.5	3.0 - 3.2	3.2 - 3.3	3.4 - 3.5
	Medium	2.8 - 3.1	2.9 - 3.2	2.7 - 3.3	2.7 - 3.0	2.8 - 3.1	3.0 - 3.3
	Low	2.1 - 2.7	2.2 - 2.8	2.3 - 2.9	2.0 - 2.6	2.1 - 2.7	2.3 - 2.9
Poor	High	3.5 - 3.6	3.6 - 3.7	3.7 - 3.9	3.4 - 3.5	3.5 - 3.6	3.7 - 3.8
	Medium	3.1 - 3.4	3.2 - 3.5	3.4 - 3.6	3.0 - 3.3	3.1 - 3.4	3.3 - 3.6
	Low	2.4 - 3.0	2.4 - 3.0	2.5 - 3.2	2.3 - 2.8	2.3 - 2.9	2.5 - 3.2
Very Poor	High	3.8 - 3.9	3.8 - 4.0	3.8 - 4.0	3.6 - 3.8	3.7 - 3.8	3.8 - 4.0
	Medium	3.4 - 3.7	3.5 - 3.8	3.5 - 3.7	3.3 - 3.6	3.3 - 3.6	3.4 - 3.7
	Low	2.6 - 3.2	2.5 - 3.3	2.6 - 3.3	2.5 - 3.1	2.5 - 3.1	2.6 - 3.3

*Recommended range of structural number (SN).

Rigid Pavement Design Catalog. Tables C-12 and C-13 present the catalog of portland cement concrete pavement slab thicknesses that may be used for the design of low volume roads when the more detailed design approach is not possible. Table C-12 is based on a 50 percent reliability level and Table C-13 is based on a 75 percent level. The assumptions inherent is these design catalogs are as follows:

(1) Jointed (reinforced or unreinforced) concrete pavement (J = 3.2).

(2) Slab thickness design recommendations apply to all six U.S. climatic regions.

(3) Subbase is 6 inches of high quality granular subbase (For very good subgrade and low traffic , this layer may be omitted).

(4) Mean PCC modulus of rupture (S_c) is 600 psi.

(5) Mean PCC elastic modulus (E_c) is 5,000,000 psi.

(6) There are no tied concrete shoulders (or curbs) required.

(7) Drainage (moisture) conditions are fair (C_d = 1.0).

(8) The 18-kip ESAL traffic levels are

High	700,000	to	1,000,000
Medium	400,000	to	600,000
Low	50,000	to	300,000

(9) The levels of roadbed soil quality and corresponding ranges of effective modulus of subgrade reaction (k-value) are:

Very Good	greater than 550 pci
Good	400 to 550 pci
Fair	250 to 350 pci
Poor	150 to 250 pci
Very Poor	less than 150 pci

It should be noted that although the minimum slab thickness shown is 5 inches, the user should consider the use of a thicker slab since an overloaded truck may, in some cases, severely damage thin slab pavements.

OVERLAY DESIGN (Refs. 1, 7)

When recycled material is used in an overlay, there are no special changes required in the overlay design methods. The recycled material is simply viewed as another source of rehabilitation material, and design properties for recycled materials are found in an identical manner as for new or virgin materials. However, from a practical viewpoint, the engineeer will normally find it more difficult to properly and accurately evaluate design properties with recycled materials. In addition to the effect that recycled material has on properties of the overlay, the structural design can also be affected by the recycling process. Projects involving the removal of

Table C-12 Rigid pavement design catalog for low volume roads: recommended minimum PCC slab thickness (inches) for three levels of axle load traffic and five levels of roadbed soil quality. Inherent reliability: 50 percent.

Relative Quality of Roadbed Soil	Traffic Level		
	Low	Medium	High
Very Good	5	5 ½	6
Good	5	5 ½	6
Fair	5	5 ½	6 ½
Poor	5	6	6 ½
Very Poor	5	6	6 ½

Table C-13 Rigid pavement design catalog for low volume roads: recommended minimum PCC slab thickness (inches) for three levels of axle load traffic and five levels of roadbed soil quality. Inherent reliability: 75 percent.

Relative Quality of Roadbed Soil	Traffic Level		
	Low	Medium	High
Very Good	5	5 ½	6 ½
Good	5	5 ½	7
Fair	6	6	7
Poor	6	6	7
Very Poor	6	6	7

a portion of the existing pavement by any means (i.e., partial reconstruction, grinding or milling) prior to placement of an overlay, such as with in-place recycling, will require special analytical procedures. When a portion of the existing pavement is removed, its structural capacity (and thus its remaining life) will be reduced. This can result in additional steps in the overlay design procedure.

The following lists the four major categories of overlays:

Overlay Type	Existing Pavement Type
Flexible (asphalt)	Flexible
Flexible (asphalt)	Rigid (PCC)
Rigid (PCC)	Flexible
Rigid (PCC)	Rigid (PCC)

NOTE: 1. Existing flexible pavements include chemically stabilized (treated) base systems that may more properly be called "semi-rigid".
2. Rigid over rigid includes three distinct types of PCC overlays: (a) Bonded, (b) Partially Bonded, and (c) Unbonded.

Recycled material can conceivably be used in all types of overlays, but its predominant use is in asphalt overlays over existing flexible pavements.

Overlay design procedures can be categorized into three types: (a) component analysis, (b) deflection based, and (c) analytically based (mechanistic). The component-analysis method essentially involves determining an effective thickness of the existing pavement, i.e., what thickness of new pavement is represented by the existing pavement. Obviously, the effective thickness decreases as the pavement deteriorates under the effects of traffic loads and environment. The overlay thickness is the difference between the thickness required for a new pavement to withstand the future traffic EALs to which the pavement will be exposed after overlay and the effective thickness of the existing pavement.

To use a component-analysis procedure, it is necessary to obtain samples of materials from the existing pavement. A sampling program, which can require six to eight (or more) sampling locations depending on length of the design section, terrain, observed conditions and prior knowledge of subgrade types, is necessary to evaluate in-place materials. In addition, a considerable amount of engineering judgement is required to evaluate the structural coefficients (or "conversion factors") used in converting the existing pavement layer thicknesses to an effective thickness.

An example of a component-analysis procedure as developed by The Asphalt Institute (Ref.8) is included in Sessions 3 and 4. The AASHTO procedure can also be used in which an effective structural capacity analysis and a remaining life factor determination are used in the calculation of the overlay thickness. Table C-14 summarizes the design equations for the various types of overlays. The effective structural capacity is equal to the initial capacity multiplied by an overall pavement condition factor ($SC_{xeff} = C_x SC_o$). The condition factor can be determined through visual condition ratings or nondestructive deflection testing (NDT). The remaining life factor, F_{RL}, is an adjustment factor applied to the effective structural

Table C-14 AASHTO Overlay Design Equations (Ref. 1)

General Structural Capacity Form: $SC_{OL}^{n} = SC_{y}^{n} - F_{RL}(SC_{xeff})^{n}$

Type Overlay	Type Existing Pavement	Specific Equation	Conditions/Remarks
Flexible	Flexible	$SN_{OL} = SN_{y} - F_{RL}SN_{xeff}$	SC=SN; n = 1.0
Flexible	Rigid	$SN_{OL} = SN_{y} - F_{RL}SN_{xeff}$	SC = SN; n = 1.0 (see Section 5.3.3 for specific equations used)
Rigid	Flexible	$D_{OL} = D_{y}$ (see remarks)	Treat overlay analysis as new rigid pavement design using existing flexible pavement as new foundation (subgrade)
Rigid	Rigid	$D_{OL} = D_{y} - F_{RL}(D_{xeff})$	SC = D; n = 1.0 (Bonded Overlay)
		$D_{OL}^{1.4} = D_{y}^{1.4} - F_{RL}(D_{xeff})^{1.4}$	SC = D; n = 1.4 (Partial Bond Overlay)
		$D_{OL}^{2} = D_{y}^{2} - F_{LR}(D_{xeff})^{2}$	SC = D; n = 2.0 (Unbonded Overlay)

capacity parameter (SN_{xeff} for flexible and D_{xeff} for rigid) to reflect a more realistic assessment of the weighted effective capacity during the overlay period. This factor is dependent upon the remaining life value of the existing pavement prior to overlay (R_{Lx}) and the remaining life of the overlaid pavement system after the overlay traffic (and subsequent serviceability) has been reached (R_{Ly}). The remaining life of the existing pavement can be obtained through analysis of traffic, time or serviceability, or through visual condition surveys or NDT measurements. Tables and charts for determining C_x, R_{Lx} and F_{RL} are contained in Reference 1.

Deflection-based overlay design procedures require some type of deflection testing. The major objective of deflection testing is to measure the overall or effective strength of the existing pavement system by imposing a known load on the pavement and measuring its response. Most deflection-based design procedures do not routinely attempt to isolate material properties of individual pavement layers. (However, extensive research and development is underway that makes it possible to estimate in-situ material properties from multi-sensor deflection measurements. These methods make it possible to do a component or mechanistic analysis based primarily on nondestructive deflection testing.)

The basic criterion of the deflection-based procedure is to provide an adequate overlay thickness to reduce the deflection to a tolerable level based on increasing the overall thickness of the pavement. If the tolerable deflection is satisfied without structural enhancement, the overlay will be of nominal thickness needed to correct surface conditions or ride quality.

There are a number of different types of equipment that can be used to measure deflection including static beam (Benkelman Beam), automated beam (La Croix Deflectograph, California Traveling Deflectometer), steady state dynamic (Dynaflect, Road Rater, WES 16-kip Vibrator) and impulse (falling weight deflectometers - Dynatest, KUAB, and Phoenix). Reference 9 contains a detailed summary of the various devices available for measuring deflection.

Table C-15 is a listing of some of the existing deflection-based overlay design procedures for flexible pavements. Figure C-9 is an example of a design chart developed by The Asphalt Institute (Ref. 8) that derives asphalt concrete overlay thickness from inputs for traffic and deflection. Deflection testing can also be performed on jointed concrete pavements and continuously reinforced concrete pavements. Of interest are cracking and load-transfer capability.

Analytically-based overlay design procedures require not only nondestructive pavement evaluation, condition surveys and traffic as input, but also some measure of the stiffness (modulus of elasticity) of each pavement layer. This can be obtained through laboratory testing or a computer solution utilizing the deflection basin from multi-sensor NDT measurements. The overlay thickness is derived from a mathematical model that places limiting criteria on pavement distress such as fatigue, rutting, slab cracking, etc. Table C-16 is a list of several analytically-based overlay design procedures for flexible pavements.

Table C-15 Deflection-Based Overlay Design Procedures (Ref. 7)

Method	Deflection Measurement	Condition Survey	Establishment of Analysis Sections	Design Deflection	Provision for Remaining Life Estimate	Overlay Thickness Determination
Asphalt Institute	Benkelman beam rebound deflection	Yes	Yes	δ + 2S adjusted for temperature and critical season	Yes	Based on response of overlayed pavement as two-layer elastic system and relationship between allowable deflection and repetitions of 18-kip EAL.
California Department of Transp.	Dynaflect; Traveling deflectometer	Yes	Yes	δ + 0.845	No	Based on relation between permissible deflection as a function of asphalt layer thickness and repetitions of 18-kip EAL and reduction in deflection achieved by different thicknesses of overlay materials.
Transport and Road Research Laboratory	LaCroix deflectograph	Yes	Yes	85th percentile	Yes[a]	Observed damping effect on deflection under 18-kip EAL for various overlay thicknesses used to develop design charts as a function of repetitions of 18-kip EAL.
Roads and Transp. Association of Canada	Benkelman beam rebound deflection	Yes	Yes	δ + 2S	Yes	Overlay thickness selection procedure similar in format to Asphalt Institute procedure.
U.S. Army[b] Corps of Engineers Waterways Experiment Station	WES heavy[c] (16-kip) vibrator	Yes	Yes	Mean DSM	Yes	With parameters developed from nondestructive testing, the CBR of the subgrade is ascertained. Using the ESWL procedure, a pavement thickness is selected according to the current CE procedure. Overlay thickness is the difference between existing pavement thickness and the new thickness.

[a] A series of relationships developed between deflection change and traffic, depending on type of base course. Includes provision for different probabilities of achieving desired design life. Overlay material is hot-rolled asphalt.

[b] For airfield pavements; all others for highways.

[c] A dynamic stiffness module (DSM), defined as force/displacement, is used as the measure of pavement response rather than deflection.

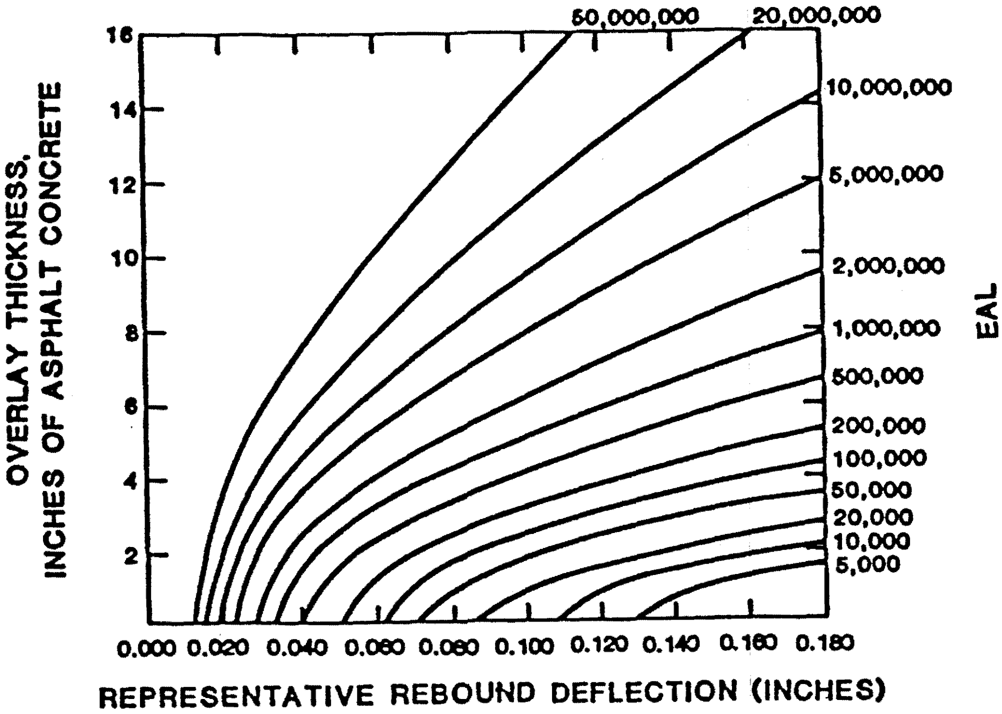


Figure C-9 Overlay Thickness Design Chart For Flexible Pavements (Ref. 8)

Table C-16 Analytically Based Overlay Design Procedures[a] (Ref. 7)

Procedure	Nondestructive Pavement Evaluation	Stiffness Determinations: In-Situ Measurement	Stiffness Determinations: Lab Testing	Analysis Procedure	Distress Mechanisms: Fatigue	Distress Mechanisms: Rutting	Provision for Existing Pavement	Overlay Thickness Determination
Shell Research	Falling weight deflectometer	Yes	No	BISAR computer program	Yes	Yes	Yes	Overlay thickness selected to (a) limit fatigue and (b) limit rutting for anticipated traffic; thickness also selected assuming existing pavement is cracked.
FHWA-ARE	Dynaflect; Benkelman beam	No	Yes	ELSYM computer program	Yes	Yes	Yes	Overlay thickness selected to (a) limit fatigue and (b) limit rutting for anticipated traffic; asphalt concrete assigned different stiffness values depending on conditions.
FHWA-RII	Dynaflect and others	Yes	Opt.	ELSYM computer program	Yes	No	Yes	Overlay thickness selected to limit fatigue for anticipated traffic; asphalt concrete assigned different stiffness values depending on conditions.
Kentucky	Road Rater	Yes	No	Graphic solution[b]	Yes	No	Yes	Overlay thickness selected as difference between pavement thickness required to accommodate all traffic (both applied and anticipated) and effective thickness of existing pavement as determined by nondestructive evaluation of existing pavement.

[a]All procedures require a condition survey, represent the pavement as a multilayer elastic solid, and provide an estimate of remaining life.

[b]Based on Chevron computer solution for multilayer elastic solid.

REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO), AASHTO Guide for Design of Pavement Structures, Washington, D.C., 1986.

2. Yoder, E.J. and M.W. Witczak, Principles of Pavement Design, John Wiley & Sons, Inc., New York, 1975.

3. American Association of State Highway and Transportation Officials (AASHTO), Proposed AASHTO Guide for Design of Pavement Structures, Draft, Washington, D.C., March 1985.

4. National Crushed Stone Association, Flexible Pavement Design Guide for Highways, Washington, D.C., April 1975.

5. Asphalt Institute, The, Research and Development of The Asphalt Institute's Thickness Design Manual (MS-1) Ninth Edition, Research Report No. 82-2 (RR-82-2), College Park, Maryland, August 1982.

6. Portland Cement Association, Thickness Design for Concrete Highway and Street Pavements, EB109.01P, Skokie, Illinois, 1984.

7. Finn, F.H. and C.L. Monismith, "Asphalt Overlay Design Procedures," NCHRP Synthesis of Highway Practice 116, Transportation Research Board, Washington, D.C., December 1984.

8. Asphalt Institute, The, Asphalt Overlays for Highways and Street Rehabilitation, Manual Series No. 17 (MS-17), College Park, Maryland, June 1983.

9. Smith, R. E. and R. L. Lytton, Synthesis Study of Nondestructive Testing Devices for Use in Overlay Thickness Design of Flexible Pavements, Report No. FHWA/RD-83/097, FHWA, Washington, D.C., April 1984.

APPENDIX D

ECONOMIC EVALUATION OF ALTERNATIVES

INTRODUCTION

If possible, all decisions to use a proposed rehabilitation alternative, including recycling, should be based on, or should at least consider, the economics of the alternatives being considered. It is quite common, at all levels of government, to base decisions on lowest first cost in order to use the funds available to meet as many immediate needs as possible. Unfortunately, this may not be the most effective solution to a problem. A low cost alternative that has a short life may not be as cost effective in the long run as an alternative with a higher first cost and a longer life.

Life-cycle cost analyses allow highway administrators to explore several feasible economic alternatives to select the best rehabilitation strategy. On a broad scale such analyses can form the basis for budgetary request. Administrators can use it to demonstrate to those controling resources the consequences to future agency costs and to the economy of not meeting identified budgetary needs. Thus, life-cycle cost analysis provides an invaluable tool for highway administrators.

Although life-cycle costing for pavements is not a new concept, it has not been widely applied by State highway agencies. The problems most often cited for not using these analyses are: the lack of certain input information particularly related to user costs, such as unknown interest rates, the time value of money, and the effect of inflation. Others question the appropriate methodology for incorporating these factors into the life-cycle cost analysis. A number of life-cycle cost techniques have been developed and applied in the United States. Most of these methods consider total pavement costs throughout the life of the pavement, and include initial capital expenditures, resurfacing and maintenance expenditures, road user costs, and salvage values. The common basis of these methods is the application of a systems approach to pavement analysis and design as discussed in Appendix A. Computerized models generate an array of alternative design strategies, compute costs associated with each feasible strategy over its analysis life, and select candidate strategies based on an appropriate economic analysis. A conceptual framework of life-cycle cost analysis used in the systems approach to pavement design is illustrated in Figure D-1.

In the simplest case, life-cycle cost analysis evaluates inputs and costs associated with a particular strategy through the analysis period, discounts the cost to the base year and generates an output report that can be used in management decision-making. Computer programs offer advantages in that they have the additional capability of examining a multiple number of strategies, maintenance treatments, and traffic scenarios in different combinations.

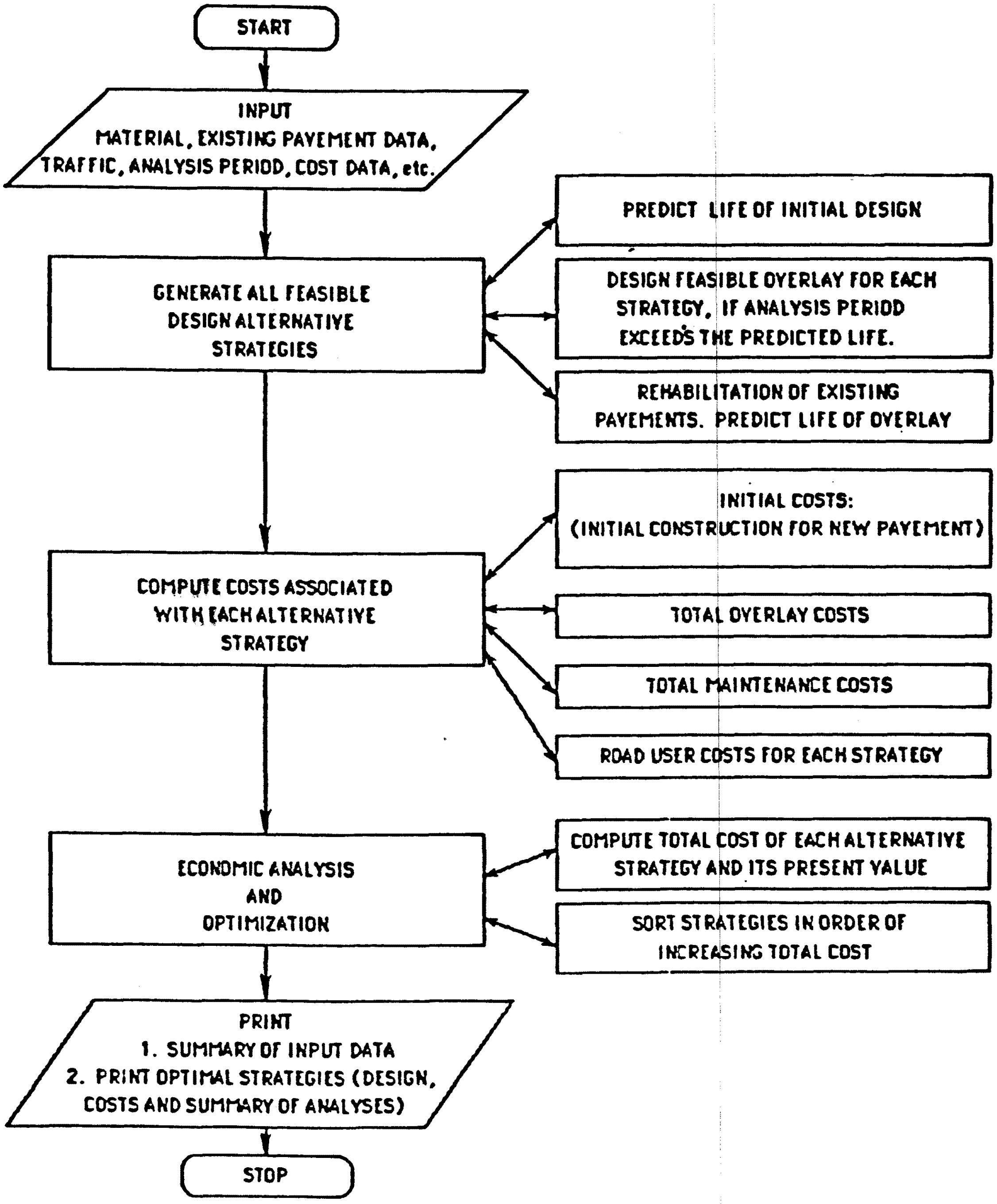


Figure D-1 A conceptual framework of a comprehensive LCC methodology.

PAVEMENT COSTS

The major costs (both initial and recurring costs) that should be considered in the economic evaluation of alternative pavement strategies include the following (Ref. 1):

A. Agency costs
   1. Initial construction costs
   2. Future construction or rehabilitation costs (overlays, seal coats, reconstruction, etc.)
   3. Maintenance costs, recurring throughout the design period
   4. Salvage return or residual value at the end of the design period (which may be a "negative cost")
   5. Engineering and administration costs
   6. Traffic control costs if any are involved.

B. User costs
   1. Travel time
   2. Vehicle operation
   3. Accidents
   4. Discomfort
   5. Time delay and extra vehicle operating costs during resurfacing or major maintenance.

References 1 and 2 provide guidelines for determining costs to be used in a life-cycle cost analysis.

Initial Construction Costs

Computing the inital cost of construction involves the calculation of material quantities to be provided in each pavement structure and multiplication by their unit prices. Material quantities are generally direct functions of their thicknesses in the structure. They are also functions of thicknesses of other layers and the width of pavement and shoulders.

The costs of in-place material in a pavement is not directly proportional to the volume required. Unit material price is dependent on material quantity to be provided, construction procedure employed, length of project, etc. Therefore care should be taken to estimate quantities and true expected costs carefully. A 2-inch layer, for example, may not be twice as expensive as a one-inch layer because the labor involved in each operation is the same. Engineering and administrative costs associated with the design should also be included.

Maintenance Costs

The estimation of all costs which are essential to maintaining pavement investment at a desirable specified level of service, or at a specified rate of deteriorating service, is essential to a proper economic analysis. The level of maintenance, i.e., the type and extent of maintenance operations, determines the rate of loss of riding quality or serviceability index.

There are various maintenance operations which are carried out for a highway. Maintenance of pavement, shoulders, drainage, erosion, vegetation, and structures, plus snow and ice control are some of the major categories. For pavement economic analysis, only those categories of maintenance which directly affect the performance of a pavement should be considered. This normally includes maintenance of pavement surface, shoulders, and related drainage.

Rehabilitation and Resurfacing Cost

Rehabilitation costs include future overlays or upgrading made necessary when the riding quality of a pavement decreases to a certain minimum level of acceptability, for example a present serviceability index (PSI) of 2.5. Resurfacing costs are included in the rehabilitation category.

Maintenance. As defined in Section 101 of Title 23, United States Code, "The preservation of the entire roadway, including surface, shoulders, roadside, structures, and such traffic-control devices as are necessary for its safe and efficient utilization". Pavement maintenance then involves the preservation of the pavement including shoulders and related drainage.

Pavement Rehabilitation. Work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway, including shoulders, to a condition of structural or functional adequacy. This could include the partial removal and replacement of the pavement structure.

Pavement rehabilitation work should not include normal periodic maintenance activities. Periodic maintenance is interpreted to include such items as resurfacing less than 3/4-inch in thickness or of short length; patching, filling potholes, sealing cracks and joints or repair of minor failures, and undersealing of concrete slabs other than as an essential part of rehabilitation; and other work intended primarily for preservation of the existing roadway.

Pavement rehabilitation projects should substantially increase the service life of a significant length of roadway. The following are a few examples of possible pavement rehabilitation work appropriate for major highway projects:

(1) resurfacing to provide improved structural capacity or serviceability (including in some cases cracking and seating)

(2) replacing or restoring malfunctioning joints

(3) substantial pavement undersealing when essential for stabilization

(4) grinding of pavements to restore smoothness or skid resistance, provided that adequate structural thickness remains

(5) removing and replacing deteriorated materials

(6) reworking or strengthening of base or subbase

(7) recycling of existing materials

(8) adding underdrains.

This list is not all inclusive, and may not apply to all road systems. There are other items that could be added which satisfy the above definition. However, it is imperative that the definition be applied consistently.

Salvage or Residual Value

Salvage or residual value is used by some agencies in economic evaluation. It can be significant in the case of pavements because it involves the value of reusable materials at the end of the design period. With the depletion of resources, such materials can become increasingly important in the future, especially when used in a new pavement by reworking or reprocessing. The practice of recycling pavements provides a dramatic and recognizable illustration of the reasons for using salvage value, as well as a basis for determining it.

Salvage value of a material depends on several factors, such as volume and position of the material, contamination, age or durability, anticipated use at the end of the design period, etc. It can be represented as a percentage of the original cost.

User Costs

Each alternative pavement strategy is associated with a number of indirect or non-agency (soft) costs which accrue to the road user and must be considered for a rational economic analysis. Such costs should not be ignored because, similar to pavement costs, user costs are related to the roughness or serviceability history of the pavement. A pavement strategy which provides an overall high level of roughness over a larger time period will result in a higher user cost than a strategy which carries the traffic on a relatively smooth surface for most of the time.

Three major types of user costs associated with pavement performance are as follows:

1. Vehicle operating cost
   a. Fuel consumption
   b. Tire wear
   c. Vehicle maintenance
   d. Oil consumption
   e. Vehicle depreciation
   f. Parts replacement

2. User travel time cost

3. Accident cost
   a. Fatal accidents
   b. Non-fatal accidents
   c. Property damage.

Each of the costs given above is a function of roughness level as well as vehicle speed resulting from such roughness level. As a pavement becomes rougher, the operating speeds of vehicles are generally reduced. Lower speeds and rough pavements result in higher travel time, discomfort, and other user costs. This is alleviated to some degree by lower fuel costs at the lower speeds. Since level of roughness for a pavement strategy depends, among other things, on its initial construction thicknesses and materials provided, the extent and times of rehabilitations, and the extent of major and minor maintenance provided during its service life, user cost is interrelated with all of these factors.

Traffic Delay Cost to User

Major maintenance or overlay placement is generally accompanied by disturbance to normal traffic flow and even lane closure. This results in vehicle speed fluctuations, stops and starts, and time losses. The extra user costs thus incurred can in certain cases become a significant factor in choice of designs and may warrant its inclusion in the economic cost calculations. Though this indirect (non-agency) cost is sometimes considered to be a "soft" cost, (i.e., not a part of the actual spending of an agency), it is certainly borne by the road users and this justifies its inclusion in the economic analysis.

In general, traffic delay cost is a function of traffic volume, road geometrics, time and duration of overlay construction, road geometrics in the overlay zone, and the traffic diversion method adopted. Cost is comprised of vehicle operating and user time values for driving slowly, fluctuating speeds, stopping, accelerating, idling, and vehicle accidents.

Design or Analysis Period

Another major factor in economic analysis is the design or analysis period, which is defined as the period of years for which traffic volume and weight data is determined and for which the 18-kip equivalent single axle load values are calculated.

A general guideline for selecting the length of the design or analysis period is that it should not extend beyond the period of reliable forecasts. For traffic, 20 years is often used as an upper limit. For other factors, 30 year mays not be unreasonable; however, the present worth of costs or benefits at such future times may be insignificant, depending on the discount rate used. Most transport studies use a range of 20 to 30 years, and this has proven to be reasonable for pavements. The particular period chosen is basically a policy decision for the agency concerned and can vary with a number of factors.

Discount Rate or Time Value of Money

A discount rate is used to adjust future expected costs or benefits to present day value. It provides the means to compare alternative uses of funds, but it should not be confused with interest rate, which is associated with costs of actually borrowing money. No reasonable economic analysis can be carried out without the use of a discount rate.

The actual rate to be used in project economic calculations is basically a policy decision. Also, this rate could vary with the factor being evaluated to reflect the associated degree of uncertainty. Most agencies, however, use a single rate for all types of projects. In the pavement field, discount rates between 4 and 10 percent have often been used. It is emphasized that the discount rate is a highly significant factor and can have a major influence on the results of an economic analysis.

Since the interest rate used in the analysis plays such an important role in selecting design strategies, this point deserves careful attention by the designer. Factors that should be considered include the price that citizens are currently paying, earning rate of private investments, probable rates of return on public works in the area, and probable rates paid by governments for borrowed money.

The question of how to take inflation into account in an economic evaluation is of concern to many engineers and administrators. Basically, the answer is that inflation should not be used in the evaluation, except where substantial evidence exists that real prices will change (i.e., "real price" is the price in constant-value money).

A significant key to life-cycle cost analysis is the economic assessment using equivalent dollars. For example, assume one person has $1,000 on hand, another has $1,000 promised 10 years from now, and a third is collecting $100 a year for 10 years. Each has assets of $1,000. However, are the assets equivalent? The answer is not so simple because the assets are spread across different periods of time. To determine whose assets are worth more, a baseline time reference must first be established. All dollar values are then brought back to the baseline, using proper economic procedures to develop an equivalent dollar value. Given the time value of money, today's dollar is simply not equal to tomorrow's dollar. Money invested in any form earns, or has the capacity to earn, interest; so that a dollar today is worth more than the prospect of a dollar at some future time. The same principle applies when comparing the cost of various pavement design alternatives over time. Each alternative may have a different stream of costs which must be transformed into a single equivalent dollar value before a meaningful comparison can be made. The rate at which these alternative cost streams are converted into a single equivalent dollar value is referred to as the discount rate.

The time value of money concept applies far beyond the financial aspects of interest paid on borrowed money. First of all, money is only a medium of exchange which represents ownership of real resources - land, labor, raw materials, plant and equipment. Secondly, the most important concept in the use of a discount rate is the opportunity cost of capital. Any funds expended for a pavement project would not otherwise stand idle. They are funds collected from the government itself by diverting funds from other purposes. If left in the private sector, they can be put to use there and earn a return that measures the value society places on the use of the funds. If the funds are diverted to government use, the true cost of the diversion is the return that would otherwise have been earned. That is the opportunity cost of capital and is the correct discount rate to use in calculating the life-cycle cost of various pavement design alternatives.

Inflation

The issue of how to deal with inflation in life-cycle cost studies is important because the procedure adopted for the treatment of inflation can have a decided effect on the results of an analysis. First, one must carefully identify the difference between two types of price changes: general inflation and differential price changes. The former may be defined as an increase in the general level of prices and income throughout the economy. Differential price change means the difference between the price trend of the goods and services being analyzed and the general price trend. During the period of analysis, some prices may decline whereas others remain fairly constant, keep pace with, or exceed the general trend in prices.

Distortions in the analysis caused by general inflation can be avoided by appropriate decisions regarding the discount rate and the treatment of future costs. The discount rate for performing present value calculations on public projects should represent the opportunity cost of capital to the taxpayer as reflected by the average market rate of return. However, the market or nominal rate of interest includes an allowance for expected inflation as well as a return that represents the real cost of capital. For example, a current market rate of interest of 12 percent may well represent a 7 percent opportunity cost component and a 5-percent inflation component. The practice of expressing future costs in constant dollars and then discounting these costs using the market, or nominal, rate of interest is in error and will understate the life-cycle cost of an alternative. Similarly, the practice of expressing future costs in inflated, or current, dollars and then discounting the costs using the real cost of capital would overstate the life-cycle cost of an alternative.

The distortion caused by general inflation may be neutralized in two ways. One is to use the nominal rate of interest (including its inflation premium) for discounting, while all costs are projected in inflated or current dollars. The other is to adjust the nominal rate of interest for inflation, discounting with the real rate component only, while measuring the cost stream in terms of constant dollars.

Because of the uncertainty associated with predicting future rates of inflation and in view of the similar results achieved by following either method, some economists have elected to use a discount rate which represents the real cost of capital while calculating life-cycle cost in terms of constant dollars. Because it avoids the need for speculation about inflation in arriving at the economic merit of a project, this is the generally accepted procedure used in the engineering profession and is recommended by the U. S. Office of Management and Budget.

Although the distortions caused by general price inflation can be easily neutralized, the issue of incorporating differential, or real, price changes into an economic analysis is an extremely complex matter. Authorities have recommended the use of differential prices only when there is overwhelming or substantial evidence that certain inputs, such as land costs, are expected to experience significant changes relative to the general price level. Such circumstances seldom relate to pavement costs and thus differential cost analysis should not be used with the Guide.

EQUATIONS FOR ECONOMIC ANALYSIS

There are several different methods that can be used to perform a life cycle cost analysis. Most often used for pavements are the annual cost and present worth methods, which have wide applicability and acceptance. Only the present worth method is presented here.

The present worth method can consider either costs alone, benefits alone, or costs and benefits together. It involves the discounting of all future sums to the present, using an appropriate discount rate. The factor for discounting either costs or benefits is

$$pwf_{i,n} = 1/(1 + i)^n$$

where $pwf_{i,n}$ = present worth factor for a particular i and n,

i = discount rate,

n = number of years to when the sum will be expended, or saved.

Published tables for pwf, are readily available in a wide variety of references.

The present worth method for costs alone can be expressed in terms of the following equation:

$$TPWX_{x1,n} = (ICC)_{x1} + \sum_{t=0}^{t=n} pwf_{i,t}[(CC)_{x1,t} + (MO)_{x1,t} + (UC)_{x1,t}] - (SV)_{x1,n}pwf_{i,n} \quad 3.3$$

where $TPWC_{x1,n}$ = total present worth of costs for alternative x_1, for an analysis period of n years

$(ICC)_{x1}$ = initial capital costs of construction, etc., for alternative x_1

$(CC)_{x1,t}$ = capital costs of construction, etc. for alternative x_1, in year t, where $t<n$

$pwf_{i,t}$ = present worth factor for discount rate, i, for t years

$pwf_{i,t} = 1/(1+i)^t$

$(MO)_{x1,t}$ = maintenance plus operation costs for alternative x1 in year t

$(UC)_{x1,t}$ = user costs (including vehicle operation, travel time, accidents, and discomfort if, designated) for alternative x1, in year t

$(SV)_{x1,n}$ = salvage value, if any, for alternative x1, at the end of the design period, n years.

The present worth of benefits can be calculated in the same manner as the present worth of costs, using the following equation:

$$TPWB_{x1,n} = \sum_{t=0}^{n} pwf_{i,t}[(DUB)_{x1,t} + (IUB)_{x1,t} + (NUB)_{x1,t}]$$

where $TPWB_{x1,n}$ = total present worth of benefits for alternative x1 for an analysis period of n years

$(DUB)_{x1,t}$ = direct user benefits accruing from alternative x1 in year t

$(IUB)_{x1,t}$ = indirect user benefits accruing from alternative x1 in year t

$(NUB)_{x1,t}$ = non-user benefits accruing from project x in year t.

It is questionable, for pavements, whether or not nonuser benefits and indirect user benefits can be measured adequately. Consequently, it is perhaps reasonable to consider only direct user benefits until such time as the state of the art is sufficiently advanced to allow for the other factors to be measured.

REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO), AASHTO Guide for Design of Pavement Structures, Washington, D.C., 1986.

2. American Association of State Highway and Transportation Officials (AASHTO), Proposed AASHTO Guide for Design of Pavement Structures, Draft, Washington, D.C., March 1985.

APPENDIX E

GUIDE SPECIFICATIONS FOR RECYCLING ASPHALT PAVEMENTS

This appendix contains two examples of guide specifications for each of the three types of asphalt pavement recycling - hot-mix recycling (Corps of Engineers and NCHRP Report 224), cold-mix recycling (Corps of Engineers and Township of Ocean, New Jersey), and surface recycling (Arizona Department of Transportation and the Asphalt Recycling and Reclaiming Association). The Township of Ocean, N.J., specification was actually used to solicit bids for an in-place cold recycling job in the summer of 1985. It is an excellent example of a recycling specification developed by a local government.

(A)

CORPS OF ENGINEERS GUIDE SPECIFICATION
MILITARY CONSTRUCTION

RECYCLED ASPHALT CONCRETE INTERMEDIATE AND WEARING COURSES FOR AIRFIELDS, HELIPORTS, AND HEAVY-DUTY PAVEMENTS (CENTRAL-PLANT HOT-MIX)

PART 1 - GENERAL

(B)

1. APPLICABLE PUBLICATIONS: The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.

1.1 Military Standard (Mil. Std.):

MIL-STD-620A & Notice 1	Test Methods for Bituminous Paving Materials

1.2 U. S. Army Corps of Engineers, Handbook for Concrete and Cement:

CRD-C 119-53 Rev Jun 1963	Flat and Elongated Particles in Coarse Aggregate

1.3 American Society for Testing and Materials (ASTM) Publications*:

C 29-78 (T 19)	Unit Weight and Voids in Aggregate
C 88-83 (T 104)	Soundness of Aggregates By Use of Sodium Sulfate or Magnesium Sulfate
C 117-80 (T 11)	Materials Finer Than 75-um (No. 200) Sieve in Mineral Aggregates by Washing
C 127-81 (T 85)	Specific Gravity and Absorption of Coarse Aggregate
C 128-79 (T 84)	Specific Gravity and Absorption of Fine Aggregate
C 131-81 (T 96)	Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact of the Los Angeles Machine
C 136-83 (T 27)	Sieve Analysis of Fine and Coarse Aggregates
C 183-83a (T 127)	Sampling and Acceptance of Hydraulic Cement

* Equivalent AASHTO specification or test method in parentheses.

D 5-83 (T 49)	Penetration of Bituminous Materials
D 75-82 (T 2)	Sampling Aggregates
D 140-70 (T 40) (R 1981)	Sampling Bituminous Materials
D 242-70 (M 17) (R 1980)	Mineral Filler for Bituminous Paving Mixtures
D 946-82 (M 20)	Penetration-Graded Asphalt Cement for Use in Pavement Construction
D 1250-80	Petroleum Measurement Tables
D 1856-79 (T 170)	Recovery of Asphalt From Solution By Abson Method
D 2041-78 (T 209)	Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
D 2172-81 (T 164)	Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
D 2216-80 (T 265)	Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures
D 3381-83 (T 226)	Viscosity-Graded Asphalt Cement for Use in Pavement Construction
D 3515-83	Hot-Mixed, Hot-Laid Bituminous Paving Mixtures

2. PLANT, EQUIPMENT, MACHINES, AND TOOLS:

2.1 General: The bituminous plant shall be of such capacity, as specified hereinafter, to produce the quantities of recycled asphalt mixtures required for the project. Hauling equipment, paving machines, rollers, miscellaneous equipment, and tools shall be provided in sufficient numbers and capacity and in proper working condition to place the recycled asphalt paving mixtures at a rate equal to the plant output.

(C)

2.2 Mixing Plants: The mixing plant shall be an automatic or semiautomatic controlled commercially manufactured unit designed, coordinated, and operated to consistently produce a mixture within the job-mix formula (JMF). The plant shall have a minimum capacity of ..... tons per hour.

2.3 Straightedge: The Contractor shall furnish and maintain at the site, in good condition, one 12-foot straightedge or other suitable device for each bituminous paver, for testing the finished surface. Straightedge shall be made available for government use. Straightedges shall be constructed or aluminum or other lightweight metal and shall have blades of box or box-girder cross section with flat bottom reinforced to insure rigidity and accuracy. Straightedges shall have handles to facilitate movement on the pavement.

3. WEATHER LIMITATIONS: Unless otherwise directed, recycled asphalt courses shall not be constructed when temperature of the surface of the existing pavement or base course is below 40 degrees F.

4. PROTECTION OF PAVEMENT: After final rolling, no vehicular traffic of any kind shall be permitted on the pavement until pavement has cooled to 140 degrees F.

5. GRADE AND SURFACE-SMOOTHNESS REQUIREMENTS: Finished surface of pavements, when tested as specified below and in paragraph ACCEPTABILITY OF WORK, shall conform to elevations shown and to surface smoothness requirements specified.

(D)

5.1 Plan Grade: Finished surfaces shall conform within tolerances specified to the lines and cross sections indicated. Finished surfaces shall vary not more than [0.03] [0.05] foot from the plan gradeline or elevation established and approved at site of work. Finished surfaces at a juncture with other pavements shall coincide with finished surfaces of abutting pavements. The deviations from the plan gradeline and elevation will not be permitted in areas of pavements where closer conformance with planned elevation is required for the proper functioning of drainage and other appurtenant structures involved. Grade will be determined and evaluated as specified in paragraph ACCEPTABILITY OF WORK.

(E)

5.2 Surface Smoothness: Finished surfaces shall not deviate from the testing edge of a 12-foot straightedge more than tolerances shown for the respective pavement category in Table I. Surface smoothness will be determined and evaluated as specified in paragraph ACCEPTABILITY OF WORK.

TABLE I. SURFACE-SMOOTHNESS TOLERANCES

Pavement Category	Direction of Testing	Intermediate Course Tolerance, Inches	Wearing Course Tolerance, Inches
Runways and taxiways	Longitudinal	1/4	1/8
	Transverse	1/4	1/4
Calibration hardstands and compass swinging bases	Longitudinal	1/4	3/16
	Transverse	1/4	3/16
All other paved areas	Longitudinal	1/4	1/4
	Transverse	1/4	1/4

6. GRADE CONTROL: Lines and grades shall be established and maintained by means of line and grade stakes placed at site of work in accordance with the SPECIAL PROVISIONS. Elevations of bench marks used by the Contractor for controlling pavement operations at the site of work will be determined, established, and maintained by the Government. Finished pavement elevations shall be established and controlled at the site of work by the Contractor in accordance with bench mark elevations furnished by the Contracting Officer.

7. SAMPLING AND TESTING:

7.1 New Aggregates:

7.1.1 Genéral: Samples of aggregates shall be furnished by the Contractor for approval of aggregate sources and stockpiles prior to the start of production and at times during production of the bituminous mixtures. Times and points of sampling will be designated by the Contracting Officer. Samples will be the basis of approval of specific sources or stockpiles of aggregates for aggregate requirements. Unless otherwise directed, ASTM D 75 shall be used in sampling coarse aggregate and fine aggregate, and ASTM C 183 shall be used in sampling mineral filler. All tests necessary to determine compliance with requirements specified herein will be made by the Government.

(F)

7.1.2 Sources: Sources of aggregates shall be selected well in advance of the time the materials are required in the work. If a previously developed source is selected, samples shall be submitted ..... days before starting production, with evidence that central-plant hot-mix bituminous pavements constructed with the aggregates have had a satisfactory service record of at least five years under similar climatic and traffic conditions. An inspection of aggregate producer's operation will be made by the Contracting Officer. When new sources are developed, the Contractor shall indicate sources and submit samples and his plan for operation ..... days before starting production. The Contracting Officer will make such tests and other investigations as necessary to determine whether aggregates meeting requirements specified for new aggregates can be produced from proposed sources. If a sample of material from a new source fails to meet specification requirements, the material represented by the sample shall be replaced, and the cost of testing the replaced sample will be at the expense of the Contractor. Approval of source of aggregate does not relieve the Contractor of responsibility for delivery at jobsite of aggregates that meet the requirements specified herein.

7.2 Bituminous Materials: Samples of bituminous materials shall be obtained by the Contractor; sampling shall be in accordance with ASTM D 140. Tests necessary to determine conformance with requirements specified herein will be performed by the Contracting Officer without cost to the Contractor. Sources where bituminous materials are obtained shall be selected in advance of time when materials will be required in the work, and samples of the asphalt cement selected by the Contractor shall be submitted for approval not less than ..... days before such material is required for use in the work.

7.3 Reclaimed Asphalt Pavement: Sampling and testing of the reclaimed asphalt pavement will be performed by the Contracting Officer to insure the job mix formula (JMF) can be met.

7.4 Recycled Asphalt Mixture: Sampling and testing of the recycled asphalt mixture will be accomplished by the Contracting Officer.

8. DELIVERY, STORAGE, AND HANDLING OF MATERIALS:

8.1 Mineral Aggregates: Mineral aggregates and reclaimed asphalt pavement shall be delivered to the site of the bituminous mixing plant and stockpiled in such manner as to preclude fracturing of aggregate particles, segregation, contamination, or intermingling of different materials in the stockpiles or cold-feed hoppers. Mineral filler shall be delivered, stored, and introduced into the mixing plant in a manner to preclude exposure to moisture or other detrimental conditions.

8.2 Bituminous Materials: Bituminous materials shall be maintained at appropriate temperature during storage but shall not be heated by application of direct flame to walls of storage tanks or transfer lines. Storage tanks, transfer lines, and weigh bucket shall be thoroughly cleaned before a different type or grade of bitumen is introduced into the system. The asphalt cement should be heated sufficiently to allow satisfactory pumping of the material; however, the storage temperature shall be maintained below 300 degrees F.

9. ACCEPTABILITY OF WORK:

(G)

9.1 General: A lot shall be that unit of construction that will be evaluated for compliance with specification requirements. A lot shall be equal to [..... tons] [..... hours' production]. Initial testing for acceptability of work will be performed by the Government. Additional tests required to determine acceptability of nonconforming material will be performed by the Government at the expense of the Contractor.

9.1.1 In order to evaluate aggregate gradation, asphalt content, and density, each lot shall be divided into four equal sublots. For density determination one random sample shall be taken from the mat, and one random sample shall be taken from the joint of each sublot. A coring machine will be used for taking mat and joint samples from the completed pavement. Any approved method of locating random samples, such as a table of random numbers or random number generator, can be used to determine sample locations. Core samples at joints will be taken with the coring machine centered over the joint. After air drying to a constant weight, random samples obtained from the mat will be used for density determination using MIL-STD-620, Method 101. Samples for determination of asphalt content and aggregate gradation shall be taken from loaded trucks within each sublot. Asphalt content will be determined in accordance with ASTM D 2172, Method A or B. Gradation of the aggregate shall be determined from the recovered aggregate according to ASTM C 136 and C 117.

9.1.2 The lowest percent payment determined for any pavement characteristic (i.e., gradation, asphalt content, density, grade, and smoothness) discussed below shall be the percent payment for that lot.

9.1.3 The Contracting Officer reserves the right to sample and test any area which appears to deviate from the specification requirements. Testing in these areas will be in addition to the lot testing, and the requirements for these areas will be the same as those for a lot.

9.2 Aggregate Gradation: The mean absolute deviation of the four sublot aggregate gradations from the JMF for each sieve size will be evaluated and compared with Table II. The percent payment based on aggregate gradation shall be the lowest value determined for any sieve size in Table II. All tests for aggregate gradation will be completed and reported within 24 hours after completion of construction of each lot. The computation of mean absolute deviation is illustrated below:

Example: Assume the following JMF and sublot test results for aggregate gradation

Percent by Weight Passing Sieve

Sieve Size	JMF	Test No. 1	Test No. 2	Test No. 3	Test No. 4
3/4 inch	100	100	100	100	100
1/2 inch	88	87	88	90	88
3/8 inch	75	72	77	78	74
No. 4	64	60	65	67	62
No. 8	53	50	56	57	52
No. 16	42	39	44	45	41
No. 30	32	30	34	35	32
No. 50	20	17	20	22	21
No. 100	10	8	10	10	11
No. 200	6	4	7	8	6

Mean Absolute Deviation (for No. 200 sieve) $= \frac{|4-6| + |7-6| + |8-6| + |6-6|}{4}$

$$= \frac{2 + 1 + 2 + 0}{4}$$

$$= 1.25$$

The mean absolute deviation for other sieve sizes can be determined in a similar way for this example to be:

Sieve Size	3/4 inch	1/2 inch	3/8 inch	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100
Mean Absolute Deviation	0	0.75	2.25	2.50	2.75	2.25	1.75	1.50	0.75

The least percent payment based on any sieve size listed in Table II would be 98 percent for the No. 200 sieve. Therefore, in this example the percent payment based on aggregate gradation is 98 percent.

TABLE II. PERCENT PAYMENT BASED ON MEAN ABSOLUTE DEVIATION OF AGGREGATE GRADATIONS FROM JMF

Sieve Size	Percent Payment Based On Mean Absolute Deviations from JMF						
	0.0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	Above 6.0
3/4 inch	100	100	100	100	99	95	90
1/2 inch	100	100	100	100	99	95	90
3/8 inch	100	100	100	100	99	95	90
No. 4	100	100	100	100	99	95	90
No. 8	100	100	100	98	95	90	reject
No. 16	100	100	100	98	95	90	reject
No. 30	100	100	100	98	95	90	reject
No. 50	100	100	100	98	95	90	reject
No. 100	100	98	95	90	90	reject	reject
No. 200	100	98	90	reject	reject	reject	reject

9.3 Asphalt Content: The mean absolute deviation of the four sublot asphalt contents from the JMF will be evaluated and compared with Table III. The percent payment based on asphalt content shall be the value determined in Table III. All asphalt content tests will be completed and reported within 24 hours after completion of construction of each lot.

TABLE III. PERCENT PAYMENT BASED ON ASPHALT CONTENT

Mean Absolute Deviation of Extracted Asphalt Content from JMF	Percent Payment
less than 0.25	100
0.26-0.35	98
0.36-0.40	95
0.40-0.50	90
Above 0.50	reject

9.4 Density: The average mat density and the average joint density shall be expressed as a percentage of the laboratory density. The laboratory density for each lot shall be determined in accordance with MIL-STD-620, Method 100 from four sets of laboratory-compacted samples. One sample will be taken from each of the four sublots and will be divided into three specimens to yield one set of laboratory samples. Laboratory samples shall be prepared from recycled asphalt mixture which has not been reheated in the laboratory. Samples shall be compacted in accordance with MIL-STD-620 within 2 hours of time mixture was loaded into trucks at asphalt plant.

9.4.1 The field density will be determined from core samples and compared with Table IV. The percent payment based on density shall be the lowest value determined from Table IV. The percent payment based on mat density will be for all of the material placed in the lot. The percent payment based on joint density will be for the amount of material represented by an area equal to the lot joint length by 10 feet wide not to exceed the lot size.

TABLE IV. PERCENT PAYMENT BASED ON DENSITY

Average Mat Density (4 Cores)	Percent Payment	Average Joint Density (4 Cores)
98.0-100.0	100.0	96.5-100
97.9	100.0	96.4
97.8,100.1	99.9	96.3
97.7	99.8	96.2
97.6,100.2	99.6	96.1
97.5	99.4	96.0
97.4,100.3	99.1	95.9
97.3	98.7	95.8
97.2,100.4	98.3	95.7
97.1	97.8	95.6
97.0,100.5	97.3	95.5
96.9	96.3	95.4
96.8,100.6	94.1	95.3
96.7	92.2	95.2
96.6,100.7	90.3	95.1
96.5	87.9	95.0
96.4,100.8	85.7	94.9
96.3	83.3	94.8
96.2,100.9	80.6	94.7
96.1	78.0	94.6
96.0,101.0	75.0	94.5
Below 96.0, Above 101.0	reject	Below 94.5

9.4.2 All density results on a lot will be completed and reported within 24 hours after construction of that lot. When the Contracting Officer considers it necessary to take additional samples for density measurements, sampling will be done in groups of four (one for each sublot). The percent payment shall be determined for each additional group of four samples and averaged with the percent payment for the original group to determine the final percent payment. Contractor shall fill all sample holes with hot mix and compact.

9.5 Grade: The finished surface of the pavement will be tested for conformance with plan-grade requirements. The finished grade of each pavement area will be determined by running lines of levels at intervals of

25 feet or less longitudinally and transversely to determine elevation of completed pavement. Within 5 working days after completion of placement of a particular lot, the Contracting Officer will inform the Contractor in writing of results of grade-conformance tests. When more than 5 percent of all measurements made within a lot are outside the specified tolerances, the payment for that lot will not exceed 95 percent of the bid price. In areas where the grade exceeds the plan-grade tolerances given in paragraph GRADE AND SURFACE-SMOOTHNESS REQUIREMENTS by more than 50 percent, the Contracting Officer shall have the option to require removal of the deficient area and replacement with fresh paving mixture at no additional cost to the Government. Sufficient material shall be removed to allow at least one inch of fresh paving mixture to be placed. Skin patching for correcting low areas or planing for correcting high areas will not be permitted.

9.6 Surface Smoothness: After completion of final rolling of a lot, the compacted surface will be tested by the Contracting Officer with a 12-foot straightedge. Measurements will be made perpendicular to and across all joints at distances along the joint not to exceed 25 feet. Location and deviation from straightedge for all measurements will be recorded. When more than 5 percent of all measurements along the joints within a lot exceed the specified tolerance, the unit price for that lot shall not exceed 95 percent of the bid price. Any joint or mat area surface deviation which exceeds the tolerance given in Table I by more than 50 percent shall be corrected to meet the specification requirements. Contractor shall remove the deficient area and replace with fresh paving mixture at no additional cost to the Government. Sufficient material shall be removed to allow at least one inch of fresh paving mixture to be placed.

10. ACCESS TO PLANT AND EQUIPMENT: The Contracting Officer shall have access at all times to all parts of the bituminous plant for checking adequacy of equipment in use; inspecting operation of plant; verifying weights, proportions, and character of materials; and checking temperatures maintained in preparation of mixtures.

11. WAYBILLS AND DELIVERY TICKETS shall be submitted to the Contracting Officer during progress of the work. Before the final statement is allowed, the Contractor shall file with the Contracting Officer certified waybills and certified delivery tickets for all aggregates, reclaimed asphalt pavement, and bituminous materials actually used in construction covered by the contract.

(H)

12. MEASUREMENT:

12.1 Intermediate- and Wearing-Course Tonnage: The amount paid for will be the number of 2000-pound tons of recycled asphalt mixture used in the accepted work. Recycled asphalt mixture shall be weighed after mixing, and no deduction will be made for weight of bituminous materials incorporated herein.

12.2 Correction Factor for Aggregates Used: Quantities of paving mixtures called for are based on aggregates having a specific gravity of 2.70 as determined in accordance with the Apparent Specific Gravity paragraphs in ASTM C 127 and ASTM C 128. Correction in tonnage of intermediate- and wearing-course mixtures shall be made to compensate for difference in tonnage of mixtures used in project, when specific gravities of aggregate used in mixtures are more than 2.75 and less than 2.65. Tonnage paid for will be number of tons used, proportionately corrected for specific gravities, using 2.70 as the base correctional factor.

12.3 Bituminous Materials: Bituminous materials to be paid for will be the number of [gallons of bituminous materials used in the accepted work, corrected to gallons at 60 degrees F., in accordance with ASTM D 1250] [2000-pound tons of materials used in the accepted work].

(H)

13. PAYMENT: Quantities of intermediate- and wearing-course mixtures and bituminous materials, determined as specified above, will be paid for at respective contract unit prices or at reduced prices adjusted in accordance with paragraph ACCEPTABILITY OF WORK. Payment shall constitute full compensation for preparing and/or reconditioning base course of existing pavement; for furnishing all materials, equipment, plant, and tools; and for all labor and other incidentals necessary to complete work required by this section.

PART 2 - PRODUCTS

14. RECYCLED ASPHALT CONCRETE shall consist of reclaimed asphalt pavement, coarse aggregate, fine aggregate, mineral filler, asphalt cement, recycling agent, and approved additives, if required, of the qualities and in the proportions required, and shall conform to the requirements contained in paragraphs PROPORTIONING OF MIXTURE and ACCEPTABILITY OF WORK.

(I)

14.1 New Aggregates: Aggregates shall consist of aggregate contained in the reclaimed asphalt pavement and also include crushed stone, crushed gravel, crushed slag, screening, sand, and mineral filler, as required. The portion of materials retained on the No. 4 sieve shall be known as coarse aggregate, the portion passing the No. 4 sieve and retained on the No. 200 sieve as fine aggregate, and the portion passing the No. 200 sieve as mineral filler. Aggregate gradation will conform to gradation(s) specified in Table V. Table V is based on aggregates of uniform specific gravity; the percentage passing various sieves may be changed by the Contracting Officer when aggregates of varying specific gravities are used.

TABLE V. AGGREGATE GRADATION

Sieve Size	Wearing Course, Percent Passing	Intermediate Course, Percent Passing

14.1.1 Coarse aggregate shall consist of clean, sound, durable particles meeting the following requirements.

14.1.1.1 Percentage of loss shall not exceed 40 after 500 revolutions, as determined in accordance with ASTM C 131.

(J)

14.1.1.2 Percentage of loss shall not exceed ..... after five cycles performed in accordance with ASTM C 88, using magnesium sulfate.

14.1.1.3 The dry weight of crushed slag shall not be less than 75 pcf, as determined in accordance with ASTM C 29.

14.1.1.4 Crushed gravel retained on the No. 4 sieve and each coarser sieve listed in Table V shall contain at least 75 percent by weight of crushed pieces having two or more fractured faces with the area of each face equal to at least 75 percent of the smallest midsectional area of piece. When two fractures are contiguous, angle between planes of fractures shall be at least 30 degrees to count as two fractured faces.

14.1.1.5 Particle shape of crushed aggregates shall be essentially cubical. Quantity of flat and elongated particles in any sieve size shall not exceed 20 percent by weight, when determined in accordance with CRD-C 119.

(J)

14.1.2 Fine aggregate shall consist of clean, sound, durable, angular particles produced by crushing stone, slag, or gravel that meet requirements for wear and soundness specified for coarse aggregate. Fine aggregate produced by crushing gravel shall have at least 90 percent by weight of crushed particles having two or more fractured faces in the portion retained on the No. 30 sieve. This requirement shall apply to material before blending with natural sand when blending is necessary. Quantity of natural sand to be added to the wearing- and intermediate-course mixtures shall not exceed 15 percent by weight of new aggregate added to the recycled mixture. Natural sand shall be clean and free from clay and organic matter. Percentage of loss shall not exceed ..... after five cycles of the soundness test performed in accordance with ASTM C 88, using magnesium sulfate.

(K)

14.1.3 Mineral filler shall conform to ASTM D 242.

(L)

14.2 Reclaimed Asphalt Pavement: The amount of reclaimed asphalt pavement used in the recycled mixture shall not exceed ..... percent.

(M)

14.3 Bituminous Materials: New asphalt cement shall conform to ....., Grade ......

(N)

14.4 Asphalt Cement from Recycled Mixture: Asphalt cement recovered from the recycled asphalt mixture in accordance with ASTM D 1856 shall have a penetration of ..... as measured in accordance with ASTM D 5.

14.5 Additives: The use of additives such as antistripping and antifoaming agents is subject to approval.

14.6 Recycling Agents: Recycling agents used in preparation of recycled mixtures shall have a proven record of satisfactory performance. The recycling agent shall be submitted for approval prior to use.

(O)

15. PROPORTIONING OF MIXTURE:

15.1 General: The JMF for the bituminous mixture will be furnished the Contractor by the Contracting Officer. The Contractor shall furnish samples of new materials for mix design at no additional cost to the Government. Sufficient quantities of each aggregate and mineral filler (if needed) shall be submitted to provide a minimum of 200 pounds of blended new aggregate in the same approximate proportions as will be used in the project. Blending of the aggregates will be accomplished by the Government. A minimum of 5 gallons each of the asphalt cement and/or recycling agent to be used in the project shall be submitted. No payment will be made for mixtures produced prior to the approval of the JMF. The formula will indicate the percentage of each aggregate and mineral filler, the percentage of reclaimed asphalt pavement, the percentage of bitumen, and the temperature of the completed mixture when discharged from the mixer. Tolerances are given in Table VI for asphalt content, temperature, and aggregate grading for tests conducted on the mix as discharged from the mixing plant; however, the final evaluation of aggregate gradation and asphalt content will be based on paragraph ACCEPTABILITY OF WORK. Recycled asphalt mix that deviates more than 25 degrees F. from the JMF shall be rejected. The JMF may be adjusted during construction to improve paving mixtures, as directed, without adjustments in the contract unit prices.

TABLE VI. JOB-MIX TOLERANCES

Material	Tolerance, Plus or Minus
Aggregate passing No. 4 sieve or larger	4 percent
Aggregate passing Nos. 8, 16, 30, and 50 sieves	3 percent
Aggregate passing Nos. 100 and 200 sieves	1 percent
Bitumen	0.25 percent
Temperature of mixing	25 degrees F.

15.2 Test Properties of Recycled Asphalt Mixtures: Finished mixture shall meet requirements described below when tested in accordance with MIL-STD-620, Method 100. All samples will be compacted with 75 blows of specified hammer on each side of sample. When recycled mixtures fail to meet the requirements specified below, the paving operation shall be stopped until the cause for noncompliance is determined and corrected.

15.2.1 Requirements for stability, flow, and voids are shown in Tables VII and VIII for nonabsorptive and absorptive aggregates, respectively.

TABLE VII. NONABSORPTIVE-AGGREGATE MIXTURE

	Wearing Course	Intermediate Course
Stability minimum, pounds	1800	1800
Flow maximum, 1/100-inch units	16	16
Voids total mix, percent (1)	3-5	5-7
Voids filled with bitumen, percent (2)	70-80	50-70

(1) The Contracting Officer may permit deviations from limits specified when gyratory method of design is used to develop the JMF.

(2) The Contracting Officer may permit deviation from limits specified for voids filled with bitumen in the intermediate course in order to stay within limits for percent voids total mix.

TABLE VIII. ABSORPTIVE-AGGREGATE MIXTURE

	Wearing Course	Intermediate Course
Stability minimum, pounds	1800	1800
Flow maximum, 1/100-inch units	16	16
Voids total mix, percent (1)	2-4	4-6
Voids filled with bitumen, percent (2)	75-85	55-75

(1) The Contracting Officer may permit deviations from limits specified when gyratory method of design is used to develop the JMF.

(2) The Contracting Officer may permit deviation from limits specified for voids filled with bitumen in the intermediate course in order to stay within limits specified for voids total mix.

15.2.1.1 When the water-absorption value of the entire blend of aggregate does not exceed 2.5 percent as determined in accordance with ASTM C 127 and ASTM C 128, the aggregate is designated as nonabsorptive. The apparent specific gravity or ASTM D 2041 will be used in computing voids total mix and voids filled with bitumen, and the mixture shall meet requirements in Table VII.

15.2.1.2 When the water-absorption value of the entire blend of aggregate exceeds 2.5 percent as determined in accordance with ASTM C 127 and ASTM C 128, the aggregate is designated as absorptive. The bulk-impregnated specific gravity method contained in MIL-STD-620, Method 105, or ASTM D 2041 shall be used in computing percentages of voids total mix and voids filled with bitumen; the mixture shall meet requirements in Table VIII.

(P)

15.2.2 The index of retained stability must be greater than 75 percent as determined by MIL-STD-620, Method 104. When the index of retained stability is less than 75, the aggregate stripping tendencies may be countered by the use of hydrated lime or by treating the bitumen with an approved antistripping agent. The hydrated lime is considered as mineral filler and should be considered in the gradation requirements. The amount of hydrated lime or antistripping agent added to the bitumen shall be sufficient to produce an index of retained stability of not less than 75 percent. No additional payment will be made to the Contractor for addition of antistripping agent required.

PART 3 - EXECUTION

(Q)

16. BASE COURSE CONDITIONING: The surface of the base course will be inspected for adequate compaction and surface tolerances specified in SECTION: ...... Unsatisfactory areas shall be corrected to meet the specification requirements.

(R)

17. EXISTING PAVEMENT CONDITIONING:

18. PREPARATION OF BITUMINOUS MIXTURES: Rates of feed of each stockpile shall be regulated so that moisture content and temperature of aggregates will be within specified tolerances. Aggregates, reclaimed asphalt pavement, mineral filler, bitumen, and recycling agent shall be conveyed into the mixer in proportionate quantities required to meet the JMF. Particles larger than 2 inches shall be removed from the reclaimed asphalt pavement prior to being added to the mixer. Mixing time shall be as required to obtain a uniform coating of the aggregate with the bituminous material. Temperature of bitumen at time of mixing will be specified by the Contracting Officer. Temperature of aggregate and mineral filler in the mixer shall not exceed 325 degrees F. when bitumen is added. Overheated and carbonized mixtures or mixtures that foam shall not be used.

19. WATER CONTENT OF AGGREGATES: Drying operations shall reduce the water content of mixture to less than 0.75 percent. Water content test will be conducted in accordance with ASTM D 2216; weight of sample shall be at least 500 grams. If water content is determined on hot bin samples, the water content shall be a weighted average based on composition of blend.

20. STORAGE OF BITUMINOUS PAVING MIXTURE shall conform to the applicable requirements of ASTM D 3515; however, in no case shall the mixture be stored for more than 4 hours.

21. TRANSPORTATION OF RECYCLED ASPHALT MIXTURE: Transportation from paving plant to site shall be in trucks having tight, clean, smooth beds lightly coated with an approved releasing agent to prevent adhesion of mixture to truck bodies. Excessive releasing agent shall be drained prior to loading. Each load shall be covered with canvas or other approved material of ample size to protect mixture from weather and prevent loss of heat. Loads that have crusts of cold, unworkable material or have become wet will be rejected. Hauling over freshly placed material will not be permitted.

22. SURFACE PREPARATION OF UNDERLYING COURSE: Prior to placing of intermediate or wearing course, the underlying course shall be cleaned of all foreign or objectionable matter with power brooms and hand brooms.

(Q)

23. PRIME COATING: Surface of previously constructed base course shall be sprayed with a coat of bituminous material conforming to SECTION: BITUMINOUS PRIME COAT.

24. TACK COATING: Contact surfaces of previously constructed pavement, curbs, manholes, and other structures shall be sprayed with a thin coat of bituminous material conforming to SECTION: BITUMINOUS TACK COAT.

25. PLACING: Bituminous courses shall be constructed only when the base course or existing pavement has no free water on the surface. Recycled asphalt mixtures shall not be placed without ample time to complete spreading and rolling during daylight hours, unless approved satisfactory artificial lighting is provided.

25.1 Offsetting Joints: The wearing course shall be placed so that longitudinal joints of the wearing course will be offset from joints in the intermediate course by at least 1 foot. Transverse joints in the wearing course shall be offset by at least 2 feet from transverse joints in the intermediate course.

25.2 General Requirements for Use of Mechanical Spreader: Range of temperatures of mixtures, when dumped into the mechanical spreader, shall be as determined by the Contracting Officer. Mixtures having temperatures less than 225 degrees F. when dumped into the mechanical spreader shall not be used. The mechanical spreader shall be adjusted and the speed regulated so that the surface of the course being laid will be smooth and continuous without tears and pulls, and of such depth that, when compacted, the surface will conform to the cross section indicated. Placing with respect to centerline, areas with crowned sections, or high side of areas with one-way slope shall be as directed. Each strip placed shall conform to requirements specified in paragraph ACCEPTABILITY OF WORK. Placing of mixture shall be as nearly continuous as possible, and speed of placing shall be adjusted, as directed, to permit proper rolling. When segregation occurs in the mixture during placing, the spreading operation shall be suspended until the cause is determined and corrected.

25.3 Placing Strips Succeeding Initial Strips: In placing each succeeding strip after initial strip has been spread and compacted as specified below, the screed of the mechanical spreader shall overlap the previously placed strip 2 to 3 inches and be sufficiently high so that compaction produces a smooth dense joint. Mixture placed on edge of previously placed strip by the mechanical spreader shall be pushed back to the edge of the strip being placed by use of a lute. Excess mixture shall be removed and wasted.

25.4 Handspreading in Lieu of Machine Spreading: In areas where use of machine spreading is impractical, the mixture shall be spread by hand. Spreading shall be in a manner to prevent segregation. The mixture shall be spread uniformly with hot rakes in a loose layer of thickness that, when compacted, will conform to required grade, density, and thickness.

26. COMPACTION OF MIXTURE: Rolling shall begin as soon after placing as mixture will bear roller without undue displacement. Delays in rolling freshly spread mixture will not be permitted. After initial rolling, preliminary tests of crown, grade, and smoothness shall be made by the Contractor. Deficiencies shall be corrected so that finished course will conform to requirements for grade and smoothness specified herein. Crown, grade, and smoothness will be checked in each lot of completed pavement by the Contracting Officer for compliance and will be evaluated as specified in paragraph ACCEPTABILITY OF WORK. After the Contractor is assured of meeting crown, grade, and smoothness requirements, rolling shall be continued until a mat density of 98 to 100.0 percent and a joint density of 96.5 to 100.0 percent of density of laboratory-compacted specimens of the same mixture are obtained. The density will be determined and evaluated as specified in paragraph ACCEPTABILITY OF WORK. Places inaccessible to rollers shall be thoroughly compacted with hot hand tampers.

26.1 Testing of Mixture: At the start of plant operation, a quantity of mixture shall be prepared sufficiently to construct a test section at least 50 feet long, two spreader widths wide and of thickness to be used in the project. Mixture shall be placed, spread, and rolled with equipment to be used in the project and in accordance with requirements specified above. This test section shall be tested and evaluated as a lot and shall conform to all specified requirements. If test results are satisfactory, the test section may remain in place as part of the completed pavement. If tests indicate that the pavement does not conform to specification requirements, necessary adjustments to plant operations and rolling procedures shall be made immediately, and test section will be evaluated as specified in paragraph ACCEPTABILITY OF WORK. Additional test sections, as required, shall be constructed and sampled for conformance to specification requirements. In no case shall the Contractor start full production of an intermediate or wearing course mixture without approval.

26.2 Correcting Deficient Areas: Mixtures that become contaminated or are defective shall be removed to the full thickness of course. Edges of the area to be removed shall be cut so that sides are perpendicular and parallel to direction of traffic and so that edges are vertical. Edges shall be sprayed with bituminous materials conforming to SECTION: BITUMINOUS TACK COAT. Fresh paving mixture shall be placed in the excavated areas in sufficient quantity so that finished surface will conform to grade and smoothness requirements. Paving mixture shall be compacted to the density specified herein. Skin patching of an area that has been rolled shall not be permitted.

27. JOINTS:

27.1 General: Joints between old and new pavements, between successive days' work, or joints that have become cold (less than 175 degrees F.) shall be made to insure continuous bond between old pavement or previous paving lane and the new paving lane. All joints shall satisfy grade and smoothness requirements specified for the pavement. Contact surfaces of previously constructed pavements coated by dust, sand, or other objectionable material shall be cleaned by brushing or shall be cut back as directed. The surface against which new material is placed shall be sprayed with a thin, uniform coat of bituminous material conforming to SECTION: BITUMINOUS TACK COAT. Material shall be applied far enough in advance of placement of fresh mixture to insure adequate curing. Care shall be taken to prevent damage or contamination of the sprayed surface.

27.2 Transverse Joints: The roller shall pass over the unprotected end of a strip of freshly placed material only when placing is discontinued or delivery of mixture is interrupted to the extent that material in place may become cold. In all cases, prior to continuing placement, the edge of previously placed pavement shall be cut back to expose an even vertical surface for the full thickness of the course. In continuing placement of strip, the mechanical spreader shall be positioned on the transverse joint so that sufficient hot mixture will be spread to obtain a joint after rolling that conforms to required density and smoothness specified herein.

27.3 Longitudinal Joints: Edges of a previously placed strip shall be prepared such that the pavement in and immediately adjacent to the joint between this strip and the succeeding strip meets the requirements for grade, smoothness, and density as described in paragraph ACCEPTABILITY OF WORK.

GENERAL NOTES

1. This guide specification is to be used in the preparation of contract specifications in accordance with ER 1110-345-720. It will not be made a part of a contract merely by reference; pertinent portions will be copied verbatim into the contract documents.

2. The capital letters in the right-hand margins indicate that there is a technical note pertaining to that portion of the guide specification. It is intended that the letters in the margins be deleted before typing the project specifications.

3. Where numbers, symbols, words, phrases, clauses, or sentences in this specification are enclosed in brackets [ ], a choice or modification must be made; delete inapplicable portion(s) carefully. Where blank spaces occur in sentences, insert the appropriate data. Where entire paragraphs are not applicable, they should be deleted completely.

TECHNICAL NOTES

A. The section number should be inserted in the specification heading and prefixed to each page number in the project specifications.

B. Paragraph 1: The listed designations for publications are those that were in effect when this guide specification was being prepared. These designations are updated when necessary by Notice, and references in project specifications need be no later than in the current Notice for this guide specification. To minimize the possibility of error, the letter suffixes, amendments, and dates indicating specific issues should be retained in paragraph 1, and omitted elsewhere in the project specifications.

C. Paragraph 2.2: The plant shall be of sufficient size to complete the job within the required time; however, in no case should the plant capacity be less than 100 tons per hour.

D. Paragraph 5.1: A tolerance of 0.03 foot will be specified when pavements in aircraft traffic areas of airfield and heliport runways, taxiways and aprons are to be recycled. A tolerance of 0.05 foot will be specified when pavements in nonaircraft traffic areas such as blast pads, roads and stabilized shoulders are to be recycled.

E. Paragraph 5.2: Designer will delete all requirements in Table I which are not applicable to the project.

F. Paragraph 7.1.2: Satisfactory service record for an aggregate will be determined based on the aggregate's ability to resist polishing, raveling, stripping, and degradation under traffic and climatic conditions similar to that expected during its use. If performance data indicate that an aggregate is susceptible to one or more of the above-mentioned problems, that source of aggregate shall be rejected.

G. Paragraph 9.1: The lot size can be specified on the basis of time (i.e., 4 hours, 1 day, etc.) or amount of production (i.e., 500 tons, 1000 tons, etc.). If the lot size is based on amount of production, it should be selected to be approximately equal to the amount of asphalt mix produced in one day's operation. The lot size generally should not exceed 2000 tons of asphalt mix. When a lump-sum contract is used (total job does not exceed 1000 tons), the lot size becomes the total job; thus the penalty is assessed to the contract price.

H. Paragraphs 12 and 13: These paragraphs may be revised to include payment for bituminous material when separate payment is not considered warranted based on local experience and job conditions. These paragraphs will be deleted if the work covered by this section of the specifications is included in one lump-sum price. Lump-sum contracts should not be used when the job exceeds 1000 tons.

I. Paragraph 14.1: Appropriate gradations from Table 4, TM 5-822-8, will be listed in Table V.

J. Paragraphs 14.1.1.2 and 14.1.2: The values of percentage of loss will be based on knowledge of aggregates in the area that have been previously approved or that have a satisfactory service record in bituminous pavement construction for at least 5 years.

K. Paragraph 14.1.3: In areas where there is a possibility that dune sand or one-size material may be used as mineral filler, the following gradation requirements will be inserted in the specifications to eliminate undesirable one-size materials.

Grain Size in mm	Percent Finer
0.05	70-100
0.02	35-65
0.005	10-22

Grain size shall be determined in accordance with ASTM D 422.

ASTM D 422 will be added to paragraph APPLICABLE PUBLICATIONS if this alternate paragraph is used.

L. Paragraph 14.2: In order to meet pollution requirements and insure the recycled mixture is satisfactory the amount of reclaimed asphalt pavement should not exceed 60 percent for drum mixers or 50 percent for batch plants.

M. Paragraph 14.3: The appropriate types and grades of bituminous materials for the anticipated use and climatic environment should be used. Requirements of ASTM D 946 should be used to specify penetration-graded asphalt cement, or ASTM D 3381 for viscosity-graded asphalt cement. The specification selected should be listed in proper numerical sequence in paragraph APPLICABLE PUBLICATIONS.

N. Paragraph 14.4: The penetration of asphalt cement recovered from the recycled mixture should be between 50 and 70 percent of that specified for a particular region for new asphalt cement.

O. Paragraph 15: The procedures for determining the JMF to be used in the mixtures are described in MIL-STD-620 and TM 5-822-10. Proportioning of the aggregates for the JMF should be carefully determined because the gradations will be those on which the Contractors' tolerances will be applied. Application of these tolerances may cause the gradation to be outside the limits of the gradation in the specifications, but this is acceptable. Only those columns in Tables VII and VIII showing test properties that are applicable to the project will be retained.

P. Paragraph 15.2.2: The antistripping agent when added to the mix must be able to produce an index of retained stability of at least 75 percent. The anti-stripping agent must have a proven record of satisfactory performance.

Q. Paragraph 16 and 23: The type of base course on which the bituminous intermediate and/or wearing courses are to be constructed will be inserted in the blanks. If project does not involve construction of recycled bituminous courses on base course, delete paragraphs 16 and 23 and renumber all subsequent paragraphs accordingly.

R. Paragraph 17: Appropriate statements covering the required conditioning of existing pavement will be inserted.

END

GUIDE SPECIFICATION

FOR

CENTRAL PLANT RECYCLING - ASPHALT CONCRETE*

1.0 DESCRIPTION

This work shall consist of removal, crushing, and stockpiling the existing pavement; mixing the processed recycled pavement with new aggregate (as required) and an asphalt modifier (as required) in a suitable central plant; recompacting the disturbed roadway; and placing and compacting the recycled material in conformance with the lines, grades and dimensions shown on the plans and/or specified in the special provisions.

2.0 MATERIALS

2.1 Recycled Aggregate: The recycled aggregate shall consist of a mixture of existing asphalt pavement and the material lying under the pavement. Existing asphalt pavement and stabilized bases shall be processed such that 100% will pass the 1 1/2 inch sieve and 90% will pass the 1 inch sieve.

2.2 New Aggregate:

(1) Base Course. The mineral aggregate for the base course mixture shall be crushed stone, crushed or uncrushed gravel, slag, sand, stone or slag screenings, mineral filler or a combination of two or more of these materials. The combined aggregate after going through the dryer shall have a sand equivalent value of not less than ...

Slag shall be air-cooled blast-furnace slag and shall weigh not less than 70 lb/ft^3 (1.12 Mg/m^3).

Mineral filler shall meet the requirements of ASTM Designation D 242.

(2) Surface Course. The mineral aggregate for the surface course mixture shall be crushed stone, crushed gravel, crushed slag, sharp-edged natural sand, mineral filler, or a combination of two or more of these materials. ... percent by weight of the combined coarse aggregate, other than naturally occurring rough-textured aggregate approved by the engineer, shall consist of crushed pieces having one or more faces produced by fracture.

*from "Guidelines for Recycling Pavement Materials", NCHRP Report 224, by J. Epps, D. Little, R. Holmgreen and R. Terrel.

The combined aggregate after going through the dryer shall have a sand equivalent value of not less than .... Combinations of aggregates that have a history of polishing shall not be used. Coarse aggregate (material retained on the U. S. Standard No. 8 sieve) shall have a percent wear by the Los Angeles abrasion machine test of not more than 40 unless specific aggregates having higher values are known to be satisfactory.

Slag, if used, shall be air-cooled blast-furnace slag and shall weigh not less than 70 lb/ft^3 (1.12 Mg/m^3).

Mineral filler shall meet the requirements of "Mineral Filler for Bituminous Paving Mixtures," ASTM Designation D 242.

2.3 Asphalt Modifier: The asphalt modifier shall be what is commonly called a softening agent, flux oil, rejuvenator or soft asphalt cement conforming to the specification for modifier contained in Appendix A.

2.4 Recycled Mixture: The recycled mixtures shall be an intimate mixture of recycled aggregate, new aggregate (as required) and asphalt modifier (as required) conforming to the mixture requirements contained in Appendix A. The percentage of new aggregate is not fixed by this specification; however, a job-mix formula must be submitted to the engineer prior to initiation of work and for any subsequent changes in the blend of the mixture.

The job-mix formula for asphalt bound recycled base course mixture shall be within the following limits:

Sieve Size*	Total Percent Passing, By Weight	
2 in. (50 mm)	____	
1 1/2 in. (37.5 mm)	____	
1 in. (25.0 mm)	____	
3/4 in. (19.0 mm)	____	
1/2 in. (12.5 mm)	____	
3/8 in. (9.5 mm)	____	
No. 4 (4.75 mm)	____	
No. 8 (2.36 mm)	____	
No. 16 (1.18 mm)	____	
No. 30 (600 μm)	____	
No. 50 (300 μm)	____	
No. 100 (150 μm)	____	
No. 200 (75 μm)	____	
Asphalt Content	____	percent by weight of total mix

Results of single extraction and sieve tests shall not be used as the sole basis for acceptance or rejection of the mixture. Any variation from the job-mix formula in the grading of the aggregate or in the asphalt content greater than the tolerances shown above shall be investigated and the conditions causing the variation corrected.

The ashpalt-bound recycled mixture shall meet the following test criteria:

Stability (Marshall, Hveem): ____

Flow (Marshall Method): ____

Swell (Hveem Method): ____

Air Voids: ____ in. (mm)

Voids in Mineral Aggregate: ____ percent

The job-mix formula for the asphalt-bound recycled surface course mixture shall be within the following limits:

Sieve Size*	Total Percent Passing, by Weight	
3/4 in. (19.0 mm)	____	
1/2 in. (12.5 mm)	____	
3/8 in. (9.5 mm)	____	
No. 4 (4.75 mm)	____	
No. 8 (2.36 mm)	____	
No. 16 (1.18 mm)	____	
No. 30 (600 μm)	____	
No. 50 (300 μm)	____	
No. 100 150 μm)	____	
No. 200 (75 μm)	____	
Asphalt Content	____	Percent by weight of total mix

The asphalt-bound recycled surface course mixture shall meet the following test criteria:

Stability (Marshall, Hveem): ____

Flow (Marshall Method): ____

Swell (Hveem Method): ____ in. (mm)

Air Voids: ____ percent

Voids in Mineral Aggregate: ____ percent

The following tolerances for the job-mix formula will be allowed per single test:

Passing Sieve	Percent
1/2 in. (12.5 mm) and larger	±8
3/8 in. (9.5 mm) and No. 4	±7
No. 8 (2.36 mm) and No. 16 (1.18 mm)	±6
No. 30 (600 m and No. 50 (300 m)	±5
No. 100 (150 m)	±4
No. 200 (75 m)	±3
Asphalt content, weight percent of total mixture	±0.5

2.5 Prime Coat: Cutback asphalt for prime coat shall be MC-30, MC-70 or MC-250 complying with the requirements of AASHTO Specification M 83 or ASTM Specification D 2027.

2.6 Tack Coat: Emulsified asphalt for tack coat shall be SS-1, SS-1h, CSS-1 or CSS-1h diluted one part water to one part emulsified asphalt. Before dilution the emulsified asphalt shall comply with the requirements of AASHTO Specification M 140 or M 208 or ASTM Specification D 977 or D 2397.

3.0 EQUIPMENT

The equipment shall include: (1) one or more asphalt heating and mixing plants designed to produce a uniform mixture within the job-mix tolerances; (2) one or more self-powered pavers that are capable of spreading the mixture to the thickness and width specified, true to the line, grade and crown shown on the plans; (3) enough smooth metal-bedded haul trucks, with covers, when required, to ensure orderly and continuous paving operations; (4) a pressure distributor that is capable of applying tack coat and prime material uniformly without atomization; (5) one or more steel-wheeled, pneumatic-tired, or vibratory rollers capable of attaining the required density and smoothness; (6) a power broom or a power blower or both; (7) hand tools necessary to complete the job. Other equipment may be used in addition to, or in lieu of, the specified equipment when approved by the engineer.

The heating and mixing plants shall be capable of producing uniform mixtures at temperatures suitable for mixing additional modifiers and for compaction on the roadway. Furthermore, the heating and mixing equipment shall be controlled to meet existing air quality requirements. Both batch plants and drum mixer central plants can be utilized provided certain modifications are made.

4.0 CONSTRUCTION

4.1 Removal of Existing Pavement and Stockpiling: The bituminous pavement shall be removed in a manner which will prevent unnecessary intermixing with underlying unstabilized base courses. If unstabilized bases are to be removed they shall be removed and stockpiled separately. Any soft spots encountered during or occurring after removal of existing materials for recycling shall be replaced with suitable materials and compacted.

The storage site and area limits for the bituminous material and base course shall be approved by the engineer prior to stockpiling. The stockpiling area shall be graded and compacted so a firm level base can be maintained at all times. Care shall be taken to avoid contamination of the recycled materials by organic or other deleterious materials.

4.2 Crushing and Stockpiling: The pavement removed for recycling shall be crushed to minus 1 inch. Portable or stationary conventional crushing materials have proven to be satisfactory. Crushing which occurs due to the nature of some pavement removal operations (cold milling operations) are also acceptable.

The crushed bituminous material shall be separated into a minimum of two sizes prior to introduction into the heating and mixing plant. The fine size shall have a minimum of 80% passing the No. 4 sieve. The coarse size shall have a minimum of 60% retained on the No. 4 sieve. Unstabilized base course material shall be stockpiled separately.

The stockpile site shall be approved by the engineer prior to stockpiling. The stockpile area shall be graded and compacted so a firm level base can be maintained at all times and so that the recycled aggregate is not contaminated with the underlying soil. Later placing, stacking conveyors or alternate approved methods shall be used in stockpiling to prevent coning or segregation of component sizes.

4.3 Heating and Mixing: The aggregates which may consist of recycled material and new aggregate shall be heated and mixed in modified plants and drum mixer central plants at temperatures suitable for mixing required asphalt modifiers and suitable for compaction.

If asphalt cement and a softening agent (flux oil, rejuvenator, etc.) are both used as an asphalt modifier a one component system shall be provided by the manufacturer or the materials shall be introduced into the mixing area through separate metering devices for each material.

A mixing time consistent with thorough coating of the aggregate shall be used. The moisture content of the bituminous mixture, sampled behind the laydown machine prior to compaction shall not exceed 1.5 percent by weight.

Temperature, total time of mixing, and asphalt mixing time shall be adequate for specified drying, mixing, coating, and compaction but shall not exceed the limits set by the engineer.

4.4 Spreading, Compaction, and Finishing: Conventional asphalt concrete construction equipment shall be utilized as outlined by standard specifications. Weather and seasonal limitations are to be covered by standard specifications for asphalt concrete construction.

4.5 Prime Coat and Tack Coat: Prime and tack coats shall be used as directed by the engineer.

5.0 GENERAL

5.1 Samples: Samples of all materials proposed for use shall be submitted by the contractor to the engineer. The material shall not be used until it is approved by the engineer.

Sampling of asphalt materials shall be in accordance with the latest revision of AASHTO Designation T 40 or ASTM Designation D 140. Sampling of aggregates should be in accordance with the latest revision of AASHTO Designation T 2 or ASTM Designation D 75. Sampling of the asphalt mixture, as required by the engineer, shall be in accordance with the latest revision of AASHTO Designation T 168 or ASTM Designation D 979.

5.2 Methods of Testing:

(1) Asphalt materials will be tested by the methods of test of the American Association of State Highway and Transportation Officials (AASHTO) or American Society for Testing and Materials (ASTM) method will be used.

(2) Mineral aggregates will be tested by one or more of the following methods of test of the American Association of State Highway and Transportation Officials (AASHTO) or the American Society for Testing and Materials (ASTM).

Characteristic	Method of Test	
	AASHTO	ASTM
Amount of Material Finer than No. 200 Sieve in Aggregate	T 11	C 117
Unit Weight of Aggregate	T 19	C 29
Sieve Analysis, Fine and Coarse Aggregate	T 27	C 136
Sieve Analysis of Mineral Filler	T 37	C 546
Abrasion of Coarse Aggregate, Los Angeles Machine	T 96	C 131
Soundness of Aggregates	T 104	C 88
Plastic Fines in Graded Aggregates and Soils by use of the Sand Equivalent Test	T 176	C2419

(3) The mixture will be tested for asphalt content by "Method of Test for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures," AASHTO Designation T 164 or ASTM Designation D 2172. The mixture will be tested for compliance with aggregate grading requirements by "Method of Test for Mechanical Analysis of Extracted Aggregate," AASHTO Designation T 30.

If the mixture is produced in a mixing plant having automatic controls and a print-out system, and the controls are in proper calibration, binder content compliance will be determined from recorded data. Hot bin analysis together with batch weight read-out data will be used to determine composition compliance.

5.3 Placement Limitations: Asphalt paving mixture shall be placed only when the specified density can be obtained. Precautions shall be taken at all times to compact the mixture before it cools too much to obtain the required density. The mixture shall not be placed on any wet surface or when weather conditions will otherwise prevent its proper handling or finishing. Asphalt surface course mixture shall not be placed when the surface temperature of the base course is below ___°F (_____°C). Asphalt base course mixture shall not be placed when the surface temperature of the underlying course is below ___°F (___°C).

Lime, cement or cold asphalt mixtures shall not be placed when the surface temperature of the underlying course is below ____ °F (____ °C).

5.4 Traffic Control: Traffic shall be directed through the project with such signs, barricades, devices, flagmen, and pilot vehicles as may be necessary to provide maximum safety for the public and the workmen with minimum interruption of the work.

5.5 Safety: Safety precautions shall be used at all times during the progress of the work. As appropriate, workmen shall be furnished with hard hats, safety shoes, asbestos gloves, respirators, and any other safety apparel that will reduce the possibility of accidents. All Occupational Safety and Health Act requirements shall be observed.

6.0 MEASUREMENT

(1) Modifier - Total number of gallons at 60°F or tons of a) asphalt cement and b) softening agent (flux oil, rejuvenator, etc.) at the job site.

(2) Recycled Aggregate - Total number of tons of pavement material removed and crushed in stockpile.

(3) Recycled Asphalt Concrete - Total number of tons of material incorporated into the work.

(4) Recycled Aggregate - Salvage Value - Total number of tons of removed and crushed pavement materials not utilized on job. With this bid the contractor is the owner of the excess recycled aggregate. The salvage value bid by the contractor will be subtracted from the total bid price if the bid price is positive or added if the bid price is negative.

(5) Asphalt Prime and Tack Materials - Total number of gallons at 60°F or tons of each material utilized.

7.0 BASIS OF PAYMENT

The quantities described above shall be paid for at the contract unit price bid for each item. Payment will be in full compensation for furnishing, hauling and placing materials for mixing, for rolling and for all labor and use of equipment, tools, and incidentals necessary to complete the work in accordance with these specifications.

In adjusting volumes of asphalt materials to the temperature of 60°F, ASTM Designation D 1250, ASTM-IP Petroleum Measurement Tables, will be used.

CORPS OF ENGINEERS GUIDE SPECIFICATION
MILITARY CONSTRUCTION

COLD-MIX RECYCLING

PART 1 - GENERAL

1. APPLICABLE PUBLICATIONS: The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.

1.1 Military Standards (Mil. Std.):

MIL-STD-620A & Notice 1	Test Methods for Bituminous Paving Materials
MIL-STD-621A & Notices 1 & 2	Test Method for Pavement Subgrade, Subbase, and Base-Course Materials

1.2 American Society for Testing and Materials (ASTM) Publications*:

D 140-70 (T 40) (R 1981)	Sampling Bituminous Materials
D 977-80 (M 140)	Emulsified Asphalt
D 1556-82 (T 191)	Density of Soil in Place by the Sand-Cone Method
D 2041-78 (T 209)	Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
D 2397-79 (M 208)	Cationic Emulsified Asphalt

2. PLANT, EQUIPMENT, MACHINES, AND TOOLS:

2.1 General: Plant, equipment, machines, and tools shall be approved. Tentative approval of specific items will be made before the start of operations. Final approval will be made only after adequacy of plant, equipment, machines, and tools has been demonstrated in full-scale production.

* Equivalent AASHTO specification or test method in parentheses.

2.2 Mixing Plant: The mixing plant shall be designed, coordinated, and operated to produce mixture within the job-mix formula (JMF). The plant shall be equipped with positive means to control the amount of additional asphalt, water, and time of mixing. Time of mixing shall be the interval between the time the bituminous material and/or water is spread on the aggregate and the time the same aggregate leaves the mixing unit.

2.3 Straightedge: The Contractor shall furnish and maintain at the site, in good condition, one 12-foot straightedge for each mechanical spreader. Straightedge shall be made available for government use. Straightedges shall be constructed of aluminum or other lightweight metal and shall have blades of box or box-girder cross section with flat bottom reinforced to insure rigidity and accuracy. Straightedges shall have handles to facilitate movement on pavement.

3. ACCESS TO PLANT AND EQUIPMENT: The Contracting Officer shall have access at any time to all parts of the paving plant for checking adequacy of equipment in use; inspecting operation of plant; and verifying weights, proportions, and character of material.

4. WEATHER LIMITATIONS: A recycled cold-mix course shall not be constructed in rain or on a layer which contains free water either within the layer or on its surface. Recycled cold-mix courses shall be constructed only when the atmospheric temperature in the shade is 50 degrees F. or above.

5. GRADE AND SURFACE-SMOOTHNESS REQUIREMENTS:

5.1 Grade: The finished and completed surface shall conform within 0.05 foot to lines, grades, cross section, and dimensions shown.

5.2 Surface-Smoothness: The finished surface of the pavement shall not deviate more than 1/4 inch from the testing edge of a 12-foot straightedge in the transverse or longitudinal direction.

6. GRADE CONTROL: Lines and grades, as indicated, will be maintained by means of line and grade stakes placed by the Contractor at site of the work in accordance with the SPECIAL PROVISIONS.

7. SAMPLING AND TESTING:

7.1 General: Type, size, number, and location of samples will be determined by the Contracting Officer. Density tests will be conducted in accordance with ASTM D 1556 when no bituminous material is added to the recycled mixture except that core samples will be taken to determine density when bituminous material is added to the recycled mixture. The Contractor shall furnish all tools, labor, and materials for obtaining samples and refilling sample locations. All tests necessary to determine conformance to specified requirements will be conducted by the Contracting Officer.

7.2 Bituminous Materials: Sampling and testing of bituminous materials shall be the responsibility of the Contractor. Sampling and testing shall be performed by an approved commercial testing laboratory, or by the Contractor subject to approval. Sampling shall be in accordance with ASTM D 140 for bituminous material, unless otherwise directed. Tests shall be performed on each batch of bituminous material to insure that materials meet specified requirements. Copies of test results shall be furnished to the Contracting Officer.

(C)

8. MEASUREMENT: Cold-mix recycling paid for will be the number of [tons] [square yards] used in the accepted work. When bituminous material is used, the unit of measurement shall be the [gallon] [2000-pound ton] as specified in the schedule. [Gallonage] [Tonnage] paid for shall be the number of [gallons] [tons] of bituminous material used in the accepted work. [Gallonage shall be determined either by measuring material at a temperature of 60 degrees F. or by correcting gallonage measured at another temperature to gallons at 60 degrees F., using a coefficient of expansion of 0.00025 per degree F. for emulsified asphalt.]

(C)

9. PAYMENT: The quantities of bituminous materials and paving mixtures, determined as provided above, will be paid for at respective contract unit prices per [ton] [square yard] for bituminous mixture and per [gallon] [ton] for bituminous materials. If deficiencies in the finished product exceed requirements specified, no payment will be made for such areas of pavement until the defective areas are corrected.

PART 2 - PRODUCTS

10. AGGREGATES:

10.1 General: Aggregates shall consist of material obtained from milling, or removing and crushing the existing in situ material, and/or new aggregate material as needed.

10.2 Aggregate Quality and Gradation: Aggregate for bituminous mixture shall be of such size that the material can be spread with a paver to the desired thickness and compacted to meet the specified smoothness, grade, and density requirements. The reclaimed material shall be handled in a manner to prevent segregation and degradation. New aggregates shall be approved and be equal to or better than the reclaimed aggregate in quality. Maximum size of new aggregate shall not exceed one-half of the layer thickness and in no case shall the maximum aggregate size exceed 1 inch.

(D)

11. BITUMINOUS MATERIALS: Bituminous materials, if required, shall be an emulsified asphalt, Grade ..... conforming to [ASTM D 977] [ASTM D 2397].

(E)

12. JOB-MIX FORMULA: The JMF for the recycled mixture will be furnished the Contractor by the Contracting Officer. The Contractor shall furnish samples of materials for mix design at no additional cost to the Government. No payment will be made for cold recycled mixtures produced prior to the approval of the JMF. The formula will indicate a definite percentage of water and asphalt to be added to the mixture. The JMF will be allowed an asphalt content tolerance of 0.3 percent. The asphalt content may be adjusted by the Contracting Officer to improve paving mixture, without adjustment in contract unit price. When asphalt is added, the optimum asphalt content will be selected to provide the following properties when samples are compacted at 250 degrees F. with 75 blows of standard Marshall hammer on each side of the specimen:

Property	Requirement
Stability minimum, pounds	1800
Flow maximum, 1/100-inch units	16
Voids in total mix, percent	3-5
Voids filled with bitumen, percent	70-80

The water content will be selected to provide maximum density when samples are prepared at the optimum asphalt content and compacted with 75 blows of Marshall hammer at ambient temperature. When no asphalt binder is added to the mixture, the water content will be selected by the Contracting Officer to provide maximum density.

PART 3 - EXECUTION

13. PREPARATION OF BITUMINOUS MIXTURES: The required amount of bituminous material for each batch, or calibrated amount of continuous mixing, shall be introduced into the mixer. Aggregates, asphalt emulsion, and water shall be mixed for 35 seconds or longer, as necessary, to thoroughly coat all particles with bituminous material. When longer mixing time is necessary, additional mixing time shall be determined by the Contracting Officer. The mixture shall not extend above the tops of mixer blades when blades are in a vertical position.

14. TRANSPORTATION OF COLD RECYCLED MIXTURES: Transportation of cold recycled mixtures shall be in trucks having tight, clean, smooth bodies. Spreading and rolling of all mixtures shall be completed during daylight, unless satisfactory artificial light is provided. Hauling over freshly placed material will not be permitted.

15. CONDITIONING OF EXISTING SURFACE: Ruts or soft yielding spots that appear in the existing pavement areas and deviations of surface from requirements specified shall be corrected.

16. TACK COATING: Contact surfaces of previously constructed pavement, curbs, manholes, and other structures shall be sprayed with a thin coat of bituminous material conforming to SECTION: BITUMINOUS TACK COAT.

17. PLACING:

17.1 Layer Thickness and Curing: Each layer of compacted mixture shall be no more than 2-1/2 inches in thickness; each layer of bituminous mixture shall be allowed to cure for at least 5 days before placing a succeeding layer.

17.2 Use of Mechanical Spreader: The cold recycled mixture shall be dumped into an approved mechanical spreader, which shall be operated so that the surface of the course being laid will be smooth and continuous without tearing and pulling, and of such depth that, when compacted, the surface will conform to the grade and smoothness requirements. Unless otherwise directed, placing shall begin along the centerline of areas paved on a crowned section or on the high side of areas with a one-way slope, and shall be in the direction of the major traffic flow. Mixture shall be placed in consecutive adjacent strips having a minimum width of 10 feet, except where edge lanes require a strip less than 10 feet to complete the area. Longitudinal joint alinements and elevations shall be controlled using a string line. The Contractor shall establish and place lines parallel to the centerline of the area to be paved for the spreading machine to follow. Placing of mixture shall be as nearly continuous as possible.

17.3 Laying Succeeding Strips: The screed of the mechanical spreader shall overlap the previously placed strip 3 to 4 inches, and shall be sufficiently high to allow for compaction accomplished by rolling, to produce smooth dense joint. Mixture placed on the edge of the strip previously laid by the mechanical spreader shall be pushed back to the edge of the strip being laid by use of a metal lute. When the quantity of mixture on the previously laid strip plus the uncompacted material in the strip being laid exceeds that required to produce a smooth dense joint, the excess mixture shall be removed and discarded.

17.4 Shoveling, Raking, and Tamping after Machine Spreading: A sufficient number of shovelers and rakers shall follow the spreading machine raking and adding mixture as required to obtain a course that, when completed, will conform to all specified requirements. Broadcasting or fanning of mixture over areas being compacted will not be permitted. When segregation occurs in the mixture during placement, the spreading operation shall be suspended until the cause is determined and corrected. Alinement irregularities left by the mechanical spreader shall be corrected by trimming behind the machine. After trimming, edges of the course shall be thoroughly compacted by tamping laterally with a metal lute. Distortion of the course during tamping will not be permitted.

17.5 Hand Spreading in Lieu of Machine Spreading: In areas where use of machine spreading is impractical, mixture shall be spread by hand. Mixture shall be dumped, distributed into place, and spread with rakes in a uniformly loose layer of such thickness that, when compacted, will conform to the required grade and thickness. During hand spreading, each shovelful of mixture shall be carefully placed by turning the shovel over in a manner to prevent segregation. In no case shall mixture be placed by throwing or broadcasting.

18. COMPACTION OF MIXTURE: Compaction of the mixture shall be conducted such that density, grade, and smoothness requirements are satisfied. Bituminous mixtures shall be rolled until all roller marks are eliminated and a density of at least 86 percent of the theoretical maximum density has been obtained when tested in accordance with MIL-STD-620, Method 101 or ASTM D 2041. Laboratory test specimens are to be prepared from uncompacted mix taken from the pavement immediately prior to field compaction. Samples of mix will be heated and compacted at 250 degrees F. with 75 blows on each side of the specimen to determine the compliance of the mixture with paragraph JOB-MIX FORMULA. When bituminous material is not added to the cold recycled mixture, the material shall be compacted to 100 percent of density determined by MIL-STD-621, Method 100, compaction effort designation CE-55.

18.1 Operation of Rollers and Tampers: The speed of the rollers shall be slow enough at all times to avoid displacement of mixture. Displacement of the mixture occurring as the result of reversing the direction of the roller, or from any other cause, shall be corrected by the use of rakes and fresh mixture applied or removed, where necessary. Alternate trips of the roller shall be of slightly different lengths. During rolling, wheels of steel-wheeled and rubber-tired rollers shall be moistened, if necessary, to prevent adhesion of the mixture to the wheels, but excess water will not be permitted. Additional rollers shall be furnished or rolling techniques shall be improved if the specified pavement density is not obtained. Rollers shall be operated by competent and experienced operators. Rollers will not be permitted to stand on finished courses until courses have been cured for 5 days. In all places not accessible to rollers, the mixture shall be thoroughly compacted with hand tampers as specified herein.

18.2 Correcting Deficient Areas: Mixture that becomes contaminated with foreign material or is defective in any way shall be removed. Skin patching of an area that has been rolled will not be permitted. Holes of the full thickness of the course shall be cut so that the sides are perpendicular and parallel to the direction of traffic and the edges are vertical. Fresh paving mixture shall be placed in holes in sufficient quantity so that the finished surface will conform to grade and smoothness requirements. Paving mixture shall be aerated, if necessary, and shall be compacted to the density specified herein. The Contractor shall provide competent workmen capable of performing all work incidental to the correction of deficiencies and defects.

19. JOINTS: Joints shall present the same texture, density, and smoothness as other sections of the course. Joints between old and new pavements or between successive days' work shall be made carefully to insure continuous bond between old and new sections of the course.

19.1 Transverse Joints: The roller shall pass over the unprotected end of freshly laid mixture only when laying of the course has been discontinued. The edge of the previously laid course shall be cut back to expose even, vertical surface for the full thickness of the course. The fresh mixture shall be raked against the joints, thoroughly tamped, and then rolled.

19.2 Longitudinal Joints: When edges of the longitudinal joints are irregular, honeycombed, or poorly compacted, the joint shall be cut back to expose an even, vertical surface for the full thickness of the course.

20. EDGES OF PAVEMENT: Edges of pavement shall be straight and true to required lines. After final rolling, excess material shall be cut off square and disposed of as directed.

21. GRADE AND SURFACE-SMOOTHNESS TESTING:

(F)

21.1 Grade-Conformance Tests: The finished surface of the pavement will be tested for conformance with grade requirements and will be tested for acceptance by the Contracting Officer by running lines of levels at intervals of ..... feet longitudinally and ..... feet transversely to determine the elevation of the completed pavement. The Contractor shall correct variations from the designated grade line and elevation in excess of the grade requirements, as directed. Skin patching for correcting low areas will not be permitted. Contractor shall remove the deficient area and replace with fresh paving mixture at no additional cost to the Government. Sufficient material shall be removed to allow at least 1 inch of recycled mixture to be placed.

(F)

21.2 Surface-Smoothness Tests: After completion of final rolling, the compacted surface will be tested by the Government with a straightedge. Straightedge shall be placed parallel to the centerline of each lane paved, at intervals of ..... feet over the width of the surface. Straightedge shall also be placed perpendicular to the centerline of each lane paved, at intervals of ..... feet over the length of the surface. Location and deviation from straightedge of all measurements will be recorded. Surface irregularities that depart from the testing edge by more than 1/4 inch shall be corrected as directed. Contractor shall remove the deficient area and replace with fresh paving mixture at no additional cost to the Government. Sufficient material shall be removed to allow at least 1 inch of recycled mixture to be placed. Skin patching for correcting low areas will not be permitted.

GENERAL NOTES

1. This guide specification is to be used in preparation of contract specifications in accordance with ER 1110-345-720. It will not be made a part of a contract merely by reference; pertinent portions will be copied verbatim into the contract documents.

2. The capital letters in the right-hand margins indicate that there is a technical note pertaining to that portion of the guide specification. It is intended that the letters in the margins be deleted before typing the project specifications.

3. Where numbers, symbols, words, phrases, clauses, or sentences in the specification are enclosed in brackets [ ], a choice or modification must be made; delete inapplicable portion(s) carefully. Where blank spaces occur in sentences, insert the appropriate data. Where entire paragraphs are not applicable, they should be deleted completely.

TECHNICAL NOTES

A. The section number should be inserted in the specification heading and prefixed to each page number in the project specifications.

B. Paragraph 1: The listed designations for publications are those that were in effect when this guide specification was being prepared. These designations are updated when necessary by Notice, and references in project specifications need be no later than in the current Notice for this guide specification. To minimize the possibility of error, the letter suffixes, amendments, and dates indicating specific issues should be retained in paragraph 1, and omitted elsewhere in the project specifications.

C. Paragraphs 8 and 9: Paragraphs MEASUREMENT and PAYMENT will be deleted if the work covered by this section of the specifications is included in one lump-sum contract price for the entire work covered by the invitation for bids. These paragraphs may be revised to include payment for bituminous material in the payment for cold-mix recycling when separate payment for bituminous material is not considered warranted based on local experience and job conditions. Lump-sum contracts can be used when the total job does not exceed 20,000 square yard-inches or 1000 tons.

D. Paragraph 11: The material being recycled may contain sufficient asphalt binder to meet the specification requirements. In this case only water will be added as a lubricant to improve compaction. Grade SS-1 or CSS-1 should be specified in moderate or cold climates. Grade SS-1h or CSS-1h should be specified in hotter climates such as the southern or southwestern areas of the United States.

E. Paragraph 12: The mix design first establishes the amount of asphalt binder to be added to the mixture and then establishes the amount of water to insure optimum compaction. The asphalt content is determined based on hot compacted samples because this produces the density that will ultimately be obtained in the field. Ideally the water content should be selected based on samples compacted at the mixture temperature which will be encountered during construction.

F. Paragraphs 21.1 and 21.2: For cold-recycled pavements used only as a base course in aircraft traffic areas such as airfield runways and taxiways, intervals will not exceed 25 feet.

END

Example of Local Government Specifications for In-Place Cold Recycling of Asphalt Pavements (Township of Ocean, New Jersey)

SPECIFICATIONS - INDEX

DIVISION 2
MILLING EXCAVATION

SECTION 1 - DESCRIPTION

2.1.1 Milling excavation shall consist of the removal of bituminous concrete surface, oiled shoulder, gravel, dirt or other existing materials, to the depth, profile, and cross slope on the plans or directed by the engineer. The depth of the milling will be in excess of 1 in. to a maximum of 4 in., averaging 2 in.

There is an alternate item consisting of milling to a depth in excess of 4 in. to a maximum of 7 in. average 5 in.

2.1.2 MATERIALS: No materials are to be supplied by the contractor. The milled material will be the property of the contractor.

2.1.3 METHOD OF CONSTRUCTION: The milling machine shall be a self-propelled planing, grinding or cutting machine with variable operating speeds, capable of removing bituminous concrete without the use of heat to the depth, profile and cross slope shown on the plans or directed by the engineer.

The milling machine shall be equipped with automatic grade controls. The reference system may be either stringline or ski type. Use of the automatic grade controls will be required except at intersections and other locations where its use is not practical.

PRIOR TO AWARD OF THE CONTRACT, THE MILLING EQUIPMENT WILL BE INSPECTED BY PERSONNEL FROM THE TOWNSHIP TO INSURE THE BIDDER IS ABLE TO COMPLY WITH THESE SPECIFICATIONS.

The milling operation, including removal of the milled material, shall be carried out in a manner that will prevent dust and other particulate matter from escaping into the air.

Teeth in the milling drum that become dislodged, broken or unevenly worn, shall be replaced immediately with teeth that are of the same length as the remaining teeth in that row.

The milling equipment, where practical, shall be operated in such a manner as to produce milled material of which 95% will pass a 2 1/2-in. sieve.

Areas to be milled not accessible to the milling machine shall be removed by other equipment.

Milling operations may be halted when those areas excavated exceeds the capabilities to provide for the safe passage of local traffic at the end of the work day.

The contractor will be responsible for doing all the trim work along the curb and around all road hardware. He will also be responsible for supplying the water.

2.1.3 The depth of the completed milling when measured from the original surface to the top of the high spots of the textured surface shall be equal to the depth of cut shown on the plans except for profile milling for which the depth of cut shall be only that necessary to remove the bituminous concrete above the bottom of wheel path ruts and transverse corrugations while producing a smooth profile and cross section.

2.1.4 QUANTITY AND PAYMENT The quantity of milling for which payment will be made will be the area actually milled in accordance with the plans or as directed by the Engineer. Deductions will not be made for areas occupied by manholes or similar structures.

Payment for milling will be made for the quantity as above determined, measured in square yards, at the price per square yard bid for the items milling, which price shall include the cost of providing test strips, cleaning of the roadway surface, loading the milled material, including material from trim work, trim work, sweeping, removal and disposal of millings, earth and debris, all labor, equipment and all else necessary therefor and incidental thereto.

DIVISION 3
PULVERIZATION AND STABILIZATION WORK

SECTION 1 - DESCRIPTION

3.1.1 This work consist of techniques used to incorporate asphalt emulsions with recycled pavement and aggregate to a depth of 6 in.

3.1.2 MATERIAL:

(a) Recycled Pavement - the scarified material shall be pulverized so that all material greater than 57 mm (2-1/4 in.) in size shall be removed.

(b) Virgin Aggregate - if deemed necessary by the engineer shall meet the standard specification of local or state agencies. The aggregate should be suitable for the purpose intended, approved by the engineer and free from stumps, brush, grass, weeds, roots, sod, rubbish, garbage, sewage and other matter that might decay. In-situ aggregate may be used if approved by the engineer.

(c) Emulsified Asphalt - emulsified asphalt for the mixture shall meet the requirements of CSS-1H or CSS-1. This emulsion shall be inspected and approved by New Jersey State DOT.

3.1.3 APPROVAL OF JOB-MIX FORMULA: All testing must be performed by a laboratory approved by the engineer. Testing shall be in accordance with ASTM-D-1559 as amended in Appendix A and other applicable ASTM Standards.

A minimum of one sample per 1000 ft shall be obtained by the contractor at the direction of the engineer, (or - the engineer shall submit the samples to the lab). Materials which are similar in gradation and appearance may be mixed together for testing to develop the job-mix formula.

Prior to the start of any work a test report must be submitted by the contractor to the engineer for his approval. As a minimum this report should indicate the following:

(a) Gradation of in-situ aggregate base (to 8 in. below surface).

(b) Optimum moisture content of the aggregate base (ASTM-D-698).

(c) Recommended emulsion content for mix and the emulsion manufacturer.

(d) Air voids, marshall stability and flow when tested in accordance with Appendix A of this specification.

(e) Density of the mixture in lbs. per cu. ft., both wet and dry in accordance with Appendix A.

3.1.3 After the job-mix formula is established, all mixtures furnished for the project shall confrom thereto. When unsatisfactory results or other conditions make it necessary, the engineer may require the establishment of a new job mix.

The Marshall stability and flow values specified below shall be used to establish the job-mix formula, but may be waived by the engineer.

(f) The stability at 104F shall be not less than 500 lbs.

(g) The flow shall be not less than 6 nor more than 18.

The optimum moisture content of the material (with no emulsion added) shall be determined by ASTM-D-698. The total liquid content of the mixture shall be the sum of the water in the aggregate and total percentage of emulsion added. The total liquid content of the mix shall be within 10% of the optimum moisture content (i.e., If optimum moisture is 8%, range is 7.2% to 8.8%).

3.1.4 METHOD OF CONSTRUCTION: Construction equipment - the contractor may use any equipment approved by the engineer which will produce the completed course meeting these specifications:

(a) An asphalt-stabilized recycled base course within 1/2 in. of that specified in the plans and containing the amount of emulsion specified by the job-mix formula within ± 0.5%.

(b) Scarification - existing pavement shall be pulverized so that all usable material is less than 57 mm, 2-1/4 in. in diameter.

REGRADING OF CARTWAY - following pulverization operations, the granular base within the cartway shall be regraded. The grading of the cartway must meet the following criteria:

1. Maximum curb reveal = 8 in.
2. Minimum gutter and cross gutter grade = 0.5%.
3. Final curb reveal at driveway depression after 2 in. surface course 1-1/2 in. maximum.
4. Final centerline elevation 6 in. above adjacent gutter line.

3.1.5 RESPONSIBILITY: It shall be the responsibility of the contractor to ensure that the above criteria are met and adequate personnel must be assigned to the project to provide the grading control. Failure to meet these criteria will be cause for rejection of the work. If any of the above criteria cannot be met due to existing physical conditions, the contractor must notify the engineer who will determine the solution to the grade problem.

Any excess granular base materials shall be removed from the site by the contractor. The contractor is advised that the Township does not have a disposal site for this material. No separate payment will be made for removal of excess materials. Contractor must make allowances for same in order contract units.

3.1.5 GENERAL: - the moisture content of the recycled aggregate at the time of addition or application of the asphalt emulsion shall be uniformly distributed through the recycled aggregate and shall be at a level such that the required total liquid content of the mix may be obtained. The total liquid content shall be within limits of Sec. 1-3 and based on that established in the approved mix design.

Aerating of the mixture may be required to reduce the excess water so the liquid content does not exceed the requirements of 3.13(g). A water truck approved by the engineer shall be available when necessary to add sufficient moisture as required in Sec. 3.13(g).

Contractor must have equipment on hand to determine moisture content and monitor such during mix operations.

The temperature range of the respective bituminous materials at the time of addition or application shall be as specified, between ambient and 150F. Bituminous material shall not be added or applied to the aggregate when the air temperature in the shade is less than 50F or when weather conditions are otherwise unfavorable. The mixture shall not be placed on a prepared area which is excessively wet or at a lower temperature than the air temperature shown above. Mixing operations shall be discontinued when the descending air temperature falls below 50F.

SECTION 2 - MIXING

3.2.1 In-Place Mixing, the required quantity of approved asphalt emulsion shall be incorporated into the recycled asphalt/aggregate material at the cutting head. The metering equipment shall be approved by the engineer and shall be capable of applying all the required amount of asphalt emulsion in one pass.

Where it is impractical to add the liquid asphalt at the travel plant cutting head for in-place mixing the required quantity of asphalt emulsion shall be applied to the recycled aggregate in place by means of an approved distributor in successive application not to exceed two gallons per square yard. Each application shall be immediately cut in or blended with the recycled aggregate with the travel plant or other approved equipment. When the required quantity of asphalt emulsion has been applied in this manner, the mixing shall be continued until a thorough and uniform mixture of aggregate and emulsion is obtained.

The travel speed and/or the number of passes of the travel plant or mixer shall be adjusted as required to obtain the desired mixtures.

With respect to Township-owned storm and sanitary manholes, the contractor shall raise or lower the manhole and cover to the new grade by adding or removing a course of brick and mortar in-place to the top of the manhole structure. Payment will be made for "raising" or "lowering" manhole castings.

3.2.2 STABILIZATION OF SOFT AREAS: - Following grading and stabilization operations, the contractor may be required to proof roll the cartway with a rubber-tired roller approved by the engineer, in his presence. At the time, if any unstable areas appear, the contractor shall pulverize and test the moisture content. If moisture content is still high and any soft unstable areas still remain, the engineer may direct the contractor to excavate and remove the existing base materials to a specified depth and refill the excavation with bituminous stabilized base paving, (Mix #I-2) and compact as directed.

3.2.3 COMPACTION: - The type, size and weights of the rubber tired compaction equipment shall be capable of attaining the density requirements listed below and meet the engineer's approval.

The maximum depth of any compacted layer shall be 152 mm (6 in.). Where the required course is more than 152 mm (6 in.) in total compacted depth, it shall be constructed in approximately equal depth layers.

3.2.3 The contractor shall employ an independent testing laboratory, approved by the engineer to obtain a sample of the freshly mixed material from the grade immediately prior to compaction. This sample will be obtained at random locations indicated by the engineer from each 2000 SQ. YARDS OF MATERIAL. The material must conform to the requirements of Sec.3.1.3 (f) and (g) unless waived by the engineer. The average in-place density shall be at least 98% of the lab density when tested in accordance with Appendix "B".

3.2.4 FINISH GRADING OF STABILIZED BASE: - The finish grading operation shall conform to the required line grades and cross sections specified under Sec. 3.1.4. A period of curing of the recycled base will be required.

3.2.5 QUANTITY AND PAYMENT: - THIS ARTICLE OF THE STANDARD SPECIFICATIONS IS CHANGED TO READ AS FOLLOWS: - Quantities will be "IF AND WHERE DIRECTED" and the Township of Ocean reserves the right to increase or decrease quantities as needed during the period of the contract. There will be no price adjustment if the quantities of any item listed in the proposal will be increased. All prices must remain as quoted and shall not be subject to increase for the duration of the contract.

SUPPLEMENTARY INFORMATION
APPENDIX "A"

Modification of ASTM-D 1559 for mixes made with asphalt emulsions: SS-1, CSS-1, SS-1H; AES-2 or AES-3.

All mixes will be made at the total liquid content as defined in Sec. of the specification.

Mixing will be at ambient temperature (i.e: 77F ± 7F)

Compaction of the specimen will be at ambient temperature (i.e: 77F ± 7F).
No heating of molds or other equipment will be necessary.

Apply 75 blows with compaction hammer...per face.
Remove from mold within 1 hour of compaction.
Weigh and measure with a caliper to the nearest 1/32nd of an inch.
Determine "Wet Density" (lb. per cu.ft.) as follows:

$$\frac{\text{Weight}}{\text{Thickness inches} \times 199.492}$$

Place specimen on its side in a flat pan and allow to sit at 77F for a minimum of 2 hours.

Transfer specimens to a forced air oven maintained at 105F ± 2F for 18 hours ± 4 hours.

Remove from oven and allow to cool for a minimum of 2 hours.
Determine Bulk Sp. Gr. of specimen by ASTM D 3203.
Determine Theoretical Max. Specific Gr. by ASTM D 2041 (or if not possible use - N.J.D.O.T. Solvent Immersion Procedure Sec. 990 (B-2) of Standard Specification.

NOTE: Report method used to determine Theo. Spec. Gravity.

Place 1 specimen in high walled pan (i.e: bread pan) and place in 140F ± 1.8F water bath for 30 to 35 minutes. Determine stability and flow within 30 seconds of removal from bath. If stability is greater than 100 lbs. place remaining specimen in water bath and test as above.

If stability is less than 100 lbs. place remaining specimen in oven maintained at 140F ± 1.8F for 2 hours then determine stability and flow within 30 seconds of removal from oven.

Report stability as "Dry Stability" if tested after oven conditioning - above.

APPENDIX "B"

A minimum sample of 35 lbs. shall be taken from the grade and immediately placed in a sealed container so that no moisture loss will occur prior to testing. A report containing the following information shall be provided for each sample taken:

Date and time sampled
Location of sample
Contractor

"Wet" and "Dry" density, stability and flow of a minimum of 3 specimens made and tested in accordance with Appendix "A".

Moisture content, percent of total, as follows:

Weight approximately 1500 gr. of fresh mix, then place in 300F ± 10F-oven for 1 hour.

$$\% \text{ Moisture} = \frac{\text{Original Weight - Oven Dry Weight}}{\text{Oven Dry Weight}}$$

% A.C. Content when tested in accordance with ASTM D 2172.
(Note: Sample must be oven dryed prior to start of test).
Gradation of extracted aggregate in accordance with AASHTO T 30.

A minimum of 10 nuclear density test shall be run at random throughout the lot area. The average nuclear density shall be at least 98% of the wet density determined above.

SECTION 409 - RECYCLING EXISTING BITUMINOUS SURFACE:

409-1 Description:

The work under this section shall consist of recycling a flexible pavement. It shall be accomplished by heating, scarifying, remixing, releveling, compacting and rejuvenating the existing bituminous surfacing material.

409-3 Construction Requirements:

.01 General:

The work shall generally be accomplished only between the dates hereinafter shown as applicable to the average elevation of the project; however, the beginning date may be moved ahead and the ending date may be extended if, in the opinion of the Engineer, weather conditions, surface temperatures and other factors will not have an adverse effect upon the work. At any time the Engineer may require that the work cease or that the workday be reduced in the event that weather or other conditions will have an adverse effect upon the work.

Average Elevation of Project, Feet	Beginning and Ending Dates
0 - 3499	February 15 - December 15
3500 - 4999	April 1 - October 31
5000 and Over	May 1 - September 30

.02 Equipment:

The equipment used to heat and scarify the bituminous surface shall be fueled by liquified petroleum gas. It shall fully meet the standards of the Bureau of Air Pollution Control, Division of Environmental Health Services, Arizona Department of Health Services. The contractor shall provide protective shields or other devices to eliminate the burning of plant life adjacent to the work.

The contractor shall furnish a sufficient number of pneumatic tired compactors, conforming to the requirements of Subsection 404-3.02(C) to compact the scarified material. The Engineer may order the contractor to furnish a tandem power (steel wheel) compactor to accomplish final smoothing; however, any additional compactor ordered by the Engineer will be paid for in accordance with the provisions of Subsection 104.03.

.03 Heating and Scarifying:

Prior to commencing heater-scarifying operations, the existing pavement shall be cleaned of all extraneous material. Power brooming shall be supplemented, when necessary, by hand brooming until all deleterious material has been removed from the existing surface.

The number of heater units utilized shall be determined by the contractor; however, if all heater units are equipped with scarifiers, only the scarifier on the last heater unit of the series shall be utilized for scarification. Multiple heater units shall be utilized in tandem such that the heat emitted and the rate of travel will achieve the specified requirements.

The existing bituminous surface shall be heated not less than six nor more than 12 inches wider than the width of the material to be scarified. The temperature of the scarified material shall be not less than 200 nor more than 300 degrees F. when measured immediately behind the scarifier.

Unless otherwise specified, the weight of the existing bituminous surface has been estimated to be approximately 144 pounds per cubic foot. On this basis, a minimum of nine pounds per square foot of the existing bituminous surface shall be scarified for a depth between 3/4 inch and one inch of unscarified material. If tests indicate that the material weighs either less than 137 or more than 151 pounds per cubic foot, the pounds per square foot to be scarified will be adjusted accordingly by the Engineer.

If the specified amount is not being scarified after the first full hour of operation, the work shall be stopped and shall be resumed only after adjustments have been made by the contractor which will satisfy the Engineer that the requirements can be met.

The scarified material shall then be processed by mechanical equipment equipped with an operating vibratory or oscillating screed capable of producing results approximating those obtained by an asphaltic concrete laydown machine. The equipment shall effectively distribute and level the material to a width no greater than the original width of the material scarified. The equipment may be a separate unit or it may be attached to or be a part of the scarifying equipment. Any equipment deemed to be producing unsatisfactory results will be rejected by the Engineer.

.04 Finishing:

The bituminous surface shall be compacted immediately after it has been distributed and leveled and while it is still hot.

Within 30 minutes after compaction, the rejuvenating coat, conforming to the requirements of Subsection 1005-3.06 for Type ERA-1, shall be applied; however, no material to which the rejuvenating coat has been applied shall be reheated and rescarified.

If the Engineer determines that excessive raveling has occurred, he may direct the contractor to apply Emulsified Asphalt (Special Type) conforming to the requirements of Subsection 1005-3.04 to the scarified material. The application rate will be specified by the Engineer.

.05 Acceptability of Scarification:

Scarification will be deemed to be acceptable when the moving average of a minimum of three consecutive random tests per hour indicates that the required amount per square foot, based on the weight per cubic foot, of the existing bituminous surface has been scarified.

The amount of material scarified will be determined in accordance with the requirements of Arizona Test Method 409.

The weight of the existing bituminous surface will be determined in accordance with the requirements of Arizona Test Method 415 from scarified material which has been compacted in accordance with the requirements of AASHTO T 245, except that the compaction temperature shall be 240 ± 5 degrees F.

409-4 Method of Measurement:

Measurement of this work will be made by the square yard of bituminous surface scarified.

409-5 Basis of Payment:

Payment for this work will be made at the contract unit price per square yard for recycling existing bituminous surface, which price shall be full compensation for the item complete, as herein described and specified.

No adjustment in the contract unit price will be made if tests indicate a weight per cubic foot of the existing bituminous surfacing differing from that shown hereinbefore and the amount of material to be scarified is adjusted accordingly.

Rejuvenating coat for bituminous surface recycling will be measured and paid for in accordance with the requirements of Section 404.

Emulsified Asphalt (Special Type) will be measured and paid for in accordance with the requirements of Section 404.

GUIDELINE SPECIFICATIONS FOR HOT SURFACE RECYCLING

Scope

The work covered by this section of the specifications consists of furnishing all labor, equipment and materials and performing all operations in connection with heating, scarifying, leveling, compacting, and applying a recycling agent.

Cleaning

Prior to commencing heater scarifying operations, the pavement shall be cleaned of all loose material. Power brooms shall be supplemented when necessary by hand brooming and such other tools as required to bring the surface to a clean, suitable condition, free of all deleterious material. Any required patching work shall be completed prior to beginning the process.

Equipment

1. The equipment used to heat and scarify asphalt surfaces shall fully meet the standards of the state and local Bureau of Air Pollution Control. The combustion chamber shall be insulated and totally enclosed to provide sufficient heat to the pavement in order to achieve specified performance. The machine shall be equipped with multiple rows of spring equalized scarifiers to insure a viscous shearing of the heated asphalt and to provide uninterrupted scarification contiguous to rigid structures. A competent operating crew shall be provided.
2. The device used to level and redistribute the scarified material shall be equipped with directional augers, crown adjustment, and depth controls at both extremities to insure a cross-section that conforms to the pavement profile specified.
3. One twelve (12) ton or greater pneumatic-tired roller and operator shall be furnished to compact the scarified material.
4. The liquid spray equipment shall be capable of applying the rejuvenator in a uniform manner across the full width of the processed material and shall incorporate a meter for continuous verification of quantities. The volume applied shall vary in direct proportion to the operating speed of the heater scarifier within a tolerance of 5% above or below the designated application rate.

Construction Details

A minimum of two heater units will be utilized in tandem so that heat emitted and the rate of travel will achieve specified requirements. The number of additional heater units shall be determined by the contractor; however, only the scarifier rakes on the final heater unit of the series shall scarify.

The existing asphalt surface shall be heated from 6 to 12 inches wider than the width to be processed. The temperature of the scarified material shall be a minimum of 250°F and shall not exceed 350°F when measured immediately behind the scarifier.

The weight of existing asphalt surface has been estimated to be approximately 144 pounds per cubic foot. On this basis, a minimum of 9 pounds per square foot of existing surface shall be scarified to obtain a depth of between ¾ and 1 inch. If the tests indicate that the material weighs either less than 137 or more than 151 pounds per cubic foot, the weight per square foot requirement will be adjusted accordingly by the engineer.

Scarification will be deemed acceptable when the moving average of three consecutive random weight tests per hour indicates that the required depth has been scarified. The weight of the existing asphalt surface will be determined in accordance with the requirement of AASHTO T-166 from scarified material compacted in accordance with requirements of AASHTO T-245, with the exception that the compaction temperature shall be a minimum of 260°F.

The rate of application of the recycling agent shall be determined by the engineer based on preconstruction laboratory analysis and adjustments dictated by field conditions.

Guidelines for Asphalt Recycling Agents

Recycling agents are hydrocarbon products that restore aged asphalt to current standards.

Physical and Chemical Guidelines

Tests	Test Method		Requirements	
	ASTM	AASHTO	Min.	Max.
Tests on Emulsion:				
Viscosity @ 25°C, SFS	D-244	T-59	15	40
Residue, %w[1]	D-244(Mod)	T-59(Mod)	60	65
Miscibiity Test[2]	D-244(Mod)	T-59(Mod)	No Coagulation	
Sieve Test, %w[3]	D-244(Mod)	T-59(Mod)	—	0.1
Particle Charge Test	D-244	T-59	Positive	
Percent Light Transmittance[4]	GB	GB	—	30
Tests on Residue from Distillation:				
Flash Point, COC °C	D-92	T-48	196	—
Viscosity @ 60°C, cSt	D-445	—	100	200
Asphaltenes, %w	D-2006-70	—	—	1.0
Maltene Distribution Ratio $\frac{PC + A_1}{S + A_2}$[5]	D-2006-70	—	0.3	0.6
PC/S Ratio[5]	D-2006-70	—	0.5	—
Saturated Hydrocarbons, S[5]	D-2006-70	—	21	28

[1]ASTM D-244 Modified Evaporation Test for percent of residue is made by heating 50 gram sample to 149°C (300°F) until foaming ceases, then cool immediately and calculate results.
[2]Test procedure identical with ASTM D-244-60 except that .02 Normal Calcium Chloride solution shall be used in place of distilled water
[3]Test procedure identical with ASTM D-244 except that distilled water shall be used in place of two percent sodium oleate solution.
[4]Test procedure is attached.
[5]Chemical composition by ASTM Methods D-2006-70:
PC = Polar Compounds, A_1 = First Acidaffins
A_2 = Second Acidaffins, S = Saturated Hydrocarbons.

Note: For gal/ton conversion use 242 gal/ton.

Prequalification Clause

The engineer shall require the successful bidder to submit a list of five comparable size projects performed using the equipment and techniques specified. Said list shall include the agency, and the name, address and telephone number of the engineers in charge.

In lieu of the above, the contractor may qualify his equipment by a demonstration on this or comparable work to the satisfaction of the engineer. Equipment not approved by the engineer shall be removed from the project and acceptable machines supplied. The cost of this demonstration shall be borne by the supplier.

Protection of Existing Improvements

Since high temperatures are required in the hot surface recycling operation, the contractor shall exercise care against possible injury or damage to existing improvements. Existing improvements damaged by the contractor shall be repaired or replaced to the satisfaction of the engineer at no cost to the agency.

Air Quality Preservation

The machine shall be operated in compliance with standards of the local Air Quality Control District. In the event an emission problem develops, due to unforseen surface contamination, the contaminant may be removed on a force account basis.

Measurement and Payment

Heating, scarifying, leveling and compacting of the pavement shall be paid for at the contract unit price per square yard. Such price shall constitue full compensation for the item as herein decribed and specified.

Recycling agent concentrate will be paid for at the contract unit price per gallon by certified weight. The certified weight shall be determined by weighing on sealed scales regularly inspected by the State Bureau of Weights and Measures. The unit price shall include full compensation for furnishing and applying the recycling agent.

APPENDIX F

GUIDE SPECIFICATIONS FOR RECYCLING PORTLAND CEMENT CONCRETE PAVEMENTS

This appendix reproduces two sets of specifications from the literature. Both sets of specifications are concerned with central plant recycling or portland cement concrete (PCC) pavements. The following additional information is provided by Forster (Ref. 1).

1. A limit should be set on the amount of allowable contamination from asphalt concrete (AC) overlay, patch, joint sealant or subbase material in the recycled material. Some amount of adhering AC is allowable and not detrimental.
2. Specify the maximum size of the recycled material depending on its intended use. Typical top size is 100% of material less than 1 1/2 in. This may have to be reduced to 100% less than 3/4 in. if material being recycled is a "D" cracked pavement.
3. Specifying 15-30% natural sand in the fines will improve workability and finishability.
4. Trial lab mixes should determine mix proportions.
5. Determine cement factor according to desired strength, as with a conventional mix.
6. Water reducing add mixtures may be specified to maintain the water/cement ratio at an acceptable level.
7. Air entrainment will increase workability.

8. If recycled PCC is air entrained, the specified air for the new concrete may have to be set higher than usual because the measured air will include the newly entrained air plus the air content of the recycled PCC.

9. Durability should be lab checked according to ASTMC-666 or equivalent.

10. Organic contamination may cause high air contents. These can be contolled with a de-air entraining agent.

From Reference 2

Submission of a Plan Incorporating Specifications for the Placement of a Recycled Concrete Pavement

The material specifications adopted for the recycled portland cement concrete pavement shall be essentially those contained in "State of Connecticut, Department of Transportation Standard Specifications for Roads, Bridges and Incidental Construction, Form 811" for conventional portland cement concrete pavements with the following modifications:

1. Coarse Aggregate: Delete section M.03.01-1(c) and replace with - the requirements for grading shall be determined from trial mixes using source material that has been run through the crushing equipment that will be used on the project in question. The use of 100% salvaged material or a combination of salvaged and virgin aggregate shall also be determined from trial mixes.

2. Fine Aggregate: Delete section M.03.01-2 paragraph 1, and replace with the following - The fine aggregate shall consist of salvaged material and/or virgin sand consisting of clean, hard, durable, uncoated particles of quartz or other rock, free from lumps of clay, soft or flaky material, loam, organic or other injurious material. In no case shall sand containing lumps of frozen material be used.

Removal of old pavement (based on Iowa's special provisions for removal and crushing of old pavement, January 4, 1977).

All mainline pavement on the project is to be removed and salvaged as described below, unless specifically excluded by the plans.

Where asphaltic concrete resurfacing is present, the asphaltic concrete shall be removed before the portland cement concrete pavement is broken up. The asphaltic concrete that is removed shall be wasted, or stockpiled if some use can be found for it. It is intended that all of the asphaltic concrete be removed. Isolated areas of tenacious asphaltic concrete up to one inch in thickness will be considered acceptable, including small patches of asphaltic concrete.

The portland cement concrete pavement shall be removed in a manner that does not develop a large amount of fines in the salvaged concrete and that excludes subgrade and subbase material to the maximum extent practicable. It is intended that this operation produce a maximum amount of salvaged portland cement concrete that can be crushed and stockpiled, and is suitable for use as aggregate in new portland cement concrete; the operation is to be conducted in such a manner as to salvage, in the stockpile, at least 80 percent of the portland cement concrete to be removed. The method employed to break and remove the old pavement shall be subject to approval by the Engineer.

All reinforcing steel shall be removed from the salvaged pavement, either prior to or during the crushing operation.

<u>Crushing and stockpiling of old pavement</u> The salvaged pavement shall be crushed and stockpiled. The crushing operation shall yield a material that passes a 1-1/2-inch sieve. Use of a hammermill secondary crusher is prohibited. The crushed material shall be separated by screening on a 3/8-inch screen, and the two products (plus 3/8 and minus 3/8 inch) shall be stockpiled separately. Processing equipment shall be set up to eliminate

all fines in the minus 3/8-inch product that pass the No. 8 screen. The Engineer shall control the processing operation so that in running a gradation on the minus 3/8-inch material, the amount of material passing the No. 200 sieve is 5 percent or less. Washing will not be required. Fines removed from the minus 3/8-inch material shall be stockpiled separately.

The two main products of the operation (the 1-1/2-inch to 3/8-inch, and minus 3/8-inch material) shall be stockpiled in a manner approved by the Engineer, and in locations designated by the Engineer.

All reinforcement, tie bars, dowels, and dowel assemblies, removed from the pavement, shall become the property of the contractor, and shall be disposed of off the project.

Mix designs - The pavement mix design shall be determined by the Laboratory based on trial mixes made at the Laboratory using salvaged materials from the anticipated source of supply after passing them through the proposed crusher and processing equipment.

Evaluation Plan

The evaluation plan is essentially that proposed in the FHWA Notice on the initiation of National Experimental and Evaluation (NEEP) Project No. 23, except for a few modifications. The evaluation plan is as follows:

As previously stated, the primary objective of this project is to evaluate a recycled pavement and compare its performance to that of a conventional portland cement concrete pavement. In meeting this objective, we will develop and implement plans for preliminary-testing and mix-design procedures, needed modifications to construction operations and equipment, job-control testing, and determine aggregate savings, cost etc. according to the following:

1. Source of Recycled Aggregate - Information on the old pavement will be ascertained. Characteristics such as age, thickness, type, percentage and arrangement of steel reinforcement, type and size of aggregate, type of distress, compressive strength, etc. will be determined prior to or during crushing. The method of removal of any asphalt overlays will be reported.

2. Concrete Pavement Removal and Crushing, and Aggregate Tests - The method of removal, type of crusher(s), the method employed to remove embedded reinforcing steel, tie bars, and dowels, the results of gradation, absorption, Los Angeles abrasion, soundness, and specific-gravity tests run on the salvaged material, the chloride content of the old pavement, and the percent of aggregate coated with old mortar in the crushed material will be reported.

3. Trial mixes - Trial mixes will be formulated and tested at the Materials Testing Laboratory to determine the optimum proportions of the various salvaged and virgin components. Also the cement content required to yield flexural and compressive strengths equivalent to a conventional concrete pavement will also be evaluated.

4. Field-Testing of recycled mix - The slump, air content, and strength (flexural and compressive) of the production-run concrete will be determined and reported.

5. New Recycled pavement - The design of the new pavement will be described, including slab width, length, and depth, type of reinforcement, load-transfer assemblies, tie bars, and surface texturing, as well as the

type of base employed and subgrade soils encountered. The alignment, cross slope, and topographic setting of the pavement will also be described.

The evaluation will include information on the paving train employed, its productivity, and any problems encountered with placement of the recycled mix. The type of curing compound and the rate of its application will be documented. Weather conditions at the time of placement and during the curing period will be described.

Pavement thickness will be determined from cores removed from the hardened concrete.

6. Cost Comparisons - The cost of the recycled pavement will be compared to that of a similar pavement constructed with conventional aggregates based on unit prices for the particular area of the State in which the recycled pavement is constructed. The salvage value of any steel in the old pavement should be considered in this evaluation.

7. Performance Evaluation - A 5-year, post-construction evaluation will be made to provide performance data on cracking, skid resistance, distress, and the overall condition of the recycled pavement. The performance of the recycled pavement will also be compared to that of similar conventional concrete pavements placed preferably in the same area of the State.

8. Reporting - A construction report will be submitted after placement of the experimental pavement. Periodic inspections will be made and a detailed final report issued after completion of the five-year evaluation period. This report will document all aspects of pavement performance from

construction through the end of the five-year period, and skid resistance, weather, and traffic data. A photographic record of pavement conditions will also be included in the report.

The construction report will be the responsibility of the Materials Testing Laboratory, while the follow-up inspections and preparation of the final report will be the responsibility of the Office of Research.

From Reference 3

IOWA DEPARTMENT OF TRANSPORTATION

Recycling Specification for Portland Cement Concrete

1.0 Description

Recycled concrete pavement shall consist of Portland Cement Concrete (PCC) of the type and class specified in the contract. Aggregate used for the concrete will be recycled Portland Cement Concrete which has been crushed and sized. Additional fine aggregate may be added to the mixture, if needed, to provide desired consistency and workability.

2.0 Types of Pavement

2.1 Plain jointed pavement - refers to Portland Cement Concrete Pavement with joints at a prescribed spacing, but without any reinforcing bars, except tie bars at longitudinal joints.

2.2 Reinforced jointed pavement - refers to a jointed Portland Cement Concrete Pavement constructed with re-inforced steel that has been inserted to control crack width.

2.3 CRCP - refers to Portland Cement Concrete Pavement that has been constructed without joints and is heavily reinforced.

2.4 Prestressed concrete pavement - refers to Portland Cement Concrete Pavement that has been post-tensioned or prestressed, and may or may not contain reinforcement.

3.0 Methods of Placement

The recycled concrete pavement may be placed in the conventional form method or by slip-forming. The construction requirements for each of these methods of placement are as detailed in the specifications for concrete pavement. Irregularly shaped areas of either type of pavement may be formed and finished by hand methods. Reinforced bridge sections should be placed in accordance with the details and limits shown on the plans.

4.0 Materials

All materials used in the pavement shall meet the requirements of AASHTO Standard Specifications, except the aggregate derived from crushing the existing pavement. The existing concrete pavement which is to be crushed and used as aggregate in the new pavement must be thoroughly evaluated by the Contracting Authority to determine if it is suitable for its intended use. Type I Portland Cement shall be used unless otherwise stipulated in the contract documents.

5.0 Removal of Old Pavement

All Portland Cement Concrete Pavement, as identified on the plans, is to be removed and salvaged as described herein, unless specifically excluded by the plans.

5.1 The existing Portland Cement Concrete shall be fractured on location with mechanical breakers having the capacity to fracture the pavement into pieces with the largest dimension not to exceed approximately 18 inches. With CRCP and joint reinforced concrete pavement, more aggressive breakage is desirable in order that crushing productivity is maintained and removal of embedded reinforcing steel is facilitated. The broken material shall be removed and transported to mixing site using conventional procedures and equipment as approved by the Engineer.

5.2 Where asphaltic concrete resurfacing is present, the asphaltic concrete shall be removed before the Portland Cement Concrete is removed. The asphaltic concrete to be removed may be buried in the fill or stockpiled and salvaged for other uses as directed by the Contracting Authority.

5.3 It is intended that all of the asphaltic concrete be removed. However, isolated areas of adhering asphaltic concrete up to one inch in thickness will be considered acceptable.

5.4 During removal of the existing Portland Cement Concrete Pavement, care must be taken to assure minimum contamination of the salvaged concrete with underlying subbase material or the soil.

6.0 Crushing and Stockpiling

The salvaged pavement shall be crushed, and stockpiled at the site designated on the plans.

6.1 The salvaged product is to be crushed to maximum size, approximately one and one-half inch.

6.2 The crushed material shall be separated by screening over a 3/8-inch screen and the two products stockpiled separately in order to minimize segregation.

6.3 Stockpiling shall be done in accordance with the standard stockpiling specifications or as designated by the Engineer. Processing equipment shall include a means by which excessive fines can be controlled, so that the maximum material passing the No. 200 sieve in the total product does not exceed 5 percent.

6.4 Washing the finished product is not considered necessary; however, certain weather and site conditions during removal or crushing may necessitate washing.

6.5 Reinforcing steel, if any, removed from the existing pavement shall become the property of the Contractor and shall be disposed of off the project.

7.0 Mix Proportions

The objective of the mix design is to utilize the crushed concrete in such a way so as to obtain a satisfactory Portland Cement Concrete Pavement.

7.1 Crushed concrete in the processed form may be suitable for use without the addition of virgin aggregates; however, finishing and workability will generally be enhanced by adding natural fine aggregate in amounts of approximately 25 percent.

7.2 Addition of natural coarse aggregate is not considered necessary unless there is a need for it to improve workability or because of quantity shortages.

7.3 Trial mixes shall be made using the crushed concrete as aggregate and test specimens will be made for evaluating the mixture. Crushed concrete for trial mixes will generally have to be laboratory produced. This is to be done prior to preparing the mix design specification. Samples of the pavement to be recycled should be obtained and sufficient quantities crushed to make necessary trial mixes and test specimens for proper evaluation.

7.4 Normal procedure is to proportion the mix so that coarse and fine crushed concrete may be consumed in the same ratio that they are produced; however, it may be necessary to add a sufficient amount of natural fine aggregate to produce acceptable workability.

7.5 The minimum cement factor will be determined by the level of strength desired and will normally be similar to that required for conventional concrete pavement mixtures.

8.0 Specific Gravity

Mix design shall be by absolute volume which requires that the specific gravity of the materials used be determined.

9.0 Water and Consistency

The quantity of mixing water used shall be that which will produce acceptable workability and uniform consistency.

9.1 Except as specifically modified by the Engineer, the slump, measured in accordance with AASHTO T-117, shall not be less than 1/2 inch or more than 3 inches for machine finished fixed-form pavement, 2 inches for machine finished slip-form pavement, or 4 inches for hand finished pavement.

9.2 If it is found impossible to produce concrete having the required consistency without exceeding the maximum allowable water-cement ratio specified, the cement content shall be increased as directed by the Engineer so that the maximum water-cement ratio will not be exceeded.

9.3 The design water-cement ratio shall be determined in the laboratory using the materials which are to be used in the project.

10.0 Entrained Air

Air entrainment shall be accomplished by the addition of an approved air-entraining admixture.

10.1 The intended air content of the finished concrete is 6.5 percent with a maximum variation of ± 1.5 percent.

10.2 If it is determined in the laboratory that the air in the crushed concrete may contain entrained air which would register on the plastic air meter, it may be necessary to use higher than normal air in order to be certain the new mortar has sufficient air.

11.0 Durability

Freeze-thaw durability of recycled concrete should be evaluated in accordance with ASTM C-666, Method B, modified to provide a 90-day moist cure period. Other tests which would provide equivalent durability information may be used. Durability factors from ASTM C-666, Method B, as modified herein, are considered acceptable if they are 80 or above.

12.0 Admixtures

When authorized by the Engineer, the same admixtures used in conventional Portland Cement Concrete shall be used in recycled concrete. An approved water-reducing admixture shall be required.

13.0 Equipment General

The Contractor shall provide sufficient equipment to perform all operations necessary to complete the work. Equipment shall meet the requirements of the Contracting Authority.

14.0 Proportioning and Mixing Equipment

Equipment and operation of equipment for proportioning and mixing concrete materials shall comply with the requirements of the Contracting Authority.

15.0 Finishing

Finishing of concrete pavement shall be in compliance with the Contracting Authority's requirements.

16.0 Curing and Protection of Pavement

After finishing operations have been completed, the pavement shall be cured and protected in accordance with the requirements of the Contracting Authority. The curing and protection operations shall be the same as that required for conventional Portland Cement Concrete Pavement.

17.0 Pavement Joints

Location, spacing, and design of contraction, expansion, and longitudinal joints shall comply with the Contracting Authority's requirements for the installation of such joints.

18.0 Filling Joints

Unless otherwise provided, before any portion of the pavement is opened to the Contractor's forces or to the general traffic, expansion joints, longitudinal, and transverse joints shall be filled with the appropriate joint filler material as approved by the Contracting Authority.

19.0 Measurement and Payment

19.1 Breaking, removal and hauling - when the contract provides for removal of old pavement and hauling to a designated area for crushing, the area of pavement removed will be computed in square yards from measurement of the width from edge to edge, or back of curb, if any, and the lineal distance on the pavement surface along the roadbed. Payment for this item will be at the contract price per square yard. Disposal of reinforcing steel, if any, shall be considered incidental to removal of the old pavement and will not be measured or paid for separately.

19.2 Crushing and stockpiling - the quantity of material going through the crushing plant and into the finished stockpile shall be paid for at the contract price per ton.

19.3 Natural fine aggregate - if natural sand is used as an additive in the concrete, the actual quantity of this material used, measured in tons, shall be paid for at the contract price per ton.

19.4 Placing Recycled Portland Cement Concrete Pavement - the total quantity of Portland Cement Concrete Pavement placed, measured in square yards, shall be paid for at the price per square yard and in accordance with the Contracting Authority's normal practice of making payment for Portland Cement Concrete Pavement in-place.

REFERENCES

1. Forster, S. W., "The Use of Recycled Portland Cement Concrete (PCC) as Aggregate in PCC Pavements", Public Roads, FHWA, Vol. 49, No. 2, pp. 37-42, Washington, D.C., 1985.

2. Christman, R. and K. Lane, Pavement Recycling - Bituminous Concrete and Concrete Mix Designs, Connecticut DOT, Hartford, July 1979.

3. Huisman, C. L. and R. A. Britson, "Recycled Portland Cement Concrete Specifications and Quality Control", Proceedings, National Seminar on PCC Pavement Recycling and Rehabilitation, Report No. FHWA-TS-82-208, December 1981.

APPENDIX G
SOURCES OF TRAINING AIDS

1) American Concrete Pavement Association
   2625 Clearbrook Drive
   Arlington Heights, IL 60005
   (312) 640-1020

   Slide Shows
   "Portland Cement Concrete Recycling - A Concrete Solution"

2) Asphalt Emulsion Manufacturers Association
   1133 Fifteenth St., N.W.
   Washington, D.C. 20005
   (202) 429-9440

   Publications
   "Use of Asphalt Emulsions in Pavement Recycling," by Jon A. Epps, Dallas N. Little, Bob M. Gallaway (1977).

   "Recycling Hot Mixed Asphaltic Concrete Pavement With Emulsified Asphalt," by Warren N. Dudley (1980).

   "Recycling With Asphalt Emulsions," by Dennis Super (1980).

   "The Economics of Recycling," by John Huffman (1981).

   "The Design of Recycled Asphalt Pavement Mix," by William Gartner, Jr. (1981).

   "Cold Recycling in Cherry Hill, New Jersey," by Dan Finocchi (1981).

   "Case History - Cold Recycling," by Bill Miteff (1981).

   "Asphalt Emulsion Hot Mix Recycling 1980 Florida Turnpike Project," by George Mariani, Jr. and Jack Hardin (1981).

   A Panel Discussion: "Asphalt Recycling: The State of the Art." Moderator: John Huffman; Panelists: William Gartner, Jr., Dan Finocchi, Bill Miteff, and George Mariani, Jr. (1981).

   Proceedings, AEMA Seminar: "Pavement Recycling with Asphalt Emulsions," Kansas City, February 1982.

   "Cold Mix Recycling: Performance Study," by L.B. Coyne (1983).

   "Case History: Cold Mix Recycling Project," by Robert Doty (1983).

   "In-Place Recycling with Asphalt Emulsions," by C.V. Owen (1984).

   Proceedings, AEMA Seminar: "Pavement Recycling with Asphalt Emulsions," Minneapolis, November 1984.

"Reconstructing and Widening Low Volume Roadways with In-Place Cold Recycling," by Zekeriya Yargici.

"Rejuvenators for Recycling: A Case History in Dickinson County, Kansas," by Steven Muncy (1985).

<u>Slide Shows</u>
"Pavement Recycling with Emulsions"

3) The Asphalt Institute
Asphalt Institute Building
College Park, MD 20740
(301) 277-4258

<u>Publications</u>
MS-20 "Asphalt Hot-Mix Recycling," (1986).

MS-21 "Asphalt Cold-Mix Recycling," (1983).

RR-84-2 "Flexible Pavement Mixture Design Using Reclaimed Asphalt Concrete," (1984).

<u>Motion Pictures</u>
VA-22 "Recycling Roads with Asphalt Emulsions"

<u>Slide Shows</u>
VA-5 "Marshall Method of Mix Design"

VA-6 "Hveem Method of Mix Design"

VA-19 "Budgeting For Rehabilitation"

<u>Workshops</u>
"Cold Recycling with Emulsions"

"Principles of Construction of Quality Hot-Mix Asphalt Pavements"

"Marshall Mix Design for Ashpalt Concrete"
(with the University of Maryland)

4) Asphalt Recycling and Reclaiming Association
#3 Church Circle, Suite 250
Annapolis, MD 21401
(301) 267-0023

<u>Publications</u>
AP-1 "Guideline Specifications for Hot Surface Recycling," (1986).

AP-2 "Guideline Specifications for Cold Planing" (1986).

AP-3 "Proven Guidelines for Hot-Mix Recycling," (1986).

AP-4 "Guidelines for Cold In-Place Recycling" (1986).

AP-5 "Surface Recycling Makes Aged Asphalt Pavements Like New," (1980).

AP-8 "Production Efficiency Study On Pavement Planing Equipment," U.S. Department of Transportation, (1979).

AP-9 "A Discussion of Selected Asphalt Pavement Recycling Alternatives," Gary Holland, (1980).

AP-10 "Cold Recycling of Asphalt Pavements On-Site and Off-Site," William Canessa, P.E., Golden Bear Div., WITCO Chemical Corporation, (1979).

AP-11 "Design and Materials Testing Requirements For Cold Recycling Operations," Dallas N. Little, Jon A. Epps, and Rick J. Holmgreen, Texas A&M University, (1979).

AP-12 "Rejuvenating Materials," William Canessa, P.E., Golden Bear Division, WITCO Chemical Corporation, (1980).

AP-15 "Recycling Asphalt Pavement." Proceedings of the two-day conference at the University of Michigan, (1980).

Slide Shows

AU-1 "Hot Surface Recycling," (1983).

AU-2 "Cold In-Place Recycling," (1983).

AU-3 "Cold Planing," (1983).

5) Chicago Testing Laboratory
3360 Commercial Avenue
Northbrook, IL 60062
(312) 498-6400

Workshops

"Recycle Mix Design"

6) International Slurry Seal Association
1101 Conneticut Ave., N.W.
Washington, D.C. 20036
(202) 857-1160

Publications

P-3 "Recycling of Asphalt Pavements Using the Heater Remix Slurry Seal Method," by G.F. Whitney.

7) National Asphalt Pavement Association
6811 Kenilworth Avenue, Suite 620
Riverdale, MD 20737
(301) 779-4880

Publications

IS 71 "Hot Recycling in Hot Mix Batch Plants," (11/79).

IS 88 "Handling and Processing of Reclaimed Asphalt Material (RAP)," (7/83).

PS 11 "Recycling Asphalt Pavements - Stretching Taxpayers Dollars While Conserving Materials and Energy," (8/80).

Slide Shows

PSS-5 "Recycling Asphalt Pavements," (1980).

Workshops

"NAPA Hot Mix Asphalt Recycling Workshop"

"Materials and Mix Design Workshop"
(with The Asphalt Institute)

8) Portland Cement Association
5420 Old Orchard Road
Skokie, IL 60077-4321
(312) 966-6200

Publications

IS197S "Recycling Failed Flexible Pavements with Cement," (1976).

Films

PC227 "Recycling Flexible Pavement with Cement," (1981).

Slide Shows

SS306 "Airport Pavement Recycling," (1982).

SS369 "Concrete Pavement Reconstruction on the Interstate System," (1985).

SS267 "Edens Expressway Reconstruction," (1979).

SS212 "Recycling Foiled Flexible Pavements," (1976).

SS290 "Recycling of D-Cracked Concrete," (1980).

Videotapes

"Recycling Reinforced Concrete Pavement"

APPENDIX H
LIST OF RECYCLING EQUIPMENT MANUFACTURERS AND CONTRACTORS*

Name of Company	Asphalt Recycling: Equipment Manufacturer	Asphalt Recycling: Contractor	PCC Recycling: Equipment Manufacturer	PCC Recycling: Contractor
All Purpose Utilities, Inc.				X
Allied Steel & Tractor Products, Inc.			X	
E/S Allison & Associates, Inc.		X		
American Mine Tool	X			
Ashbach Construction Co.		X		
ASTEC Industries, Inc.	X			
Barber-Greene Co.	X		X	
Barco, Inc.		X		
Angelo Benedetti, Inc.		X		
Best-Way Paving Co.		X		
Bituminous Materials Co., Inc.		X		
Blair Paving, Inc.		X		
BOCA Construction, Inc.		X		
BOMAG (USA)	X		X	
Brodersen Manufacturing Corp.			X	
Brown & Brown, Inc.		X		
T.J. Campbell Construction Co.		X		
Caterpillar Tractor Co. (Also markets CMI & RayGo)	X		X	
Charbon Milling Co.		X		
Coady Construction Co.		X		X

* This is only a partial listing. It is not intended to be inclusive of all companies that provide recycling equipment or services.

Name of Company	Type of Business: Asphalt Recycling — Equipment Manufacturer	Asphalt Recycling — Contractor	PCC Recycling — Equipment Manufacturer	PCC Recycling — Contractor
Conmaco			X	
Contech Products Consolidated Technologies Corp.			X	
R.A. Cullinan & Son, Inc.		X		
Cutler Repaving, Inc.	X	X		
CYCLEAN, Inc.	X			
Ding Magnetic Group			X	
Donohue & Associates, Inc.				X
Dustrol, Inc.		X		
DYNAPAC Manufacturing Inc.	X		X	
E.D. Etnyre & Company	X			
J.M. Fahey Construction Co.		X		
Galion Manufacturing Co.	X		X	
George & Lynch, Inc.		X		
Gomaco Corp.	X		X	
Guest Industries, Inc.			X	
HARTL Powercrusher USA Corp.	X			
HED Corp.			X	
Hercules Manufacturing Corp.			X	
Hill Milling, Inc.		X		
W.R. Hodgeman & Sons			X	
Hughes Micon			X	
Hughes Tool Co.	X			
Impulse Hydraulics			X	
Ingersoll-Rand Co.	X		X	

Name of Company	Type of Business			
	Asphalt Recycling		PCC Recycling	
	Equipment Manufacturer	Contractor	Equipment Manufacturer	Contractor
Ingram Excavation, Inc.		X	X	
Iowa Manufacturing Co.	X		X	
Kent Air Tool Co.			X	
Kokosing Construction Co., Inc.		X		
Koss Construction Co.				X
Las Vegas Paving Corp.		X		
Microwave Pavement Heating Co.	X			
Mid America Milling Co.		X		X
Midland Machinery Co., Inc.	X			
Midwest Stabilization, Inc.		X		
Monarch Asphalt Co.		X		X
National Asphalt Heat Treating, Inc.		X		
Neal Equipment Co.			X	
Newton Asphalt Co., Inc., of Virginia		X		
Pallette Stone Corp.		X		
Payne-Whitney Co.	X	X		
Pfaft Construction Co.				X
Racine Construction Tool Co.			X	
Ramirez Rotomilling & Construction, Inc.		X		
Reilly Construction Co.				X
Resonant Technology Co.			X	
Sakai America, Inc.	X			
Schramm, Inc.			X	

Name of Company	Type of Business: Asphalt Recycling: Equipment Manufacturer	Asphalt Recycling: Contractor	PCC Recycling: Equipment Manufacturer	PCC Recycling: Contractor
Sii Mining Tools	X			
Standard Havens, Inc.	X			
Stedman Machine Co., Inc.	X			
Swank Associated Co., Inc.		X		
Teledyne CM Products Inc.			X	
Tilcon Massachusetts, Inc.		X		
Trimount Bituminous Products Co.		X		
Universal Engineering Corp.			X	
Valentine Surfacing Co.		X		
Vernon Paving Co.		X		
Vulcan Asphalt Process Co., Inc.		X		
G.A. & F.C. Wagman, Inc.		X		
Fred Weber, Inc.		X		
Wirtgen Corp.	X	X		
Wolverine Tractor & Equipment			X	
Wood Construction Corp.		X		
Yates Corporation	X			

Names and Addresses

All Purpose Utilities, Inc.
7010 S. 66th St.
La Vista, NE 68157
402-331-2550

Allied Steel & Tractor Products, Inc.
5800 Harper Rd.
Solon, OH 44139
216-248-2600

E/S Allison & Associates, Inc.
13320 NE 70th St.
Redmond, WA 98052
206-883-1311

American Mine Tool
Division of GTE Products Corp.
P.O. Box AG
Chilhowie, VA 24319
703-646-8990

Ashbach Construction Co.
P.O. Box 65738
St. Paul, MN 55165
612-224-7611

ASTEC Industries, Inc.
P.O. Box 72787
4101 Jerome Ave.
Chattanooga, TN 37407
615-867-4210

Barber-Greene Co.
400 North Highland Ave.
Aurora, IL 60507
312-859-2200

Barco, Inc.
(dba Woodland Construction)
55 Turnpike St.
West Bridgewater, MA 02375
617-583-5791

Angelo Benedetti, Inc.
84 First Ave.
Bedford, OH 44146
216-439-3420 or 526-1239

Best-Way Paving Co.
131 N. 35th Ave.
Greeley, CO 80633
303-353-1654

Bituminous Materials Co., Inc.
P.O. Box 1264
El Dorado, KS 67042
316-321-6760

Blair Paving, Inc.
4055 E. La Palma, Ste. A
Anaheim, CA 92807
714-630-9070

BOCA Construction, Inc.
P.O. Box 343
Norwal, OH 44857
419-668-5575

BOMAG (USA)
P.O. Box 959
1210 Kenton St.
Springfield, OH 45501
513-325-8733

Brodersen Manufacturing Corp.
P.O. Box 5517
Cenera, KS 66215
913-888-0606

Brown & Brown, Inc.
P.O. Box 2000
Salina, KS 67402
913-827-4439

T. J. Campbell Construction Co.
P.O. Box 15129
6900 S. Sunnylane Rd.
Oklahoma City, OK 73155
405-672-6768

Caterpillar Tractor Co.
Caterpillar Paving Products
(Also markets CMI & RayGo
equipment)
P.O. Box 1985
Oklahoma City, OK 73101
405-787-6020

Charbon Milling Co.
P.O. Box 249
Madisonville, KY 42431
502-821-2742

Coady Construction Co.
1455 East Fifth Ave.
Columbus, OH 43219
614-253-8723

Conmaco
820 Kansas Ave.
P.O. Box 5097
Kansas City, KS 66119-9990
913-371-3930

Contech Prods. Consolidated
Technologies Corp.
5070 Oakland St.
Denver, CO 80239
303-371-8090

R.A. Cullinan & Son, Inc.
121 W. Park St.
Tremont, IL 61568
309-925-2711

Cutler Repaving, Inc.
P.O. Box 3246
Lawrence, KS 66044
913-843-1524

CYCLEAN, Inc.
2000 S. Church St.
Georgetown, TX 78626
516-863-4117

Ding Magnetic Group
4740 W. Electric Ave.
Milwaukee, WI 53219
414-672-7830

Donohue & Assoc., Inc.
6325 Odana Rd.
Madison, WI 53719
608-271-1004

Dustrol, Inc.
P.O. Box 308
1200 E. Main
Towanda, KS 67144
316-536-2262

DYNAPAC Manufacturing, Inc.
P.O. Box 368
Kelly Pl.
Stanhope, N.J. 07874
201-347-0700

E. D. Etnyre & Co.
200 Jefferson St.
Oregon, IL 61061
815-732-2116

J. M. Fahey Construction Co.
408 High Grove Rd.
Grandview, MO 64030
816-763-3010

Galion Manufacturing Co.
Div. of Dresser Inds.
P.O. Box 647
Galion, OH 44833
419-468-4321

George & Lynch, Inc.
113 West 6th St.
New Castle, DE 19720
302-328-6275

Gomaco Corp.
Hgwys. 59 & 175
Ida Grove, IA 51445
712-364-3348

Guest Industries, Inc.
3601 Winstead Rd.
Torrington, CT 06790
800-243-5390 or 203-482-1118

HARTL Powercrusher USA Corp.
25 Charles Street
Westwood, N.J. 07675
201-664-7535

HED Corp.
P.O. Box 17
Issaquah, WA 98027-0017
206-392-7511

Hercules Machinery Corp.
P.O. Box 5198
Ft. Wayne, IN 46895
800-348-1890 (USA)
800-552-4848 (IN)

Hill Milling, Inc.
P.O. Drawer 1356
Leesburg, FL 32749
904-787-5897

W. R. Hodgeman & Sons
1100 Marcos
Fairman, MN 56031

Hughes Micon
3001 South Hwy. 287
Corsicana, TX 75110
214-872-5671

Hughes Tool Co.
Washington Cty. Industrial Park
State Rte. 1717
Bristol, VA 24201
703-669-8311

Impulse Hydraulics
4747 Old Cliffs Rd
San Diego, CA 92120
714-286-6600

Ingersoll-Rand Co.
Ingersoll Drive
Shippensburg, PA 17257
717-532-9181

Ingram Excavation, Inc.
504 S. Kane St.
Baltimore, MD 21224
301-633-5300

Iowa Manufacturing Co.
916 16th St., N.E.
Cedar Rapids, IA 52402
319-363-3511

Kent Air Tool Co.
711 Lake St.
Kent, OH 44240
216-673-5826

Kokosing Construction Co., Inc.
P.O. Box 226
Waterford Rd.
Fredericktown, OH 43019
614-694-6315

Koss Construction Co.
620 Liberty Bldg.
418 Sixth Ave.
Des Moines, IA 50308
515-244-7146

Las Vegas Paving Corp.
1770 Industrial Rd.
Las Vegas, NV 89102
702-384-9040

Microwave Pavement Heating Co.
(Morris R. Jeppson)
Box 221489
Carmel, CA 93922
408-624-3152

Mid America Milling Co.
P.O. Box 698
Jeffersonville, IN 47131
502-895-6766

Midland Machinery Co., Inc.
101 Cranbrook
Tonawanda, N.Y. 14150
716-692-1200

Midwest Stabilization, Inc.
32500 Concord Dr., Ste. 356
Madison Hgts., MI 48071
313-589-3273

Monarch Asphalt Co.
P.O. Box 709
Skokie, IL 60067
312-673-5750

Nat'l Asphalt Heat Treating, Inc.
13341 Southwest Hgwy.
Orland Park, IL 60462
312-448-9540

Neal Equipment Co.
P.O. Box 889
Barrington, IL 60016
312-528-1211

Newton Asphalt Co., Inc.,
of VA
P.O. Box 9420
5601 Courtney Ave.
Alexandria, VA 22304
703-751-7100

Pallette Stone Corp.
P.O. Box 145
Washington St.
Saratoga Springs, N.Y. 12866
518-584-2421

Payne-Whitney Co.
3401 Caster St.
Santa Ana, CA 92704
714-751-1952

Pfaft Construction Co.
6801 W. 150th St.
Apple Valley, MN 55124
612-338-8785

Racine Construction Tool Co.
2200 South St.
Racine, WI 53404
414-639-6770

Ramirez Rotomilling &
Construction, Inc.
P.O. Box 9127
Casper, WY 82609
307-265-3194

Reilly Construction Co.
P.O. Box 99
Ossian, IA 52161
319-532-9211

Resonant Technology Co.
P.O. Box 20128
Reno, NV 89515
702-331-1550

Sakai America, Inc.
98 Quigley Blvd.
New Castle, DE 19720
302-323-0500

Schramm, Inc.
Pneuma-Tractor Div.
800 E. Virginia Ave.
West Chester, PA 19381
215-696-2500

Sii Mining Tools
7700 St. Clair Ave.
Mento, OH 44060
216-953-9111

Standard Havens, Inc.
8800 East 63rd St.
Kansas City, MO 64133
816-737-0400

Stedman Machine Co., inc.
Franklin St.
Aurora, IN 47001
812-926-0038

Swank Associated Co., Inc.
P.O. Box 96
Parnassus Station
New Kensington, PA 15068
412-441-8000

Teledyne CM Products, Inc.
30675 Solon Rd.
Cleveland, OH 44139
216-248-7168

Tilcon, MA, Inc.
430 Howard St.
Brockton, MA 02403
617-588-3660

Trimount Bituminous Prods. Co.
1935 Parkway
Everett, MA 02149
617-387-3100

Universal Engrg. Corp.
800 First Ave., N.W.
Cedar Rapids, IA 52405
319-365-0441

Valentine Surfacing Co.
4107 N.W. 151st St.
Vancouver, WA 98685
206-574-2313

Vernon Paving Co.
2544 Woodland Dr.
Anaheim, CA 92801
714-527-8600

Vulcan Asphalt Process Co., Inc.
P.O. Box 856
Isleton, CA 95641
916-777-5198

G.A. & F.C. Wagman, Inc.
P.O. Box M-76
3290 Susquehanna Trail North
York, PA 17405
717-764-8521

Fred Weber, Inc.
7929 Alabama Ave.
St. Louis, MO 63111
314-638-1570

Wirtgen Corp.
2300 N. Mayfair Rd.
Milwaukee, WI 53226
414-257-1556

Wolverine Tractor & Equipment
25900 W. Eight Mile Rd.
Detroit, MI 48240
313-356-5200

Wood Construction Corp.
1260 Souter Blvd.
Troy, MI 48083
313-589-1022

Yates Corp.
P.O. Box 11008
Columbia, S.C. 29211
803-796-1700

APPENDIX I

BIBLIOGRAPHY

1. American Association of State Highway and Transportation Officials (AASHTO), Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Washington, D.C., 1982.

2. American Concrete Paving Association, Minutes of Portland Cement Concrete Recycling Committee, August 10, 1978.

3. Anderson, D.I., D.E. Peterson, M. L. Wiley and W. B. Betenson, Evaluation of Selected Softening Agents Used in Flexible Pavement Recycling, Report No. FHWA-TS-79-204, FHWA, Washington, D.C., April 1978.

4. Anderson, D.R., "Maintenance Management Systems," NCHRP Synthesis of Highway Practice 110, Transportation Research Board, Washington, D.C., 1984.

5. Asphalt Institute, The, Principles of Construction of Hot-Mix Asphalt Pavements, Manual Series No. 22 (MS-22), College Park, Maryland, 1983.

6. Asphalt Recycling and Reclaiming Association (ARRA), Guideline Specifications for Cold Planing, Annapolis, Maryland, 1986.

7. Asphalt Recycling and Reclaiming Association (ARRA), Guidlines for Cold In-Place Recycling, Annapolis, Maryland, 1986.

8. Beckett, S., Recycling Asphalt Pavements, Demonstration Project No. 39, Interim Report No. 1, FHWA, Region 15, Washington, D.C., January 1977.

9. Betenson, W.B., Hot Recycling of Asphaltic Concrete Pavement, SR-100, US-50 to Holden, Final Report, Utah Department of Transportation, Salt Lake City, April 1985.

10. Betenson, W.B., "Recycled Asphalt Concrete in Utah," AAPT, Proceedings, Vol. 48, Association of Asphalt Paving Technologists, Minneapolis, 1979.

11. Betenson, Wade. B., Recycled Asphalt Pavement, Utah DOT, 1976.

12. Britson, R. and G. Calvert, "Recycling of Portland Cement Concrete Roads in Iowa," Highway Focus, Vol. 10, No. 1, February 1978, pp 16-21.

13. Brownie, R.B. and M.C. Hironaka, Recycling of Asphalt Concrete Airfield Pavements, Naval Civil Engineering Laboratory, Port Hueneme, California, April 1978.

14. Buck, A.O., Recycled Concrete, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, May 1972.

15. Buck, A.O., "Recycled Concrete as a Source of Aggregate," Journal of the American Concrete Institute, Vol. 74, May 1977, pp 212-219.

16. Buck, A.O., Recycled Concrete Report No. 2: Additional Investigations, Concrete Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1976.

17. Chevron U.S.A., Inc., Cold-Mix Recycling Manual, San Francisco, August 1982.

18. Chevron U.S.A., Inc., Hot-Mix Recycling Manual, San Francisco, March 1982.

19. Civil Engineering, "Cold Recycling of Roads Paying Off in Texas," Vol. 50, No. 11, New York, November 1980.

20. Civil Engineering, "Georgia's Low-Cost Approach to Rehabilitating Concrete Pavements," Vol. 53, No. 8, New York, August 1983, pp 50-54.

21. Concrete Construction, "Dig That Broken Concrete," February 1973, p 45.

22. Concrete Construction, "Old Pavement Recycled into New Subbase," Vol. 20, No. 10, October 1975, pp 41-42.

23. Construction, "Solving the Aggregate Shortage Problem," Vol. 43, No. 15, July 1976, pp 62-64.

24. Dallaire, E.E., "Concrete-Pavement Recycling Could Slash Rehab Costs 30%," Civil Engineering, Vol. 52, No. 11, New York, November 1981, pp 73-74.

25. Dallaire, E.E., "Pavement Recycling Catching On," Civil Engineering, Vol. 50, No. 11, New York, November 1980, pp. 45-49.

26. Davidson, D.D., W.E. Canessa and S.J. Escobar, "Practical Aspects of Reconsitiuting Deteriorated Bituminous Pavements," American Society for Testing and Materials (ASTM), STP 662, Philadelphia 1977.

27. Davidson, D.D., W.E. Canessa and S.J. Escobar, "Recycling of Substandard or Deteriorated Asphalt Pavements, A Guideline for Design Procedures," AAPT Proceedings, Vol. 46, Association of Asphalt Paving Technologists, Minneapolis, 1977.

28. Dresser, J.G., "Rehabilitation of Runway 13-31: A Concrete Recycling Project," Jensen of Jacksonville, Inc., Jacksonville, FL, January 1978.

29. Dunning, R.L., R.L. Mendenhall and K.K. Tischer, "Recycling of Asphalt Concrete - Description of Process and Test Sections," AAPT Proceedings, Vol. 44, Association of Asphalt Paving Technologists, Minneapolis, 1975.

30. Eaton, R.A. and D.A. Garfield, Pavement Recycling Using Heavy Bulldozer Mounted Pulverizer, Cold Regions Research and Engineering Laboratory, Department of the Army, Hanover, New Hampshire, September 1977.

31. Engineering News Record, "Breaker Slices Concrete," January 6, 1983, p 21.

32. Engineering News Record, "Pavement is Half Glass and ConcreteWaste," Vol. 180, No. 17, New York, October 1972, pp 17.

33. Engineering News Record, "Urban Expressway Rebuilt on Recycled Concrete Base," Vol, 203, No. 22, New York, November 1979, pp 24-25.

34. Epps,J.A., Pavement Recycling in Texas, Presented at National Asphalt Pavement Association Meeting, January 1976.

35. Epps. J.A. and C.V. Wootan, Economic Ananlysis of Airport Pavement Rehabilitation Alternatives,U.S.D.O.T., Report DOT/FAA/RD-81/78, Washington, D.C., October, 1981.

36. Epps, J.A., D.N. Little, R. J. Holmgreen, R. L. Terrel and W. B. Ledbetter, "Supplement A, Guidelines for Recycled Pavement Materials," NCHRP Report 224, Transportation Research Board, Washington, D.C., August 1980.

37. Escobar, S.J. and D.D. Davidson, "Role of Recycling Agents in the Restoration of Aged Asphalt Cements," AAPT Proceedings, Vol. 48, Association of Asphalt Paving Technologists, Minneapolis, 1979.

38. Exline, M. K., "U.S. 40: Indiana's First Hot Mix Recycle Project," AEMA, Proceedings, (Pavement Recycling with Asphalt Emulsions), Asphalt Emulsion Manufacturers Association, Washington, D.C., February 1982.

39. FHWA, "Concrete Recycling Project Ready," FHWA Newsletter, Issue No. 8, Washington, D.C., October 1978.

40. FHWA, Measurement of The Effectiveness of the Federal Highway Administration Technology Transfer Program: 1985 Survey of Technology Adoption , Use and Benefits, Washington, D.C., September 1985.

41. FHWA, Hot Recycling-Minnesota-Modified Dryer Drum, Technology Sharing Report, Washington, D.C., 1980.

42. FHWA, Hot and Cold Recycling of Asphalt Pavements, FHWA Notice N 5080.93, Washington, D.C., 1980.

43. FHWA, Pavement Recycling: Summary of Two Conferences, Technology Sharing Report, Washington, D.C., April 1982.

44. FHWA, Proceedings, Workshop in Pavement Rehabilitation, Salt Lake City, Utah, Report No. FHWA-TS-84-224, Federal Highway Administration, Washington, D.C., September 1984.

45. FHWA, Public Roads, Vol. 47, No. 3, Washington, D.C., December 1983, p 106.

46. Gallagher, D.R. and J.A. Epps, Fracturing Portland Cement Concrete Pavement Through an Asphalt Concrete Overlay, Report Prepared for NAPA, Riverdale, Maryland, October 1979.

47. Ghose, R.K. and M. Dinakarran, "Breaking Load for Rigid Pavements," ASCE Transportation Engineering Journal, Vol. 96, No. TE1, New York, February 1970, pp. 87-107.

48. Habercom, G.E.J., "Recycled Materials for Road Building 1964 - May 1980 (Citations from the NTIS Data Base)," National Technical Information Service, Washington, D.C., June 1980.

49. Habercom, G.E.J., "Recycled Materials for Road Building 1970 - May 1980 (Citations from the Engineering Index Data Base)," National Technical Information Service, Washington, D.C., June 1980.

50. Halverson, A.D., Recycling Portland Cement Concrete Pavement, Minnesota DOT, FHWA-DP-47-3, Interim Report, St. Paul, May 1981.

51. Hankins, R.B. and T.M. Borg, Recycling PCC Roadways in Oklahoma, Tri-Regional Pavement Rehabilitation Conference, Oklahoma City, Oklahoma, May 1984.

52. Heavy Construction News, "Tests Completed on New Type of Pavement Breaker," March 21, 1983, p 24.

53. Hellriegel, Edgar J., Bituminous Concrete Pavement Recycling, Interim Report, New Jersey DOT, FHWA/NJ-81/002, Trenton, July 1980.

54. Henderson, G.L., Demonstration Project No. 47: Recycling Portland Cement Concrete Pavements, October 1978.

55. Henely, Richard P., Evaluation of Recycled Asphalt Concrete Pavements, Final Report For Kossuth County, Iowa, February 1980.

56. Highway and Heavy Construction, "Concrete Cutter and Forklift Remove Taxiway Pavement," Vol. 126, No. 8, August 1983, pp 54-55.

57. Highway and Heavy Construction, "Concrete Interstate Widened and Recycled Under Traffic," Septembr 1984, pp 42-43.

58. Highway and Heavy Construction, "Concrete Pavement Recycled," Vol. 119, September 976, pp 30-31.

59. Highway and Heavy Construction, "Concrete Recycling to Grow as Interstates Age," February 1982, pp 59-62.

60. Highway and Heavy Construction, "Concrete Rehabilitation Without Overlays," July 1982, pp 44-45.

61. Highway and Heavy Construction, "New Pavement Breaker Hums on Cable Car Job," Vol. 126, No. 8, August 1983, pp 40-41.

62. Highway and Heavy Construction, "New Pavement Breaker Passes First Test," February 1983, p 42.

63. Highway and Heavy Construction, "Recycled Concrete Used in Cement Treated Base," April 1980, p 70.

64. Highway and Heavy Construction, "Recycled Slab is New Runway Base," Vol. 120, No. 7, July 1977, pp 30-33.

65. Highway and Heavy Construction, "Simple Plant Turns Concrete into Aggregate," February 1983.

66. Hironaka, M.D., R.B. Brownie and G.Y. Wu, Recycling of Portland Cement Concrete Airport Pavements - A State-of-The-Art Study, Civil Engineering Lab (Navy), Port Hueneme, CA, and the Federal Aviation Administration, Washington, D.C., April 1981.

67. Highway Focus, Vol. 10, No. 1, February 1978. (Recycling of existing asphalt and portland cement concrete roadways).

68. Huffman, J., "The Economics of Recycling," Paper presented at AEMA Eighth Annual Meeting, Asphalt Emulsion Manufacturers Association, Washington, D.C., March 1981.

69. Huisman, C.L., Iowa's Experience in Recycling of Pavements, Report for National Crushed Stone Association Regional Seminar, November 1980.

70. Ingberg, R.C., R.M. Morchinek and R.H. Casselius, Minnesota Heat Transfer Method for Recycling Bituminous Pavement, Investigation No. 646, Minnesota DOT, St. Paul, 1978.

71. Jensen, I.F., "P.C. Pavement Recycled," Mid-West Contractor, Vol. 139, No. 3663, October 1976, pp 16-18.

72. Joint Departments of the Army and Air Force USA, Standard Practice for Pavement Recycling, Technical Manual TM 5-822-10/AFM 88-6, Chapter 6, Washington, D.C., February 1984.

73. Kallas, B.F., Ed., Pavement Maintenance and Rehabilitation, American Society for Testing and Materials, (ASTM) Special Technical Publication 881, Philadelphia, December 1983.

74. Lane, K.R., "Connecticut - FHWA Demo Job Evaluates PCC Recycling," Rural and Urban Roads, Vol. 18, No. 11, Des Plaines, Illinois, November 1980, pp 31-32.

75. Lane, K.R., Construction of a Recycled Portland Cement Concrete Pavement, Connecticut DOT, Hartford, September 1980.

76. Lane, K.R., Energy Equivalents for Selected Pavement Materials - Their Production and Placement, Connecticut DOT, Hartford, March 1981.

77. Lane, K.R., Pavement Recycling - Phase I, Energy, Environmental and Material Considerations, Connecticut DOT, Bureau of Highways, Federal Highway Administration Materials Division, Hartford.

78. Lane, K.R., and D.G. Bowers, Portland Cement Concrete Pavement Recycling - Phase II, Connecticut DOT, Office of Research, Federal Highway Materials Division, Hartford.

79. Lawing, R.J., Use of Recycled Materials in Airfield Pavements - Feasibility Study, Soils and Pavement Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, August 1975.

80. Lee, D.Y., W.J. Kennedy, Jr., W.W. Sanders, Jr., and C.D. Huisman, Data Bank for Recycled Bituminous Pavements, Engineering Research Institute, Iowa State University, Ames, Iowa (For Office of Research and Development) USDOT, FHWA, Washington, D.C., August 1982.

81. Lee, T., R.L. Terrel and J.P. Mahoney, "Test for Efficiency of Mixing Recycled Asphalt Paving Mixtures," Transportation Research Record 911, Transportation Research Board, Washington, D.C., 1983.

82. Lewis, D.R., Production Efficiency Study on Pavement Planing Equipment, Demonstration Project No. 23, Interim Report, FHWA, Washington, D.C., March 1979.

83. Lokken, E.C., Recycling Portland Cement Concrete, UWEX-ENR Technical Institute for Recycling Pavements, October 1978.

84. Malhorta, V.M., "Recycled Concrete - A New Aggregate," Canadian Journal of Civil Engineering, Vol. 5, No. 1, March 1978, pp 42-52.

85. Marini, R., "New Ideas on Recycling Asphalt Pavements," 3rd Eurobitume Symposium, Volume I (Summaries and Papers), September 1985.

86. Maupin, G.W., Jr., "Recycling of Water-Susceptible Pavements," Report No. VHWA/VA-80/45, Virginia Highway and Transportation Research Council, Charlottesville, Virginia, May 1980.

87. Mid-West Contractor, "Iowa Takes Leadership Role in Research, Development, Use of PCC Pavement," October 24, 1983, pp 17-19.

88. Musannif, A.A.B., "The Nibbler - A New Concept in Concrete Breaking," Building Research Establishment, Building Research Station, Garston, England, 1974.

89. National Asphalt Pavement Association (NAPA), Recycling Asphalt Pavements, Promotional Series 11, Riverdale, Maryland, 1980.

90. National Asphalt Pavement Association (NAPA), "Hot Recycling of Yesterday," Recycling Report, Vol. 1, No. 2, Riverdale, Maryland, September 1977.

91. National Asphalt Pavement Association (NAPA), "State of The Art: Hot Recycling," Recycling Report, Vol. 1, No. 1, Riverdale, Maryland, May 27, 1977.

92. National Asphalt Pavement Association (NAPA), "State of The Art: Hot Recycling 1978 Update," Recycling Report, Vol. 2, No. 3, Riverdale, Maryland, October 1978.

93. Neal, B.F., and J.H. Woodstrom, Evaluation of Cold Planers for Grinding PCC Pavements, California DOT, Transportation Laboratory, Sacramento, September 1978.

94. Newcomb, D.E. and J.A. Epps, Asphalt Recycling Technology: Literature Review and Research Plan, Engineering and Services Laboratory, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, June 1981.

95. Ortgier, Bernhard H., Recycling Cass County I-80 Asphalt Concrete, Progress Report HR-1101, Iowa DOT, Division of Highways, Ames, October 1977.

96. Page, B.G., Appraisal of Alternative Methods for Restoration of Pavement Surface Texture, California DOT, Transportation Laboratory, Sacramento, January 1980.

97. Peterson, D.E., "Evaluation of Pavement Maintenance Strategies," NCHRP Synthesis of Highway Practice 77, Transportation Research Board, Washington,, D.C., September 1981.

98. Petrarca, R.W., and V.A. Galdiero, "Summary of Testing of Recycled Crushed Concrete," Transportation Research Board, Paper presented at 63rd Annual Meeting, Washington, D.C., January 1984.

99. Portland Cement Association (PCA), "Kansas Salvaged Old Road Base," Soil Cement News, Skokie, Illinois, 1942.

100. Portland Cement Association (PCA), "Recycling Failed Flexible Pavements With Cement," IS197S, Skokie, Illinois, 1976.

101. Proudy, H., G. Gregory and J. Hodge, Recycled Asphalt Concrete, Implementation Package 75-5, FHWA, Washington, D.C., September 1975.

102. Public Works, "Recycling Rubble for Highway Purposes," Vol. 103, No. 10, Ridgewood, New Jersey, October 1972, pp 87-88.

103. Rand, D.W., Houlton-Littleton Hot Recycling Paving Project, Maine DOT, Project No. 50-1 (20), FHWA-DP-39-30, Augusta, March 1980.

104. Ray, G.K., "Quarrying Old Pavements to Build New Ones," Concrete Construction, Vol. 25, No. 10, October 1980, pp 725-729.

105. Ray, G.K., Recycled Concrete, Portland Cement Association, Skokie, Illinois, September 1977.

106. Ray, G.K., and H.J. Halm, "Energy Saving Through Concrete Recycling," Transportation Research Board, Paper presented at 57th Annual Meeting, Washington, D.C., January 1978.

107. Roads and Bridges, "Oklahoma Romps Through a 7-mile 3R Job on I-System," Vol. 21, No. 10, Des Plaines, Illinois, October 1983, pp 22-24.

108. Roads and Bridges, "Recyclers and Crushers Need a Daily Data Diet," Vol. 21, No. 10, Des Plaines, Illinois, October 1983, pp 20-21.

109. Robertson, J.R., "Update on Recycling," Rock Production, June 1984.

110. Rural and Urban Roads, "Can PC Recycling Methods Improve?," Des Plaines, Illinois.

111. Rural and Urban Roads, "Cold-Planing and Overlays Answer Kansas Bridge Needs," Vol. 18, No. 11, Des Plaines, Illinois, November 1980, pp 30-31.

112. Rural and Urban Roads, "Concrete Recycling: An Historical Overview," Des Plaines, Illinois, March 1980, pp 70-71.

113. Rural and Urban Roads, "International Aspects of Pavement Recycling," Vol. 19, No. 7, Des Plaines, Illinois, July 1981, pp 22-25.

114. Rural and Urban Roads, "The Edens 3R Project: Showcase for Recycling," Vol. 18, No. 3, Des Plaines, Illinois, March 1980, pp 34-35.

115. Ruth, B.E., H.E. Schweyer and C.F. Potts, "Cost and Energy Effectiveness of Recycling".

116. Texas Transportation Institute, (TTI), Engineering Economy and Energy Consideration, Cooperative Research Project, Texas State Department of Highways and Public Transportation and Texas Transportation Institute at Texas A&M University, College Station, December 1975.

117. Transportation Research Board (TRB), "National Seminar on Asphalt Pavement Recycling," Transportation Research Record 780, Washington, D.C., 1980.

118. Transportation Research Board (TRB), "National Seminar on PCC Pavement Recycling and Rehabilitation," FHWA, Washington, D.C., September 1981.

119. Van Deusen, Chuck, "Cold Planing of Asphalt Pavements," AAPT, Proceedings, Vol. 48, Association of Asphalt Paving Technologists, Minneapolis, 1979.

120. Van Krevelen, R.C., Recycling of D-Cracked Concrete Pavement, Concrete Paving Association of Minnesota, 1981, pp 189-203.

121. Vollor, T.W., Asphalt Pavement Recycling Primer, U.S. Army Corps of Engineers, Misc. Paper GL-86-4, Waterways Experiment Station, Vicksburg, Mississippi, February 1986.

122. Whitcher, D.J., "Out With the Old - In With the Old," Concrete International, July 1984.

123. Yasunobu, Shinichi, Kazuhiro Rukuda and Kohji Kawamura, "New Concrete Demolishing and Pavement Breaking Method - Featuring Low Noise, Less Vibration," Japan Telecommunications Review, Vol. 21, No.2, April 1979, pp 132-136.

124. Yrjanson, W.A., "Recycling Portland Cement Concrete," American Concrete Paving Association Proceedings, April 1981, pp 431-444.

✩ U.S.GOVERNMENT PRINTING OFFICE:1988-516-018/80379

RTAP/7-88(2M)E