# Report on the 1990


**AASHTO . FHWA · NAPA- SHRP · TAI - TRB**

DENMARK FRANCE GERMANY ITALY SWEDEN UNITED KINGDOM

# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

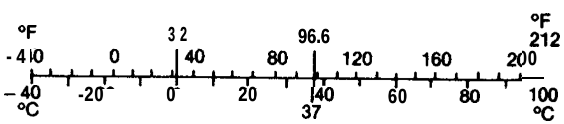
| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| in | inches | 25.4 | millimetres | mm |
| ft | feet | 0.305 | metres | m |
| yd | yards | 0.914 | metres | m |
| mi | miles | 1.61 | kilometres | km |
| | **AREA** | | | |
| $in^2$ | square inches | 645.2 | millimetres squared | $mm^2$ |
| $ft^2$ | square feet | 0.093 | metres squared | $m^2$ |
| $yd^2$ | square yards | 0.636 | metres squared | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | kilometres squared | $km^2$ |
| | **VOLUME** | | | |
| fl oz | fluid ounces | 29.57 | millilitres | mL |
| gal | gallons | 3.765 | litres | L |
| $ft^3$ | cubic feet | 0.026 | metres cubed | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | metres cubed | $m^3$ |

NOTE: Volumes greater than 1000 L shall be shown in $m^3$.

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | **MASS** | | | |
| oz | ounces | 26.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |
| | **TEMPERATURE (exact)** | | | |
| °F | Fahrenheit temperature | 5(F-32)/9 | Cekius temperature | °C |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| mm | millimetres | 0.039 | inches | in |
| m | metres | 3.28 | feet | ft |
| m | metres | 1.09 | yards | yd |
| km | kilometres | 0.621 | miles | mi |
| | **AREA** | | | |
| $mm^2$ | millimetres squared | 0.0016 | square inches | $in^2$ |
| $m^2$ | metres squared | 10.764 | square feet | $ft^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | kilometres squared | 0.386 | square miles | $mi^2$ |
| | **VOLUME** | | | |
| mL | milliliires | 0.034 | fluid ounces | fl oz |
| L | litres | 0.264 | gallons | gal |
| $m^3$ | metres cubed | 35.315 | cubic feet | $ft^3$ |
| $m^3$ | metres cubed | 1.308 | cubic yards | $yd^3$ |
| | **MASS** | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams | 1.102 | short tons (2000 lb) | T |
| | **TEMPERATURE (exact)** | | | |
| °C | Cekius temperature | 1.8C + 32 | Fahrenheit temperature | °F |




• SI is the symbol for the International System of Measurement

(Revised April 1989)

# EUROPEAN ASPHALT STUDY TOUR

**1990**

# SPONSORING ORGANIZATIONS

**American Association of State Highway and Transportation Officials**

**Federal Highway Administration**

**National Asphalt Pavement Association**

**Strategic Highway Research Program**

**The Asphalt Institute**

**Transportation Research Board**

**ACKNOWLEDGEMENT**

**The sponsors and members of the European Asphalt Study Tour team would like to express our appreciation and thanks to all the people in the countries visited who contributed to making the trip the success that it was. We would also like to extend a special debt of gratitude to two individuals from the Federal Highway Administration--Mr. Richard F. Weingroff and Mrs. Deborah L. Stroessner--for their efforts in editing and rewriting sections of the report prepared by members of the tour group, and for the proofreading, graphic design, and page layout work performed.**

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# TABLE OF CONTENTS

A metric conversion table has been provided on the inside front cover for your convenience. A list of commonly used acronyms and technical terms has also been provided to assist you. It can be found on page 115.

# INTRODUCTION

# INTRODUCTION

by
**Thomas D. Larson**
**Federal Highway Administrator**

For the average motorist, one question about highways is of top priority: is the pavement smooth? Dating back to the 1970's the answer to that question has, unfortunately, often been "no."

The reasons for the problem are many. Some involve political decisions, such as how much funding is available for pavement maintenance. But to a large extent, the issues are technical. How can we make our predictions about pavement use more reliable? What is the best design? What surface is most durable for current traffic loadings? How can we best recycle old pavements? Just to cite a few.

In addition to the usual research and knowledge gained from experience, we have launched several major efforts to find the answers. The best known and the most promising is the Strategic Highway Research Program (SHRP). The need for new or improved pavement technologies was one of the driving forces behind the SHRP's development and most of its work is directed toward these technologies. The result of the SHRP's efforts should be recommendations for both the industry and the State highway agencies for improving the durability and longevity of the Nation's pavements.

One element of pavement research has, however, been missing--until now. That element is research into how other countries build and maintain their pavements. This is not an idle question. During my years of teaching at Penn State, I had the opportunity to work with engineers from the United Kingdom and Sweden, and I learned many new and innovative techniques to deal with common highway problems. I also learned that we can gain a great deal through joint efforts with our counterparts in other countries who have advanced the state-of-the-art in roads and bridges.

Since being appointed Federal Highway Administrator, I have gained increased respect for the European highway community's knowledge and understanding of pavements. This renewed respect is a result of my own observations of European highways in the past 2 years, as well as conversations with European experts who have visited the United States to learn how we solve common problems. Although the purpose of their visit in many cases is to gain knowledge about SHRP and the Federal-aid highway program, they often comment on the poor condition of pavements in the United States and contrast them with their own experience in Europe.

The National Asphalt Pavement Association (NAPA) provided the impetus for the 1990 European Asphalt Study Tour (EAST). John Gray, President of the NAPA, asked me to promote a closer relationship between government and industry asphalt experts and to expand the concept to include European experts. He proposed an "on-the-ground" pilot program to review and evaluate foreign pavements and asphalt technology.

I agreed, as did the American Association of State Highway and Transportation Officials (AASHTO), and we decided to arrange a study tour of Europe. The objective was to exchange ideas and experience with highway agencies and the construction industry in Europe on design, production, and placement of asphalt pavements. We were particularly interested in the design of asphalt wearing courses, the use of asphalt modifiers and the benefits they offer to improve the durability of asphalt pavements, as well as recycling--both hot and cold. In addition, we were interested in contracting practices that would be innovative in the United States and cooperative public/private activities, not only in design and financing, but in research into new materials,'methods, and machines. Most important, we wanted not only to discuss these and other subjects, but to see European technology at work.

Working together, the AASHTO, the NAPA, and the Federal Highway Administration (FHWA) selected a 21-member study group that included six AASHTO and eight industry representatives, as well as the Chairman of the Transportation Research Board, the President of The Asphalt Institute, and two SHRP officials. I asked Deputy Federal Highway Administrator Gene McCormick to represent the FHWA.

Through cooperation with six government and industry representatives in Europe, we arranged a 14-day study tour of six countries: Denmark, France, Germany, Italy, Sweden, and the United Kingdom. It began on September 7, 1990, with a flight from Dulles Airport to Goteborg, Sweden, and ended on September 22 with weary study tour participants arriving at Dulles after a flight from London. Whatever else the tour may have been, it was an exhausting experience for all concerned.

If the participants began with any chauvinistic ideas about the superiority of United States technology, they quickly realized we have a lot to learn from Europe about asphalt pavements and about pavement philosophy in general. European pavements are better than ours and it's no accident. The Europeans invest more in research, development, and deployment of new pavement technology. They build their pavement foundations better. They use innovative--for us--surfaces, such as Stone Mastic Asphalt (SMA), and mix in additives to a greater extent and with better results than we do. Government and industry have a closer relationship--probably closer than would ever be possible in the United States--that encourages innovation and quality. And, the Europeans maintain their pavements to get the maximum life out of them.

Upon return to the United States, the participants developed the plan for this report. It describes the mission of the tour, and provides an overview, as well as a description of the activities observed in each country; summarizes the findings not only for asphalt technology but for innovative contracting practices and innovative construction equipment; and provides a plan for applying these findings in the United States.

The implementation plan may be the most important part of the report, because we do not see the 1990 EAST as the culmination of our efforts. It's just the start. The FHWA will work with the NAPA, the AASHTO, the SHRP, and other industry and State officials to begin incorporating what we have learned into everyday practice.

The success of the study tour is the result of a lot of hard working people. Dick Morgan of the NAPA, Frank Francois of the AASHTO, and Doug Bernard of the FHWA deserve special thanks for making the arrangements. At times, the tour--trying to get 21 people across Europe in 14 days--was something like doing a jigsaw puzzle, but amazingly, they fit all the pieces together and the picture proved to be perfect.

In the end, though, the success of the study tour depended on the willingness of European highway and industry officials to share their ideas and their technology. Tour participants found their European counterparts not only willing but eager to do so. This was especially appreciated because the tight schedule imposed restrictions on the European hosts, too. Nevertheless, the schedules were adhered to in every case, and with good cheer. In every country, team members made many new friends.

For too long, we have seen international technology transfer as a one-way street, with the United States showing other countries how to build better highways. Today, we can no longer afford such an attitude. Our transportation network is our greatest economic asset. If we do not give it our best--and Europe's best--we will undermine our own success. Internationally, our ability to compete in the world markets is dependent on our ability to demonstrate our expertise. We are, today, a world leader in highway technology, but that reputation will slip, along with our competitiveness, if we do not expand our technology sharing, in both directions, with the international community.

Some of the European technologies seen, such as SMA and some mix design testing equipment, will be displayed at AASHTO's 'Technology Transfer Fair," in conjunction with that organization's annual meeting in Milwaukee, Wisconsin. The "Fair" is scheduled for October 12 and 13, 1991, and booths will be staffed by specialists, who can discuss the technologies displayed and answer questions.

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# OVERVIEW

# THE 1990 EUROPEAN ASPHALT STUDY TOUR

## ANOVERVIEW

In mid-September 1990, a team of pavement specialists from the United States participated in a 2-week tour of six European nations. The team included representatives from the AASHTO, the FHWA, the NAPA, the SHRP, TAI, and the TRB. The full European Asphalt Study Tour (EAST) team visited, in order, Sweden, Denmark, Germany, France, and the United Kingdom, while a subcommittee drawn from the AASHTO and the FHWA participants visited Italy.

The six nations have much in common with the United States. All are industrialized, have extensive highway and road systems, and rely increasingly on motor vehicles for moving people and freight. While the six nations have mature railroad networks that move large numbers of passengers and considerable freight, the number of motor vehicles and the use of trucks to move goods have grown constantly. All the nations visited have modern, capable highway agencies and a mature construction industry. Some also have extensive highway research facilities.

The emerging European Economic Community of the 1990's will cause tariff and trade barriers to decline among the nations, leading to a confederation that--to some extent--will resemble the United States, but without our strong national government. The coming together of the nations is affecting highways, as it is many other aspects of life in Europe. For example, a highway system is emerging that is comparable in many ways to the Interstate System in the United States. The European motorway network totals some 40,000 km (about 25,000 miles), including approximately 13,500 km (8,400 miles) of toll roads. It will be capable of moving goods by truck from Norway in the north to Italy in the South, and from Eastern Europe to the Atlantic ports.

Despite these similarities, the six nations differ from the United States and from each other in many ways. The tables found on the following two pages illustrate some of the differences in demographics, including density of population (table 1); the number of vehicles per person and on an area basis as well as the density of the road system (table 2); and the overall approach to government finance (table 3). In addition, while all the nations visited are Western industrial democracies, each country has a more centralized government than does the United States . The Federal-State partnership that has been essential to the success of the Federal-aid highway program in the United States has no counterpart in Europe.

The 1990 EAST visited asphalt mixing plants, contracting firms, government agencies, laboratories, and material suppliers, and inspected scores of pavements and ongoing paving projects in

# Table 1 a/

## NATIONAL STATISTICAL COMPARISONS
## DEMOGRAPHICS

| Nation b/ | Population (millions) (1990) | Pop. Density (person/sq km) (1986) | Percent Urban (percent) (1985) | Auto Expense as % of Pers. Spndg. (1980-85) |
|---|---|---|---|---|
| U.S. | 248.0 | 25.7 | 74 | 6 |
| Sweden | 8.2 | 18.6 | 86 | 2 |
| Denmark | 5.2 | 118.8 | 86 | 5 |
| W. Germany | 60.7 | 245.6 | 86 | 4 |
| Italy | 57.4 | 190.0 | 67 | 3 |
| France | 55.4 | 101.3 | 73 | 3 |
| U.K. | 55.8 | 231.9 | 92 | 4 |

# Table 2 a/

## NATIONAL STATISTICAL COMPARISONS
## HIGHWAY FACTORS

| Nation b/ | Vehicles (millions) (1987) | Pers. Per Veh. (tot./per car) | Veh. Density (veh./sq km) (1987) | Hwy. Density (km/sq km) (1987) |
|---|---|---|---|---|
| U.S. | 179.04 | 1.4/1.8 | 14.5 | 0.67 |
| Sweden | 3.63 | 2.3/2.5 | 7.6 | 0.4 |
| Denmark | 1.88 | 2.7/3.2 | n/a | n/a |
| W. Germany | 30.11 | 2.0/2.1 | 113.9 | 1.98 |
| Italy | 24.72 | 2.3/2.5 | 77.5 | 1.01 |
| France | 24.85 | 2.2/2.5 | 40.0 | 1.46 |
| U.K. | 23.02 | 2.5/2.8 | 74.1 | 1.53 |

# Table 3 a/

## NATIONAL STATISTICAL COMPARISONS
## TAXATION EFFORT

| Nation b/ | Tot. Tax Receipts as % of GNP (1985) | Road Taxes as % of Total Receipts | % of User Fees Used for Roads |
|---|---|---|---|
| U.S. | 29.2 | 4.7 | 100 |
| Sweden | 50.5 | 6.3 | 34 |
| Denmark | 49.2 | 6.2 | 31 |
| W. Germany | 37.8 | 3.7 | 64 |
| Italy | 34.7 | n/a | d a |
| France | 45.6 | 15.0 | n/a |
| U.K. | 38.1 | 11.5 | 23 |

&Tables 1, 2, and 3 are drawn from a variety of sources, including the World Bank, the International Road Federation, The World Almanac, the Organization for Economic Cooperation and Development, and MVMA Motor Vehicles Facts and Figures '89. Statistics compiled prior to the unification of Germany.

b/The nations are listed in the order visitied, with the United States added as the first country, for comparison purposes.

five of the countries visited--Sweden, Denmark, Germany, France, and the United Kingdom. The subcommittee that visited Italy inspected a mixing plant, a paving project, as well as roadway facilities, and met with officials of government agencies and *Societa **Autostrade,*** a concessionaire with responsibility for a large portion of Italy's toll motorways. While some local roads were observed first hand, the tour concentrated primarily on major highways and motorways comparable to the Interstate System . and similar high-volume highways in the United States.

The highway systems observed during the study tour are similar to their United States counterparts in some ways, but different in others. Among the similarities:

- All six countries have Interstate-type motorways. Like their United States counterparts, the motorways typically make up a small percentage of the nation's overall road network but carry large shares of its highway traffic (approximately 25 percent).

- Heavy motor truck traffic is concentrated on these routes, often representing 20 percent or more of all vehicles.

- Road professionals in every country complained of inadequate road-investment levels.

The observations reported here are impressions based on the study tour's site visits, dozens of interviews, and many hundreds of miles of highway travel by motor coach. The impressions, however, are just that: subjective comments based on the people met and the things seen.

A few impressions will help put the technologies, procurement procedures, and organizational roles into context. By far the study team's most striking observation was that the pavements on European motorways and trunk routes are in superior condition. The extreme forms of distress that are evident in many parts of the United States--rutting, raveling, cracking, and potholes--were, simply, rarely seen. Even pavements that were being rehabilitated or resurfaced were in fairly good condition by United States standards.

This observation is 'true even though motor truck usage in Europe is around 20 percent of the total traffic, with volumes growing on many highways, and European axle weights substantially exceed those allowed in the United States. Germany, for example, allows an 11.5 metric ton axle loading, or about 25,400 pounds, while France allows a 13 metric ton axle loading, or about 31,200 pounds. These weights may also be carried in Europe on "super singles"--a tire configuration that concentrates much of the weight of the vehicle in a fairly narrow path.

Aside from superior pavement conditions, the European highways are generally not more advanced than comparable United States highways. For example, many routes were congested and opposing lanes of traffic generally ran close together. The alignment of lesser routes, particularly in the United Kingdom, was not always suited to modern traffic needs.

The superior pavement condition of European motorways appears to stem from, or be related to, several differences between United States and European approaches:

## STRONGER EMPHASIS ON DURABILITY

Most of the countries visited use a 40-year analysis period for the design of their motorway pavements, as opposed to the 20-year design period used in the United States. In the 40-year analysis, European highway officials consider the initial pavement design and various rehabilitation strategies, as well as the anticipated life and cost of the design and the strategies. In the United Kingdom, a 40-year life-cycle cost analysis is required for all pavement designs.

Most of the countries emphasize building a sound subgrade and base rather than trying to solve subgrade problems in the pavement design process. Structurally sound design practices are generally used even when they impose significant construction costs through excavation and replacement of subgrade material or incorporation of active drainage systems. The most striking instance of this was in Germany, where one official stated that, "We no longer design roads; we have done that. Now, we simply look at a table and select the appropriate pavement design."

German pavement design practices are predicated on the fact that the subgrade is structurally sound and adequately drained. Over-design of pavement structures is not needed as a way of compensating for inadequacies in the subgrade. The economic implications of high durability were not challenged. On the contrary, the German representative noted that, "Whether or not it is more economical to tolerate some frost heaves is a debate we should not start."

The German approach to sound design stands out as exceptional, even among European practices. However, all the countries visited aim for longer design-life than in the United States and appear more willing to increase initial costs to avoid problems later. Strong, well-drained bases and subbases are the norm throughout the countries visited, rather than the exception.

Five of the six countries have prohibited the use of studded snow tires. The exception is Sweden, where studded tires are a major source of rutting. Relatively short lives for wearing courses in Sweden are inevitable because of the damage from studded tires. One unusual aspect of the resulting accelerated replacement of wearing courses is that the pavement structure is continually restored or even improved. When resurfacing takes place, the underlying structure is still sound and relatively new. This structural predictability has helped to make some innovative forms of contracting for surface courses work effectively (namely, functional contracts and guarantees).

## STRUCTURAL, NOT VISUAL, FACTORS TRIGGER REHABILITATION

Pavement-management practices in the countries visited appear to be driven more by structural condition, and less by visual condition, than is the case in the United States. Systems for monitoring pavement condition and for programming rehabilitation projects rely primarily on deflectograph or falling-weight deflection measurements. Some European officials noted that by the time visual distress is evident, it is too late to correct structural problems. *Societa **Autostrade*** in Italy, for example, virtually ignores visual distress on its 3,000 km of motorways in favor of twice-yearly total pavement surveys with condition-measuring devices that examine skid resistance, bearing capacity, rutting and surface texture, profile, and other cross-slope geometrical characteristics.

## STRONGER EMPHASIS ON NOISE REDUCTION AND SKID RESISTANCE

Great emphasis is placed on skid resistance and pavement noise reduction in all the countries visited. While these are serious concerns in the United States as well, they play a much more prominent role in determining when and how resurfacing work is done in Europe. Open-graded friction courses, under such names as drain asphalt and porous asphalt (PA), are advocated in several countries largely because of favorable noise and skid properties. Some of the concerns raised about the durability of earlier versions of these mixes appear to have been resolved by the use of modified binders. However, long-term performance information on durability is not fully available.

Because of concern about noise, the public in Europe appears to be involved in riding surface design decisions to a far greater extent than is common in the United States. The type of riding surface used is itself a subject of direct public participation--in at least some countries, the noise properties of different riding surfaces are matters of public knowledge. An agency's choice of treatment may be influenced by popular demand.

As in the United States, noise barriers are common, although their extent and the number of design variations are greater along European motorways. This fact, coupled with the European public's involvement in decisions on riding surface, may be good indicators of where the United States is headed as traffic increases and as our own public concerns about highway noise continue to grow.

## ASPHALT MODIFICATION

European officials described many types of asphalt modification. They include mineral and cellulous fibers for SMA and the use of carbon black, EVA, SBS, polyethylene, and ground rubber in other mix designs, as well as the addition of secret or proprietary materials whose nature is unclear (e.g., an ingredient identified to the study tour only as "dope" was used in one contractor's modified mixtures).

The use of these modifiers appears to be widespread, judging from the number of references and the time devoted to them by the European hosts. On the other hand, the fact that they knew in advance of the study group's desire to see and discuss "cutting-edge" technology undoubtedly encouraged a strong focus on modification, even though it may not be common practice. Some comments from contractors and officials suggested that modified binders still represent a small, special-purpose nitch in the overall pavement market.

Regardless of the extent, several nations clearly have drawn up high-performance standards or contracting approaches that permit and, in fact, encourage contractors to use a range of modified binders and innovative mix designs. Of the nations visited, France appears to make the largest and most sophisticated use of additives and modifiers, and French contractors have developed several patented pavement materials. In Italy, to cite another example, ***Societa Autostrade*** is making extensive use of proprietary modified mixes and processes.

It should be noted that compared with the United States, the nations visited often have fewer stable sources of asphalt. In Sweden and Denmark, for example, Venezuela is essentially the only source of asphalt. The European nations find that developing specifications based on the known characteristics of this asphalt is easier than if they had multiple sources.

## INNOVATIVE SPECIAL-PURPOSE MIX DESIGNS AND ADVANCED MIX-DESIGN SYSTEMS

Mix designs similar to the conventional, continuous-graded designs employed in the United States are used for much of the construction, rehabilitation, and maintenance of European motorways and trunk roads. All the countries visited, however, also use special-purpose mix designs, particularly in surface courses, to enhance the resistance of high-volume pavements to rutting, skidding, and, to a lesser degree, fatigue and thermal cracking.

Examples of such mix designs are SMA in Sweden, Denmark and Germany; hot rolled asphalt (HRA) and penetration macadam in the United Kingdom; gussasphalt in Germany; and special thin and very thin asphalt overlays in France. To achieve superior performance, these mix designs tend to feature gap-graded aggregate blends and modified or low-penetration grade binders, sometimes with the addition of fibers, as in the case of SMA. Several of these designs are intended to control rutting and other distress for as long as 10 to 12 years under heavy volumes of truck traffic and, in Sweden, SMA is used to combat the deterioration stemming from the use of studded tires.

The use of “large-stone” mixes, with top aggregate sizes of 40 mm (1.5 inch or more), to resist rutting does not appear to be prevalent in Europe. Surface courses generally employ a top aggregate size of from 11 to 16 mm (about .5 to .75 inches). Many European mix designs also appear far richer in binder content than conventional wisdom in the United States would dictate for rut-resistant surfaces. However, the different aggregate gradings and the modifiers and filled mastics generally appear to prevent rutting, flushing, and bleeding. None of these conditions were observed on anything approaching the scale they are found in the United States.

Mix design systems in Europe are similarly varied, as illustrated by these examples from three of the countries studied:

- Germany: Mix designs in the usual sense of the term are not done. Rather, mix designs for the surface and base courses on motorway projects are selected from a series of standard designs that have been developed through experience for various classes of traffic volume.

- France: The national laboratory, the Central Laboratory of Bridges and ‘Roads *(Laboratoire Central des Ponts et* Chaussees--LCPC), developed the mix design system that is used today. This system incorporates both gyratory and rolling-wheel compactors, with sophisticated wheel-tracking and direct tension equipment used to determine the rutting, stripping, and load-related fatigue characteristics of trial mixes.

- United Kingdom: The Marshall design method is used by some county authorities (which correspond to the state highway administrations in the United States), but others rely on standard “recipe” designs with a history of good service.

## SCALE, DIVERSITY, AND EFFICIENCY

In most of the countries visited, a few large companies appear to receive (through bid or negotiation) a large majority of contracting jobs on motorways and major national routes. At the same time, asphalt paving contractors clearly have to supply quality materials meeting the numerous, diverse specifications of agencies at different levels of governments. Asphalt plant owners frequently noted the large number of different mix designs--generally over 100--programmed into their batch-plant control rooms. The inefficiency of an excessive number of mixes was broadly recognized. In fact, it is part of the reason that the German national government decided to adopt a manageable number of standard pavement designs, and why the United Kingdom's standard-setting groups are concentrating on a small number of "preferred designs."

Production rates in the asphalt plants visited were typically one-half to one-third the productivity of their United States counterparts. Likewise, unit costs of paving materials and constructed pavements ran two or more times the corresponding costs in the United States.

Comparing cost or production rates in Europe and the United States, however, requires caution. The EAST participants recognized the difficulty of interpreting European economic conditions in the United States context, due to different materials prices, hauling distances, tax systems, labor conditions and rates, design differences, scale economics, and other factors. Amidst so many economic factors, each of which differs from its United States counterpart, isolating the extra cost attributable to some individual performance-enhancing feature is not possible.

In short, where higher quality was evident in Europe, study tour participants could not gauge cost-effectiveness with any accuracy. The large disparity in final cost means that when United States officials or pavement experts examine a high-performance European technology, they should carefully evaluate likely cost-effectiveness, as well as quality, in possible domestic applications. Improvements in quality do come at a price, but while the quality is evident, the value, in relation to cost, remains to be determined.

What was clear to study tour participants was that the European nations visited have looked at the cost-benefit equation for building high performance pavements on well engineered subgrades and bases--and have found such pavements to be in their national interest. The commitment to quality is obvious, and the Europeans have been willing to pay the cost. This commitment is something that Federal and State highway officials in the United States should carefully consider if this country intends to offer a highway system competitive with that of the European Economic Community in the 1990's.

## PERFORMANCE-ENHANCING CONTRACTING PROCEDURES

One of the most striking features of the European paving practice is the ability of European countries to stimulate contractor innovations and apply them within a competitive process. These innovations include the use of modifiers and additives within asphalt-binders, the use of high-quality aggregates, and new mix designs. While components of some innovative European mix systems are of a proprietary nature, public agencies are able to obtain them by competitive procedures that do not require particular proprietary materials or processes. Each country has its own approach, but these procedures generally had two features that differ from the current process of competitive bidding in the United States:

- Specifications were broader than most of the method specifications used in the United States, allowing contractors greater latitude to select effective materials and designs; and

- Contracts require contractors to offer guarantees or warranties that extend 1 to 5 years after the work is completed.

The first feature gives the contractor greater responsibility in selecting an effective approach. The second holds the contractor accountable for that choice.

Together, they apparently provide a working arrangement for tapping the experience and ingenuity of the contractor while maintaining sufficient control to ensure public funds are spent effectively. Contractors appear to accept the guarantee or warranty requirement, at least in part because of the existence of good quality pavement designs that, in many cases, they had a role in formulating. The study tour participants believe that in the absence of high quality pavement designs trusted by the contractors, European contractors would oppose guarantees and warranties.

The countries visited do not generally use performance-based specifications, which gauge the quality of the finished product. They also do not use end-product specifications, which pin down key characteristics of the final product. Rather, the European procedures reviewed during the study tour generally depend upon guarantees and latitude within method specifications to build a contracting environment that encourages contractors to use advance technologies to enhance performance. In addition, Sweden has experimented with projects using completely functional (design/build/maintain) specifications, with some apparent success.

## ENVIRONMENTAL CONCERNS

Public concern about the environmental aspects of highway construction in genera1 and asphalt paving in particular were clearly evident wherever the study tour went in Europe. Concerns covered topics ranging from location of asphalt plants to how the roads are constructed.

Because of the generally dense population and the proximity of plants to projects, the European countries appear to rely on permanent plants, with portable units that can be relocated being the exception. The choice of location for permanent plants is a sensitive local land-use issue. As a result, totally enclosed plants were seen in Germany and the United Kingdom, and landscaping requirements appeared to be extensive in some cases. Common practice is for an asphalt plant to serve several contractors. Some plants were independently owned, while others were owned by groups of contractors.

Generally, study tour participants found that at the paving site, environmental regulations for laying asphalt pavements did not appear to be any stricter than those in the United States. Indeed, blue-smoke emissions from gussasphalt paving (which requires higher temperatures than normal asphalt concrete) were tolerated in Germany, as were noticeable emissions from in-place recycling. When members of the study tour inspected an asphalt recycling machine in Italy, they found thick deposits on the exhaust stack, apparently left by plant emissions and particulates.

The study tour also observed the safety environment for construction workers. Some innovative work zone traffic management concepts were observed, especially in Sweden. Overall, however, safety in work zones is apparently not generally emphasized to the same extent as in the United States.

## STRONGER RESEARCH EMPHASIS

Tour participants found that the emphasis placed on highway and asphalt research, by both contractors and central governments, is much stronger in Europe than in the United States. Denmark, France, Germany, Sweden, and the United Ringdom have large centralized research facilities and capabilities, including full-scale pavement testing devices and test tracks (France and the United Kingdom), wheel-tracking tests for rutting, accelerated wheel-wearing devices for evaluating surface treatments (Sweden and Germany), rolling compactors for preparing large test specimens, and extensive laboratory capabilities. In four of these countries, laboratories were larger (in staff and budget) than the FHWA's Turner-Fair-bank Highway Research Center, even though the population of the countries is only 4 to 25 percent that of the United States.

Research and development by private contractors is not only common, but much greater than in the United States. This is reflected in the diverse array of specialized paving mixtures and equipment that contractors have developed so they can compete in European markets outside their own country.

## PENDING MARKET CHANGES

The planned adoption of uniform standards throughout the European Economic Community after 1992 has stimulated public officials, contractors, and research laboratories to examine their own approaches and to prepare for broader competition. On large-scale jobs, agencies are already required to solicit bids from the entire European Economic Community, not just from the country where the project is located. To date, cross-national awards do not appear cornmon on paving work, although some contracts for bridge projects and other specialized work have been awarded to contractors from other countries. As standards become more uniform, contractors and materials suppliers are expected to be able to compete in broader markets. Large contracting firms already appear to be exploring the prospect of international expansion.

Officials of the centralized research laboratories likewise recognize that changes planned for the post-1992 era will affect the need for, and suitability of, some current activities. The European national laboratories recently formed the Forum of European National Highway Research Laboratories, an international association that is helping to reconcile their activities in the face of those changes. Development of the SHRP's binder and mixture specifications, which are likely to be released in 1992, is being watched with considerable European interest because parts of the SHRP's battery of performance-oriented specifications and tests could find uses within the new system of standards.

## INDUSTRY/GOVERNMENT RELATIONSHIPS AND INDUSTRIAL STRUCTURE

The study tour participants found that the business climate in the European paving industry differs significantly from that in the United States in two main respects: public/private cooperation and concentrated industry structure.

### Public/Private Coooeration

Government and industry in Europe cooperate to obtain high quality, even though costs may be higher. Industry plays a much more active role in research, product development, and new product testing than in the United States. The national governments cooperate with industry by helping to develop or approve standardized tests, by arranging field trials of new industry products, and by setting specifications that ensure adequate performance but permit sufficient latitude to embrace innovative industry products.

The method used to select contractors also affects quality. For example:

- The United Kingdom: On at least some projects, only qualified companies selected by agency officials are allowed to bid. In addition, various lane-rental approaches are used at the national and county (state) levels so the duration of lane closure is factored directly into the cost comparison.

- Sweden: Only a few large, well-qualified companies appeared able to offer the necessary assurances under the performance-guarantee system used there.

- Germany: A combined system of cost and quality-related factors is used to select the most acceptable contractor, namely the one with the best combination of quality and cost.

Each of these contractual approaches had subtleties that varied from country to country and even from project to project, but each system differs from United States practices in several ways:

- In Europe, much greater emphasis and latitude are given, within competitive contracting procedures, to encouraging and hence achieving quality products;

- Government and industry work cooperatively to develop improved products;

- And, government officials in Europe have a much stronger ability than their counterparts in the United States to limit competition to well-qualified contractors, and to consider their performance on projects in the past and the quality of that work in the final selection process.

**Concentrated Industrv Structure**

In Europe, the paving industry is more concentrated within a small number of large firms than is the case in the United States, even after the smaller scale of European countries is taken into account. Further, the contractors are often linked through overlapping ownership of shares, ownership of common suppliers, or other financial ties. In Italy, the national government may even own substantial stock in the contractor. Because of these links, the European contracting industry is even more concentrated than the limited number of firms would imply.

The concentrated industrial structure helps explain how some features of the close industry/government association can work. For example, larger "up front" investments in research and development make more sense in this structure, as does industry's acceptance of the government's strong role in qualifying and choosing high-quality contractors.

Moreover, government authorities have a large influence on the management of each company. Perhaps the most pronounced cases of this are the French and Italian tollway concessions, which are operated much like a utility in the United States. They appear to generate neither excess profits nor potential losses. As in the United States, though, concessionaires or toll agencies can generate greater-than-minimum costs for providing and maintaining their motorways, which the governments in Europe are apparently willing to pay for in recognition of the obviously high-quality highways they receive.

## SUMMARY

Based on 2 weeks of discussions with private contractors and many government officials, as well as detailed observation of pavements, plants, and laboratories, EAST participants formed several general impressions:

- European motorways are in much better condition than equivalent roads in the United States, despite axle weight limits substantially above United States limits and truck traffic that often accounts for 20 percent of highway usage.

- Greater durability is engineered into pavement structures in Europe, with more emphasis on providing well-drained, structurally sound subgrades.

- Rehabilitation is typically triggered by structural measures, not by the appearance of visible distress.

- Concerns about noise reduction and skid resistance dominate the timing and selection of surface treatments to a far greater extent than in the United States.

- European countries appear to be making more use of modified binders, commonly proprietary, than is the case in the United States.

- Innovative mix designs are applied on the wearing courses of heavily travelled routes. The designs often use gap-graded mixes and modified or low-penetration binders (between 40-60 percent).

- The scale and diversity of hot-mix products, together with numerous economic features of the European environment, result in unit costs for hot-mix products that appear to be substantially above their United States counterparts.

- European countries have developed contracting approaches that encourage contractors to innovate and enhance the quality and performance of their products.

- Environmental controls on European paving projects appear to be no greater than in the United States and are perhaps looser, while zoning controls of asphalt plants in at least some countries appear much stricter.

- European governments are much more active than governmental agencies in the United States in supporting highway research laboratories. European hot-mix contractors also do more research than their United States counterparts.

- Research results tend to be more aggressively marketed in Europe, particularly in France where the LCPC sometimes markets directly, or licenses manufacturers to market, its proprietary inventions.

- The coming of standards in 1992 that will apply to the entire European Economic Community is a dominant general concern of contractors and governments alike.

- One response to the need for the development of European Economic Community standards may be the adop tion of European performance specifica tions, which could be more easily adapted by each European nation to its own high way system procedures and practices.

- European governments and the private sector work more closely than is true in the United States. At least part of the reason for the presence of higher quality highways in Europe can be traced to this cooperation.

- The concentration of Europe's highway industry into a few companies, often with overlapping ownership and sometimes with a degree of ownership by government, provides for an improved climate of cooperation, but at the cost of the intense competitive environment that exists in the United States and provides the countries with lower cost highways.

# TRIP SUMMARIES


SWEDEN

# SWEDEN

Items with the Highest Potential for Implementation in the United States:

- Stone Mastic Asphalt
- Drainage asphalt (also known as PA)
- Contract administration procedures, including warranties and functional contracts

## ITINERARY

The Swedish tour consisted of a Sunday afternoon seminar with government and industry officials, as well as tours of projects, both active and completed, and an asphalt plant.

## SUMMARY

The Sunday afternoon seminar featured presentations on several subjects:

1. Heavy duty asphalt pavements (SMA and PA).
2. Government and industry perspectives on the Swedish experience with SMA and PA.
3. The Swedish experience in functional contracts and the use of guarantees.

Unlike the other countries visited, Sweden faces the problem of extensive use of studded tires, which cause rutting. In the northern region, 90 to 95 percent of all vehicles use studded tires. In the Goteborg area, reported use was 50 percent. Swedish authorities have concluded that designing conventional asphalt concrete mixes with good shear resistance as well as satisfactory durability and resistance to cracking is difficult, if not impossible. In Sweden, the answer is SMA.

The three main characteristics of an SMA mix are:

1. The coarse particles must form a stone skeleton with firm contact between the particles.
2. The glue between and the coating of the coarse particles should consist of a void-less mastic.
3. The mastic must be stabilized so it does not drain off the coarse particles during storage, hauling, and laying.

Mastic, as used in this context, means the asphalt cement, fine aggregate (less than 2 mm), and filler.

Stone Mastic Asphalt is a gap-graded mix using high-quality crushed aggregate with a maximum size of 16 mm. Approximately 80 percent of the aggregate is larger than 2 mm, with 65 to 70 percent larger than 8 mm. By weight, the binder content ranges between 6.6 and 7 percent of the total mix. The main additives used to stabilize the mastic seem to be either cellulose or mineral fibers. The fibers look like rock wool and are reported to be approximately 1.5 mm long. In short, the SMA mix basically consists of two parts: a rather single-sized coarse aggregate and the mastic.

Porous asphalt, sometimes called drainage asphalt, is also receiving considerable attention in Sweden. This mix, which seems to be similar to our open-graded friction courses and some plant mix seals, has excellent noise reduction and skid resistance properties. It has not, however, shown sufficient durability in Sweden. In the view of Swedish authorities, this mix can be improved by using fibers or modified asphalt binders. They also emphasized that the existing surface must be sealed prior to laying PA.

Field reviews of projects completed and underway generally confirmed what was presented in the seminar. City streets surfaced with SMA and subjected to heavy truck traffic and abuse from studded tires seemed to hold up well. A heavily traveled PA city street had a rut depth of approximately 25 mm after 6 years. The pores in the mix appeared to be clogged with debris, and this blockage tends to destroy the strong skid resistance of the mix.

The two active projects reviewed involved SMA construction. The contractor for each project used different SMA mixes, as was evident from their appearance. Compaction was achieved with steel-wheeled rollers. As a general rule, pneumatic-tire rollers are not used on surface courses in Europe. The typical SMA overlay in Sweden is between 30 and 40 mm thick. Both active projects have thicknesses of approximately 30 mm.

The price difference between SMA and the standard asphalt concrete mix was difficult to tie down. Comments indicated, however, that SMA is somewhere between 10 and 12 percent more expensive. The cost of PA is somewhere between the two. Top quality aggregate is used in all the mixes, even if the material must be imported at significant cost. In May 1990, 40 Nordic asphalt technologists compared different asphalt mixes with standard hot mix asphalt (HMA). The table on the facing page shows the results.

One Swedish expert offered the opinion that SMA and PA will dominate the surface market in Europe for the foreseeable future. Nobody argued with his conclusion.

Cooperation between the private and public sectors in Sweden seemed very good. In general, Sweden operates under a quality assurance process and requires 2- to 3-year warranties on asphalt pavements. Neither government nor industry has any problems with the warranty concept. The required surety of up to 5 percent of the contract price is released after satisfactory completion of the warranty.

In the early 1980's, Sweden tried two projects with completely functional (design/build/maintain) specifications, including a maximum tolerated rut depth, smoothness, and friction. No defects were allowed and warranties of 5 years were required. These projects were successful, but have not yet resulted in further functional contracts. Swedish officials are tentatively planning more, but believe functional contracts have only limited application.

| PROPERTY | RANKING COMPARED WITH HOT-MIX ASPHALT | | |
|---|---|---|---|
| | **Hot-Rolled* Asphalt** | **SMA** | **Porous Asphalt** |
| Shear resistance | -(-) | + + | + + |
| Abrasion resistance | + | + + | (-) |
| Durability | + +(+) | + + | -(-) |
| Load distribution | (-) | (-) | -(-) |
| Cracking resistance | + +(+) | +(+) | (-) |
| Skid resistance | 0 | + | +(+) |
| Water spray | 0 | 0 | + + + |
| Reflection | + | + | +(+) |
| Noise reduction | | 0 | + + + |
| Public recognition | + | + + | + + + |

* The hot-rolled asphalt is the British surface mix.

**KEY:**

0 Means equal to the asphaltic concrete
+ Means better than asphaltic concrete
+ + Means much better
+ + + Means very much better
- Means worse
-- Means much worse
--- Means very much worse
Items in ( ) indicate a half mark

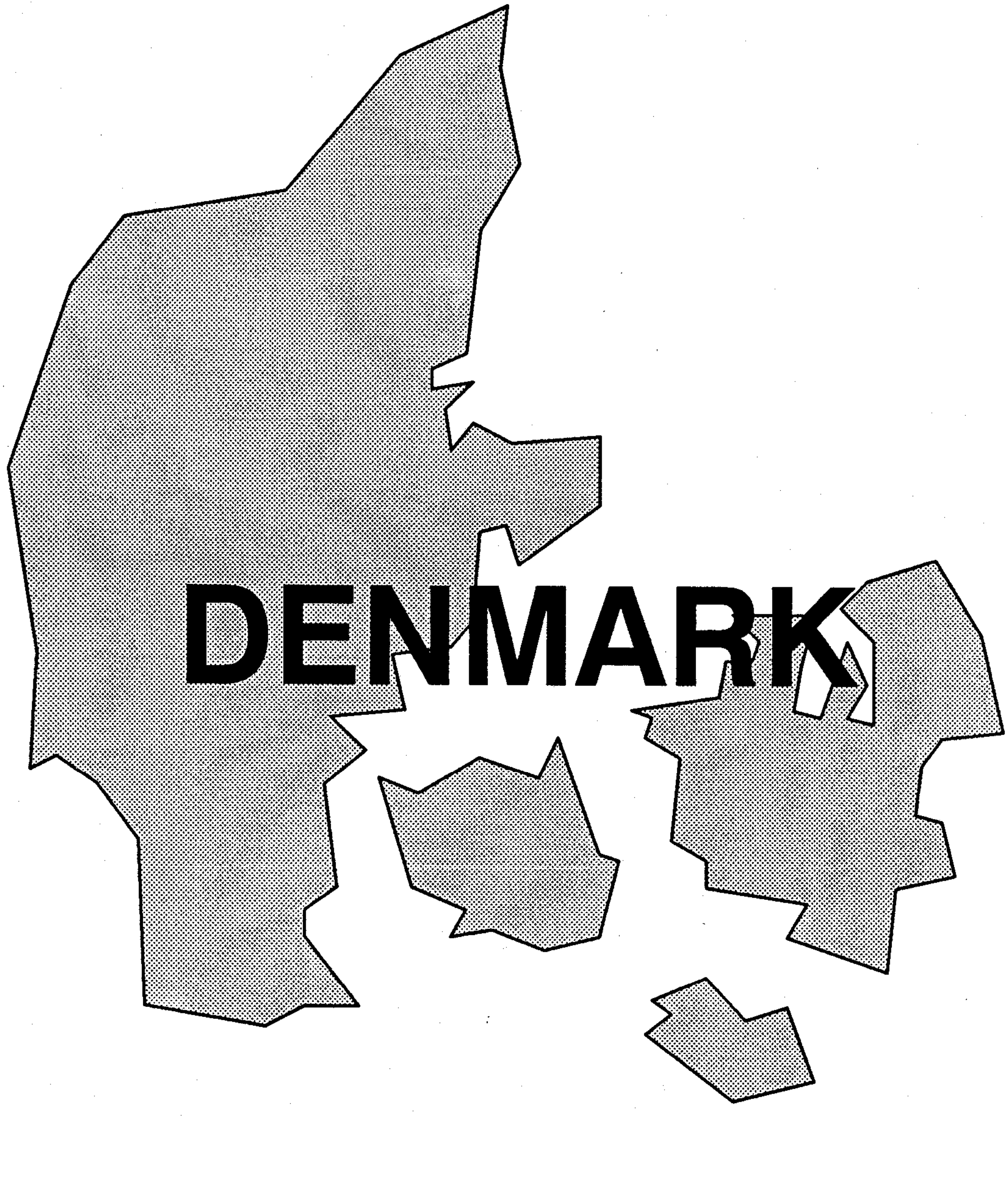
The large contractors--but not small contractors--seem to favor this type of contract, but have some concerns. They would like the government to set less demanding specifications. One major contractor stated that functional contracts provide an opportunity to emphasize and measure the real quality of the work. The current system, as the large contractors see it, often measures the exactness of theoretical recipes, rather than quality. They also believe current test methods are often unreliable and unrepeatable, a view that contractors in the United States have expressed about tests in this country.

Two large multinational contractors do about 85 percent of the asphalt pavement business in Sweden. Each has trade names for several of its products. Whether or not patent rights or proprietary rights were involved with any of the mix designs or mix processes was not clear. Swedish specifications are reportedly open enough that anyone can compete, although the market dominance by the two major contractors makes market entry for other contractors difficult.

The two large contractors own and operate the asphalt plant visited in Sweden. As in the rest of Europe, this plant and others in Sweden are not geared to high production. The one visited could reportedly produce about 240 metric tons per hour. The plant was equipped with a conveyor that introduces fibers into the mix for SMA. The fibers are either cellulose or mineral, depending on which contractor's mix is being produced. To make it easier to introduce cellulose fibers into the mix, pellets can be made consisting of 50 percent bitumen and 50 percent fiber. The bitumen and fiber can be hauled in bulk and introduced into the mix directly. The other fibers are introduced into the ix in bags.

## CONCLUSIONS

Stone Mastic Asphalt has the potential to assist United States highway agencies in solving some of the problems we have had with HMA surfaces, at least in the northern tier of States. The effect that the higher temperatures in the South and Southwest would have on this mix needs further evaluation. The Swedish experience suggests several factors that will have to be kept in mind in deciding how SMA might be used in this country. It must be placed on a sound pavement structure. It requires premium aggregates. In addition, SMA is sensitive to variations in mix proportioning, so tighter controls in mixing and placement are necessary.


DENMARK

# DENMARK

Items with the Highest Potential for Implementation in the United States:

- Use of additives

- Contract administration procedures, including warranties

- Bridge deck protection

## ITINERARY

The Study Tour stayed in Denmark less than 1 day. The stay included a visit to the offices and laboratory of the Danish Asphalt Pavement Association, a review of a paving project at the Copenhagen Airport, a briefing by officials of the Danish Road Directorate, and a review of completed projects.

## SUMMARY

The paving project at the Copenhagen Airport consisted of paving a taxiway. The project was particularly well run. Two pavers operating side-by-side eliminated any appearance of a longitudinal joint in the wide mat. Seven rollers operated behind the paver in a relatively confined space. Carbon black was used as an additive in the mix (12-15 percent). According to contractor personnel, the carbon black makes the mix extremely difficult to compact. According to the consultant, however, the difficulty is justified because the carbon black improves temperature susceptibility and resistance to aging. The contractor also reportedly used lime and cellulose fibers in the mix. This project required an S-year warranty.

According to Road Directorate officials, Denmark is experiencing some problems with rutting. The country does not permit studded tires, so the rutting that does occur is caused by traffic--namely increased commercial vehicles and higher tire pressures. Pavements that have been in place for some time have, in recent years, started to rut. The Road Directorate is using SMA-type surfaces to try to overcome this problem. Gap-graded HMA with pre-coated chips rolled in has also been widely used. However, SMA seems to hold the most promise for a rut-resistant surface course.

Denmark requires a 5-year warranty on highway pavements covering smoothness, durability, and skid-resistance. The contractors select the mix design within the Road Directorate's guidelines. The structural design was the responsibility of the Road Directorate, not the contractor. The contractor is responsible for routine testing, with periodic checks by the Road Directorate. Of the contract price, 5 percent is withheld during the warranty period.

Denmark seems to do more recycling than the other European countries, mainly for environmental reasons although economic benefits result, too. The country's road contractors reportedly recycle about 200,000 tons of HMA per year.

Danish road officials emphasize bridge deck protection and claim considerable success with the process used. All bridge decks, whether concrete or steel, are covered by a protective system of four bituminous layers ranging from a membrane seal to a chip seal wearing course.

The Danish Asphalt Pavement Association's laboratory is well-equipped and appears to be used mainly for testing mixes and mix design. The tests basically give contractors a level of comfort with their designs--an important factor because of the warranty requirement on all major highway projects.

A Danish contractor demonstrated innovative equipment for applying edgeline pavement strips. The process is marketed as "Spotflex." A machine applies dots approximately 3 mm high but can be any width desired. The marking material consists of a two component acrylic resin used as a binder, glass beads, titanium dioxide, and filling substances. They are laid on the road at a distance commensurate with the height of the dots, giving the driver the impression of an unbroken line. Because of the height of the dots, incidental light from headlights is reflected toward the driver, thereby enhancing visibility, while the raised dots create a noise that alerts the driver when the vehicle is leaving the roadway.

## CONCLUSIONS

The problems Denmark is experiencing with its asphalt surfaces are similar to those in the United States, though not as extensive. As in other countries, SMA shows great promise as a solution. The Road Directorate is participating in the Strategic Highway Research Program, so perhaps mutual solutions can be found.

Contract administration features, including the warranty provisions, should be further studied for potential use in the United States.


GERMANY

# GERMANY

Items With the Highest Potential for Implementation in the United States:

- o Splitmastixasphalt (SMA)
- o Drainage asphalt
- o Contract administration procedures

## ITINERARY

The German leg of the study consisted of meetings with government and industry personnel, a tour of the Federal Highway Research Center (*Bundesanstalt fur Strassenwesen*--BAST) near Bonn, visits to construction sites where activities ranged from laying HMA base to thin overlays and projects to fill ruts. Personnel from all three levels of government (city, state and federal) were involved at one time or another in the meetings and on-site reviews.

## SUMMARY

The review in Germany concentrated on the Autobahns and major arterial routes. The Autobahns are the main arteries of commerce in the German transportation system carrying approximately 30 percent of the traffic. Although trucks comprise about 20 percent of the total, study tour participants observed a much higher percentage of trucks on some sections.

The Autobahns generally have 1940's geometry. Because of environmental concerns, German road officials have found that improving the Autobahns to United States freeway standards is extremely difficult. Motorway pavement structures are designed for a 40-year life, as opposed to the 20 years often used in the United States. Surface conditions are generally excellent, but some rutting and cracking was observed on a few sections. In general, the Autobahn network is a mature system with many miles under rehabilitation, much the same as our Interstate system.

Most major highways have a bituminous surface (71 percent of the Autobahns and 99 percent of federal highways). The main types of bituminous surface are Gussasphalt, SMA, and HMA. The Germans consider Gussasphalt to be their most durable surface, followed by SMA and HMA.

Gussasphalt is a poured mastic mix with chips rolled into the mixture. It requires special equipment, as well as quite a bit of hand work, and is placed at approximately 425' F. German officials use Gussasphalt on sections of the Autobahn with the highest traffic volumes and on bridge decks.. The expected service life is 12-18 years and it costs about 90 percent more than HMA.

Germany is given credit for inventing SMA, which is used as a surface coarse on normal traffic sections of the Autobahn and on other major federal highways with high traffic counts. The maximum aggregate size used for SMA in Germany was smaller than in Sweden. In some cases, a maximum size of 8 mm is used, but 11 mm is typical. The grading curve also seems to be a little flatter than in Sweden. Asphalt cement content is relatively high (7 percent, plus or minus) and fibers are used as a stabilizer for the mastic. Sand is sometimes added to the surface to increase initial skid resistance. Expected service life is 10-15 years. Splittmastixasphalt, as SMA is known in Germany, costs 20 to 30 percent more than HMA. Hot-mix asphalt is used as a surface course on other Federal, state and county highways. The expected service life is 8-12 years.

Porous asphalt is not yet in general use in Germany. Because, however, of a strong emphasis on noise abatement, PA may become more common. German road officials see it as having strong potential for reducing noise as well as increasing safety. They are looking not only to reduce the noise caused by the interaction of tire and pavement, but to dampen traffic noise created from all sources.

The Germans underlay the PA surface with a sealing membrane to eliminate water intrusion into the structure. A cross-section of one such project also showed an underdrain system in the existing pavement structure to take away the water. This surface is limited to high velocity traffic areas because debris tends to fill up the voids. Porous asphalt is about as expensive as Gussasphalt, probably because of the requirement for the membrane sealer and drainage.

A patented slurry seal process known as Ralumac is being used with some success as a rut filler and thin overlay. The major advantage is that it will adhere to PCC and is quick setting. Traffic can be placed on it within a half-hour after it is laid. Several States in the United States are using this product.

The Germans no longer do individual structural designs for pavement projects. Typical structural sections have been developed for asphalt and PCC pavements on the basis of traffic volume and classification. Mix designs are selected the same way. These structural sections and designs are based on experience and the Germans are not interested in any other approach. Because the Germans do not tolerate frost or moisture problems in the underlying layers, they do not have to try designing the upper courses to compensate for inadequacies in the subgrade or subbase. They can base their design practices on the fact that the subgrade is structurally sound and adequately drained.

Specifications seem to reflect a combination of method and end result. The contractor does the mix design within limits shown in the government's recipes for different mixes. The contractor also does the quality control, but the government does the quality assurance, either with its own staff or, most often, through private labs. Of the countries visited, the German government appears to exercise the most oversight of contractor operations.

Study tour participants observed major reconstruction on older sections of the Autobahn, but most work involved correcting such surface problems as rutting and skid resistance. The German pavement engineering philosophy is to fix the problem before it occurs. As a result, much of the work was on pavements that would be considered in good condition in the United States. The Germans also believe in fixing only the existing problem. If one lane is deformed or is losing skid resistance, the Germans will mill off and resurface only that lane. Often, two different mixes can be observed in adjoining lanes because one was rehabilitated and the other was not.

Contracts are awarded to what the Germans termed “the most acceptable bidder.” Time did not permit the study tour participants to collect enough information to determine how the selection process works. In most cases, the contract reportedly is awarded to the lowest bidder, but technical elements are also considered. While bid documents may specify the type of pavement (asphalt or PCC), the contractor can propose an alternate type. This process appears to be more like value engineering than alternate bidding.

For reconstruction projects, how the bidders propose to use recycled asphalt pavements (RAP) is another technical factor considered in the award. The contractor is required to recycle materials, to the highest level possible, on the project. For example, a contractor who demonstrated he could use 50 percent RAP in the binder course would be favored over a contractor who planned to use the RAP as subbase material or fill. No RAP is permitted in the surface course. Study tour participants could not determine how often technical factors override cost considerations in awarding contracts. Several large contractors seem to dominate the market, a situation that also exists in the other countries visited.

A 4-year warranty is required on highway contracts. On most projects, an amount equal to 3 percent of the bid price is retained during the warranty period. Whether this is a cash retainage or can be bonded was not clear. The contractor is responsible for any defects that occur during the 4-year period. In essence, he is responsible for maintaining the pavement while the warranty period is in effect.

The sophisticated asphalt plant near Hamburg was completely enclosed except for its 15 cold storage bins and its aggregate stockpiles. The plant has two dryer drums, although it still uses a batch mixer. One drum preheats the RAP, while the other heats virgin material. Exhaust gas from the virgin drum, which has a burner, goes through the other drum to preheat the RAP. The plant is fully automated and reportedly capable of producing 160 different mixes. It routinely produces, however, only about 20. German asphalt plants are not geared to high production, ranging from 160-250 tons per hour. Shared ownership of a plant by two or more contractors is reportedly fairly common.

As in the other European countries, Germany has a large centralized research facility. The BAST employs about 350 people--more than twice the number at the FHWA’s Turner-Fairbank Highway Research Center. The lab includes a full-scale pavement testing device, wheel tracking tests for rutting, and accelerated wheel wearing devices for evaluating tire-pavement interaction. Germany has made a much stronger commitment than the United States to research as a major part of the problem-solving process.

The Germans are dedicated to protecting bridge decks and assuring good rideability. The noise levels of traffic on bridges is also an important consideration. Bridge deck protective systems seem quite expensive, but they are effective. The systems generally consist of an epoxy resin on top of the surface to be protected, followed by an asphalt seal with a gussasphalt surface.

## CONCLUSIONS

For the United States, SMA has strong potential. While a 40 mm overlay seems to be standard in Germany, thinner overlays with SMA are used, as are a smaller maximum size course aggregate. Gussasphalt, by contrast, does not have strong potential for use in the United States. Factors working against the use of

Gussasphalt are its cost, special equipment requirements, and high laydown temperature, which poses potential air pollution problems.

Prudent use of fibers and polymers can enhance a mix, but cannot compensate for poor mix design or poor materials. In Germany, as in the other countries visited, premium crushed aggregate is used where premium mixes are required. Hauling aggregate several hundred miles or importing it from other countries is the rule rather than the exception.

Again, as in the other countries, quality control by the private and public sectors in Germany appears excellent. Warranty requirements are partly responsible. Another major reason is the fact that each contractor has more responsibility than contractors in the United States for mix design, production, and laydown operations.

Warranty provisions should be given closer review to see if they would be applicable in the United States. Similarly, the provisions in the bid documents allowing the contractor to submit alternate solutions should be examined.


ITALY

# ITALY

Items With Highest Potential for Implementation in the United States:

- System of concessionaires to build motorways
- Contracting procedures
- Use of modifiers and additives
- Pavement management system

## ITINERARY

A subcommittee of AASHTO and FHWA study tour participants visited Italy for one evening and a full day. The group toured several installations, including the headquarters of the National Road Board (*Azienda Nazionale Autonoma delle Strada*--ANAS), an asphalt plant using the Novophalt process and a section of motorway where the modified asphalt was being laid, and a restaurant concession operated by Ferretti at the *Flaminia Est* Highway Service Area north of Rome. During a visit to the *Societa Autostrade* Laboratory at *Fiano Romano,* the subcommittee learned about Italian highway engineering and asphalt technology, as well as the process and equipment used to manage pavements on the motorways the company controls.

## SUMMARY

The ownership, management, and operation of the Italian highway system is quite different from what we are familiar with in the United States, and may seem complicated by comparison. Following World War II, the Italian government established a new national highway agency to reconstruct the nation's war-damaged highways. That agency evolved into today's ANAS, which operates autonomously, with the Italian Minister of Public Works serving as Chairman. The ANAS is responsible for overall highway planning in Italy and works to bring highways to both wealthy and poor areas.

In the early years after World War II, Italy concentrated on repairing its damaged highways and bridges. In the mid-1950's, development of a major motorway network began. The Italian government, short on resources, decided that the best way to build the motorways was to grant concessions to private companies. They would design and build toll motorways and operate them for 30 years, before turning them over to the government. In addition to providing a mechanism for using private capital, this arrangement had the advantage of allowing the concessionaires to avoid the bidding procedures normally used by ANAS for letting construction contracts. The concessionaires, being wholly responsible for the motorways under their control, are free to negotiate contracts as private businesses.

Today, ANAS is directly responsible for some 50,000 km of state highways and roads, including about 1,000 km of toll-free motorways. The agency also supervises the network of concessionaires and may make capital contributions toward concession toll roads. It does so when a concessionaire is constructing a motorway in a depressed area where toll revenues may not be sufficient. In all, 27 concessionaires manage 6,000 km of Italy's 7,000 km of existing or planned motorways.

***Societa Autostrade,*** which received the first concession for a motorway in 1958, controls some 3,000 km of the motorway network. The company is part of a corporate structure that goes back to the postwar period when capital was short and the country needed to reestablish its private industrial activity. One method used to overcome these problems was creation of large private companies funded mainly with public money. The giant Institute for Industrial Reconstruction, known as the IRI Group, is one of these companies. It includes many subsidiary corporations in a variety of fields. Within the IRI Group is the IRI-INTALSTAT Group, which includes ***Societa Autostrade.***

Another IRI-INTALSTAT Group company, PAVIMENTAL S.P.A., is the contractor for construction and maintenance of motorways under concession to IRI-INTALSTAT. Similarly, the group's BONIFICA is a civil engineering consulting company that works for ***Societa Autostrade***. This is a greatly simplified description of a complex array of relationships developed over several decades. In essence, though, ***Societa Autostrade*** differs from United States toll authorities in its ability to negotiate contracts for work by what are, in effect, related companies with overlapping ownership and directors--and with no apparent use of competitive bidding.

In several ways, ***Societa Autostade*** is similar to toll authorities in the United States. The company has a large engineering staff and a well-equipped laboratory in which development was observed to be underway on several new ideas in pavement technology. Tolls generate a healthy revenue, with ANAS observing that typically, the Italian concession companies have maintenance funds available that are "five/six fold higher than" funds available to ANAS. Italy, like toll authorities in the United States, uses concessions for the operation of restaurants and other service facilities on its toll roads; the one visited by the subcommittee was excellent. According to ***Societa Autostrade*** officials, nearly 25 percent of the company's operating revenues are generated by the service facilities or the leasing of excess land at interchanges.

In Italy today, the highway and road system carries 85.4 percent of all passengers and 61.5 percent of all goods movements. Highway traffic growth has been high in recent years, with ***Societa Autostrade*** reporting a 45.4 percent increase on its motorways between 1984 and 1989 (47 percent for passengers, 40 percent for goods). In 1989 alone, the company saw a 7.6 percent increase (7.2 percent for passengers, 9.1 percent for goods).

***Societa Autostrade's*** concessions were recently extended and now run to 2018. Since the concession started in 1958, the extension means the company will be responsible for some motorways for about 60 years. This realization, and the desire to reduce maintenance costs and thereby increase net revenue from tolls, caused ***Societa Autostrade*** to establish a comprehensive pavement management system. It includes a twice-yearly structural examination of all 3,000 km of its motorways. The company reported that its system has resulted in an overall cost reduction of around 30 percent because of a more intelligent use of maintenance activities.

*The Societa Autostrade* pavement management system tries to reduce all factors to numbers, which are then compared with pavement performance curves to design specific maintenance activities. The analysis devices have been phased in over the years, and now include a SCRIM skid resistance truck (1982), a falling weight deflectometer (1983), an ARAN truck for measuring profile and geometric characteristics (1985), an APL device for measuring the longitudinal profile (1988), and a newer truck, known as SUMMS, for measuring skid resistance and texture. The machines take measurements at different intervals and operate at different speeds, as follows: ARAN, 20 m and 60 km/h; APL, 25 cm and 72 km/h; and SUMMS, 10 m and 60 km/h. The falling weight deflectometer stops for 10 measurements every km, with one minute per measurement.

*Societa Autostrade* has placed pavement maintenance activities in six categories: reinforcing, surface dressing, milling and repaving, deep repaving, recycling in place and at plant, and poly-functional composite pavement. The company is increasingly using open-graded bituminous mixes, both to reduce rolling noise and hydroplaning, and does considerable recycling.

Deep repaving is done with base course polymer-modified asphalt mixes, sometimes at night. The old asphalt mix is cold-milled and recycled in place. Then a non-woven fabric is placed, followed by the laying of a polymer-modified asphalt base course and asphalt mix binder and wearing courses.

Poly-functional composite pavements are just being introduced. They are being considered for future reconstruction of all motorways. One has been placed on the Fiano-S. Cesareo connector. It comprises a continuously reinforced concrete pavement (CRCP) course laid on a graded aggregate base and covered with an open graded drainage course of asphalt concrete. The CRCP provides resistance to fatigue, while the wearing course is considered as a renewable surface that has high skid resistance and reduces water spray and rolling noise.

The subcommittee visited an asphalt plant that produces a modified asphalt by the Novophalt process. It blends used polyethylene scraps, in this case from ground electrical insulation, into the asphalt cement. While costs increase substantially with the Novophalt process, the pavement reportedly might last more than twice as long.

At the same plant, the subcommittee examined two asphalt recycling pavement trains owned by PAVIMENTAL. The exhaust of one train was coated with asphalt, indicating a possible problem with substantial operating emissions. Another machine is being modified for operation in the Soviet Union.

The subcommittee was told about Italian asphalt practice, which includes extensive use of such modifiers as polyethylene and rubber (the fact that the rubber was not from tires was emphasized). The aggregates used in Italy are usually either basalt or limestone. In a basaltic base course, asphalt content will typically be about 4.5 percent. The second course may use limestone, with about 5.2 percent asphalt and 3-4 percent voids. The typical wearing course has aggregate in the 10-15 mm range, with an asphalt content of about 6 percent and 2-3 percent voids. However, for drainage or PA wearing courses, aggregates average around 18 mm, with an asphalt content of about 8 percent and 22 percent voids.

## CONCLUSIONS

The Italians have amply demonstrated that toll authorities can construct and maintain a modern motorway system, although the specific institutional arrangements used in Italy seem unique to that nation's situation. *Societa Autostrade*'s pavement management process and some of its highway engineering developments, such as its proposed use of composite pavement, are worth further study.


FRANCE

# FRANCE

Items with the Highest Potential for Implementation in the United States:

- Patented additives and polymer-modified binders
- Contract Administration Procedures
- Well-equipped laboratories, both government and private
- Thin overlays and surface treatments

## ITINERARY

In France, the study group's travel was mostly by air and rail, rather than by motor vehicle as in the other countries. The trip included a tour of the Central Laboratory of Bridges and Roads (*Laboratoire Central des Ponts et Chausees*--LCPC), the main laboratory of the Ministry of Public Works in Nantes. Most government-sponsored civil engineering research and development occurs in the laboratory. The 2-day tour was rounded out by tours of active and completed projects in the vicinity of Nantes and Lyon as well as visits to contractor facilities and laboratories. The work underway generally consisted of thin overlays and slurry seals.

## SUMMARY

France has approximately 7,000 kilometers of motorways comparable to our Interstate System. Most are toll facilities designed, built, and operated by concessionaires (about 6,000 kilometers). Of the eight concessionaires involved, seven are quasi-public entities (public-private partnerships) and one is fully private. A three-person commission representing the Ministries of Transport, Finance, and Development selects the concessionaires, whose contracts are for 35 years and can be renegotiated. A 5-year warranty is required. The concessionaire sets toll rates, with the approval of the Finance Minister.

France uses more polymer-modified asphalt than the United States and probably uses more than any other country in Europe. In fact, France reportedly uses more than half the polymer sold in Europe. Approximately 7 percent of all asphalt mixes used in France are polymer-modified, but the polymers are used only in the surface course. The comparable figure for polymer-modified asphalt in the United States is 2-3 percent. Polymer-modified binders cost about twice as much as standard asphalt cement and on average, the mix is approximately 20 percent more expensive.

More patented or proprietary mixes, additives, and processes appeared to be in use in France than in the other countries visited or in the United States. Each large contractor the study group met with had several. In some cases, the products were developed by government-industry cooperative ventures. Some of the products are marketed and used in the United States.

Overall, in fact, the French system encourages innovation by giving contractors the opportunity to use their own technology in pavement design and construction. For example, specifications usually identify desired end-results. While many patented additives and processes can be used in the six basic mixes described below, contractors may propose other solutions--and the contracting agency often accepts them. The proposer of an innovative solution, however, must be able to demonstrate to the owner's satisfaction that the desired results can be achieved. This public-private cooperative approach seems to result in superior products and superior pavements.

The study tour members observed a particularly unique patented operation used to produce a stress absorbing membrane (SAM). The operation consists of a modified binder strengthened by continuous synthetic organic threads spread over the binder and covered by chips. The unusual feature was that the binder and the threads were distributed by the contractor's patented machine. Large reels were mounted on the back of this machine and the threads were dispersed over the binder in a single operation. A conventional spreader following the other piece of equipment distributed the chips. The result seemed to be similar to fabrics embedded in a sprayed binder. It's obviously an expensive operation but the contractor claimed it was successful. Other contractors reported that they had their own less expensive version of a SAM that did not include the threads.

The government specifies six basic classes of hot-mix for use in France:

1. Conventional hot-mix road base--This mix, which is 120 to 180 mm thick, is placed in a single lift. Maximum size aggregate is 20 mm and all aggregate is crushed. It contains approximately 4.2 percent asphalt, which has either 40/50 penetration or 60/70 penetration.

   A variation of this mix is high modulus road base, which contains 6 percent asphalt with a 10/20 penetration and a polyethylene additive. The French claim a 25-40 percent thickness reduction for the same structural effect with the high modulus mix.

2. Conventional HMAconcrete--This is used in new construction and for overlays. Thickness is 60-80 mm while the maximum size of aggregate is 14 mm for the thicker lift and 10 mm if the lift is 60 mm. Only crushed aggregate is used. It is continuous-graded, with 30-35 percent passing the 2 mm sieve. Asphalt content is 5.7 percent of 40/50 penetration or 60/70 penetration with 5 percent plus or minus voids.

3. Thin asphalt concrete--This mix is used for overlays of approximately 40 mm. It's a gap-graded mix with a maximum aggregate size of 10 mm using 100 percent crushed aggregate. Asphalt content is 5.7 to 6 percent using a 40/50 penetration or 60/70 penetration. The French claim excellent rut resistance and skid resistance with this mix.

4. Very thin asphalt concrete--This mix, which is used for overlays of approximately 25 mm, is similar to the thin asphalt concrete just described. The differences are that the binder is modi-

fied with polyrners, rubber, or fibers and the asphalt cement content can go up to 7 percent, depending on the modifier used. In addition, a heavy tack of polymer modified emulsion is used.

5. Porous asphalt--This mix is similar to the open-graded friction course used in the United States and the PA and drainage asphalt used in other European countries. It's a gap-graded mix with a maximum aggregate size of 14 mm and a 22 percent void content. The thickness is 40 mm or less. In most cases, a modified binder of polymer, rubber, or fibers is used.

6. Paver laid chip seal--The LCPC and a private contractor developed this relatively new product. It's approximately 15 mm thick. The binder layer is a polymer-modified emulsion and the chips are between 6 and 10 mm, pre-coated hot with sand and asphalt. This mix, which is used only on pavements that are not deformed, is intended to improve surface characteristics. A special paver was also developed to lay this material.

France does not use SMA, which has produced excellent results in other European countries. The chief concern is reportedly the difficulty of achieving the desired micro-texture for skid resistance.

The LCPC laboratory at Nantes is the flagship of the public works laboratories network, which includes an additional 17 regional laboratories. In all, the network employs about 2,700 people. The LCPC alone employs about 580 people, of which 200 are engineers. The lab includes a full-scale accelerated testing facility that is similar in concept to the FHWA's ALF (Accelerated Loading Facility). The loading wheels of LCPC's facility rotate in a circular pattern from a fixed center point at a speed of 70 km/hr, adjusted from 8 to 18 metric tons, with either single- or dual-wheel configuration. Laboratory officials reported that a 20-year load for a typical major highway could be achieves in about 2 months. The facility has three separate tracks that allow for continuous testing while new structural sections are constructed.

Another unique feature of the LCPC complex was the equipment testing area. Part of it is dedicated to testing such equipment as pavers and finishing machines for speed, vibration, accuracy of control, etc. Another part of the facility tests mixers for speed of production and measuring accuracy. A unique feature was an attempt to use electronic screening with an optical readout to check gradation. If such a feature became operational, it would'significantly improve plant operation by permitting accurate and consistent batching.

Some of the equipment used in mix design and verification was of a type not generally seen in the United States. The gyratory compactor, the pneumatic-tire compactor, the rolling wheel rut tester, and the fatigue equipment were particularly impressive. The LCPC developed much of the equipment, which private concerns manufacture and distribute under exclusive licenses.

Laboratories operated by the major contractors are also well equipped, generally with the LCPC-designed equipment. One result is that the contractors are highly confident when testing their mixes because the government will use the same model of equipment and the same tests. Agreements on test procedures to be used to predict performance of proprietary products were worked out after private/public sector discussions over 2 years.

As in the other countries visited, several large contractors dominate the market. Contracts are generally awarded by competitive bid except for motorway construction. As mentioned previously, motorway construction contracts require a 5-year warranty, but on other highways, the warranty is for 1 year.

All bridge decks were sealed with asphalt material for protection and to improve rideability. Several patented processes for this purpose would be worth looking into for use in the United States.

Another similarity with the other countries visited was the fact that hot-mix manufacturing facilities are not geared to high production. Because of the sophisticated surface mixes used, the facilities arc designed more for quality and uniformity. Shared ownership of plants by two or more contractors is reportedly fairly common.

The emphasis in France is on preventive maintenance. The government promotes innovative solutions. In addition, the government requires top quality aggregate and sophisticated surface mixes. Recycling occurs, but the recycled asphalt product is never used in the surface courses.

## CONCLUSIONS

The United States should try the French approach to mix design and the equipment used as tools to verify the designs in the laboratory. French testing simulates the real-world performance of the products. Several of these concepts and some of the equipment are being evaluated by the SHRP. The private sector accepts the results because of the extensive public/private dialogue and the evaluation of testing approaches before adoption.

France is far advanced in the use of polymers and modified binders. These mixes are used judiciously and, seemingly, successfully. An in-depth study of the French experience should be undertaken for possible application in the United States.

The cooperation between industry and government in France fosters innovation. The institutional relationships are different from those in the United States, but some techniques could be borrowed for use in this country to promote closer government-industry cooperation. The result would be a higher quality product.

# UNITED KINGDOM

# UNITED KINGDOM

Items With the Highest Potential for Implementation in the United States:

- Heavy Duty Asphalt Bases
- Pavement Management Equipment
- Contract Administrations Procedures (Lane Rental)
- University Highway Research Program

## ITINERARY

The itinerary in the United Kingdom (U.K.) consisted of a tour of the laboratory at the University of Nottingham; a review of active construction projects, where activities ranged from placing HMA lower base course to surfacing with HRA; a discussion with government and industry officials at the Transportation Road Research Laboratory (TRRL); a tour of the TRRL facilities; and a visit to a completely enclosed production facility.

## SUMMARY

In the U.K., the federal Department of Transport is responsible for approximately 4 percent of total road mileage. This 4 percent, which consists of 1,600 miles of Motorway (equivalent to the Interstate System) and 5,000 miles of trunk highways, carries approximately 30 percent of all traffic. Approximately 90 percent of all roads are surfaced with asphalt.

The study tour participants reviewed work on the Motorway system, including major reconstruction on the M-l motorway and new construction for an extension of the M-40. The extension was the only major construction on new location that was observed during the European trip. In Europe, as in the United States, construction on new location is rare because of environmental concerns and the high cost of right-of-way acquisition.

On the M-l, the existing structure contains 340 mm of asphalt on a limestone subbase. The structure has 200 mm of macadam base, 60 mm of HRA base course, 40 mm of HRA wearing course, and an overlay of 40 mm of HRA, which was put down in the early 1980's. The reconstruction project varied from complete replacement of the full-depth asphalt pavement structure in the outer lane, where truck traffic is heavy, to milling and replacement of the upper base and/or wearing course on the other lanes.

The new structural section consists of approximately 380 mm full-depth asphalt construction over the same limestone subbase--40 mm of HRA wearing course, 215 mm of upper road base, and 125 mm of lower road base. This design is the preferred pavement structure for high-volume motorways in the U.K. It is based on a 40-year design, with planned surface replacement in 20 years.

The unique feature of this section is that the highest strength lift is the lower road base. It is a gap-graded mix with a maximum size aggregate of 40 mm and an asphalt content of 5.7 percent--50 pen asphalt cement was used and 60 percent of the aggregate was larger than 2 mm. The base is designed for stone-on-stone bearing with no specified density requirement. It has high tensile strength and is fatigue-resistant and waterproof.

The upper road base is a dense-graded bituminous macadam. The maximum size aggregate is 40 mm with approximately 3.7 percent of 50 pen asphalt cement.

The surface or wearing course was a HRA gap-graded mix with a maximum aggregate size of 14 mm and 7.9 percent of 50 pen asphalt cement. This course is unique because pre-coated chips are rolled into the surface to enhance skid resistance and improve drainage. The chipping operation is labor intensive, with three laborers following the spreader to make sure chips are evenly distributed. It is similar to the so-called sprinkle mix that was tried briefly in the United States several years ago. United Kingdom officials, who claim the chips do stay imbedded and are not a hazard to windshields, are satisfied with this HRA surface course.

On the M-40 new construction project, the structural section varied slightly in the thickness of the base course layers but followed the same principles.

The HMA manufacturing facilities in the U.K. seemed geared more toward production than those in the other countries visited. On the M-l and M-40 projects, the contractor was laying about 5,000 metric tons per day from three plants.

The plant visited, which was not involved in either project, included 13 aggregate storage bins and 28 cold feed bins. It was unique because it was completely enclosed, having been built in an existing building (50 by 240 meters) to satisfy the concerns of the surrounding community. While the plant looked neat from the outside, the interior was noisy and dusty. It has a capacity of 600 tons per hour and is expected to produce 650,000 tons this year. The owner of the plant hauls aggregate in from his own quarries on trains that he also owns. He has several other plants in the area, all of which are drum mixers, in contrast to what was observed in the other countries visited.

Incidentally, this company regularly ships granite aggregate to Houston, Texas, at a reasonable price of $6 to $8 per ton. The cost can be kept relatively low because the aggregate is used as ballast when ships hauling grain to Europe return to Houston for a new load.

Additives are not used extensively in the U.K. as yet. Only one, natural rubber, is found in the specifications. Officials are researching such other additives as polymers and manganese and are trying to develop a functional specification. Now, when additives are specified, it is by trade name and, as in the United States, U.K. officials do not favor this method. The use of polymers is reportedly increasing, but EAST participants did not learn if polymers were in any of the mixes they observed.

The mixes are basically recipe mixes except that surface mixes are reportedly designed. As was observed in Germany and France, a large number of mixes are in use throughout the country. Only a few basic mix designs are used, but the many specifying agencies (all levels of Government) add their own twists to the recipes. The plant visited by the EAST participants reportedly produced 158 types of mixes last year.

New specifications are being developed to identify a small number of "preferred mixes" for various applications in the hope of reducing the large number of mixes in use today. Generally, current specifications are of the method type. In the revised version, U.K. officials are striving more for end-result or end-product specifications. One factor motivating U.K. officials to revise the specifications is a concern about what will happen when EC 92 comes about and each country has different specifications and testing procedures. They believe that all the countries of Europe should move towards common end-result specifications and common testing procedures.

Warranties, per se, are not required in the UK; however, the contractor must maintain the project for 1 year, after which any needed corrections are made and it is given final acceptance. During that time, 1.5 percent of the contract cost is retained.

Officials in the UK would like to move to the quality assurance/quality control (QA/QC) concept. The contractors seem to favor it but are leery of the third-party concept being advanced by some advisors and consultants. Under this concept, an independent third party would have the final say-so over the quality of the work. The third party might be an engineering society or a consultant (not retained by either party). The contractors' concerns are that this system would create another level of oversight, with resultant added paperwork, and that the specifications and test procedures are not precise enough to impose such a system.

In the U.K., a "lane rental" contract is used on sensitive projects where the project must be re-opened at the earliest possible time. This type of contracting is being used on 25 to 30 projects a year. Three types of lane rental contracts have been used:

1. The contractor's bid includes the cost of the work and the time he needs to complete it. The bid with the shortest completion time becomes the base. The government adds whatever the pre-determined daily incentive is to the other bids proposing longer times. The low bidder is then selected on the basis of cost to do the work plus time to complete it. On the M-l reconstruction project, for example, the incentive/disincentive was 25,000 pounds sterling per day, the highest amount allowed by the Department of Transport. If the contractor completes the work in advance of the total days he specified, that amount is his daily bonus. If he goes beyond the specified time, he is penalized a like amount.

2. The contractor pays a pre-determined daily rate for the site. The quicker he gets in and out, the less his rental payment is.

3. In a true lane rental arrangement, the contractor pays a daily rate for the closed lanes. This, again, is a pre-determined amount. Obviously, the fewer days the lanes are closed, the less he pays.

The first option, which has been adopted as standard, is a variation on the incentive/disincentive clauses used in some States in the United States. The variation--sometimes referred to as A + B type contracting--has been tried in several States as well. The lane rental concept or incentive/disincentive concept is only practical if a large degree of certainty exists on the scope of work. If several structures are involved or if completion depends on completion of an adjoining section by another contractor, the concept is not used. Officials stated that a change order on a lane rental project is essentially a blank check. The other two types of lane rental contracting are no longer used in the U.K.

On a large project, the government uses a request-for-proposal (RFP) process to select a contractor. An advertisement is published inviting solicitations of interest. The responses are short-listed, normally to six contractors but the number can range from as low as four to as high as seven. The selected contractors are invited to submit detailed proposals (bids). The contractor who submits a technically acceptable proposal with the lowest cost will be awarded the contract. Naturally, if the project involves a lane rental contract, the time and cost to do the work will determine which contractor is selected.

As in the other countries visited, several contractors dominate the market. None of the contractors who met with the EAST participants expressed discomfort with the RFP process and all supported the lane rental contract approach.

Some of the contractors' concerns, however, are similar to those heard in the United States. They claim the process involves too much paperwork and too much bureaucracy. Further, problems often occur in getting decisions on a project. To solve this problem, the contractors would like an experienced project engineer on the project, full-time, with decisionmaking authority. According to some contractors, contract lettings and funding involve too many peaks and valleys. Moreover, contractors would like more control over the work, preferably using the QA/QC system, and recommend the U.K. consider adopting the use of warranties, as in the other countries of Europe. Government officials are looking into it, but they are just not ready to go into warranties now. In this area, as in others, concerns exist because of EC 92. The other countries in Europe require some type of warranty and give contractors more control over projects.

The pavement research group at the University of Nottingham has been in existence since 1954 and handles research as well as technology transfer. Officials and staff members see bridging the gap between research and development work and practical technology as one of their main missions. They have received funding from industry (oil companies, contractors, suppliers, and consulting engineers), U.K. government agencies, and United States agencies (the Army, Air Force, SHRP, NAPA, and NCHRP). They are affiliated with a private consultant and contracting firm with offices on-site. The private contractor plays a major role in technology transfer. Current major activities include asphalt mix design, reinforced haul roads, asphalt modification, pavement foundations, and structural evaluation.

The lab has a pavement test facility that is about 5 meters long and can test a pavement that is 1.5 meters deep. The test pavement is loaded by a wheel with a loading capacity of 1 ton. It applies a single-direction load with a realistic distribution of transverse variation in the actual wheel path. Other smaller scale wheel-tracking devices for fatigue tests are also in use. The staff has done some work on correlating field performance with the various laboratory tests but cannot fully validate the results. They are working on this. Validation is, of course, a common problem for virtually any lab in the world. If the pavement research group can overcome the problem, it will be a major step forward.

The TRRL is the flagship facility for road research in the U.K. It is involved in research in all three elements of the highway system (the highway, the vehicle, and the driver). The equipment used for pavement management at TRRL was of particular note. While the equipment itself may not be unique, what was unique was the fact that it is used in the decision-making process. Certain readings on pavement condition act as a "trigger" to initiate improvements.

The machine to measure deflection is, in essence, a mobile Benkelman Beam. The equipment consists of a truck with Benkelman Beams, which are mounted on opposite sides of the vehicle in front of the rear wheels, and equipment inside the vehicle for recording and analyzing data. The measurement cycle includes lowering the beams, rolling the vehicle forward while measuring the deflection, and then lifting the beams. In the U.K., 17 machines of this type are in use and the Motorway system is measured every 3 years.

A standard, trailer-mounted Falling Weight Deflectometer (FWD) is used for more detailed analyses of the pavement. Personnel of TRRL are experimenting with ground radar to determine pavement condition and they think this approach looks promising. Some work of this type is also underway in the United States.

A high-speed road monitor is used for overall condition survey work. It uses lasers as the detection system. The first version, a trailer, is in routine use. The newest version is self-contained and incorporates television survey equipment similar to that used by SHRP. This device can measure rutting, cross-slope, grade, curvature, and microtexture. It is used more on the rural and lower-order systems because it can be operated at high speeds and generally gives sufficient information rapidly to determine if improvement is needed.

A considerable amount of human factors research has been done at a TRRL test track. The diverse subjects covered include the noise impacts on occupants of a house adjacent to a roadway, the acceptability of a driverless bus, and the effect of alcohol and drugs on the driver.

## CONCLUSIONS

The public/private partnership is not as pronounced in the U.K. as in the other countries visited, except in the research area. Particularly noteworthy was the public/private partnership at the University of Nottingham. It appears to be an efficient, effective approach to problem solving and to basic research. More of this type of partnership may be on the horizon in the United States if the concept of University Research Centers takes hold. Some barriers will have to come down and some effort will be required for this concept to be accepted in the United States, but experience in the U.K. suggests it can work.

Practices in the U.K. seem similar to the United States in many ways. These include method specifications, contract administration (except, of course, for the RFP process), pavement designs, the NIH syndrome (Not Invented Here), and industry objections to government oversight, red-tape, and paperwork.

A noticeable difference is that little litigation is involved in government/ contractor disputes. They are usually settled administratively, as they are in the other countries visited. Often, in fact, when EAST participants asked about lawsuits, the government and industry people looked perplexed because they were surprised to learn that in the United States, claims are commonly settled in court, rather than administratively. In general, the adversarial relationship that exists in the United States does not exist Europe, so government and contractors seem able to work things out much better. They are not litigious societies.

Large Scale Pavement testing devices are used in most of the countries visited, as well as in other European countries. Calibrating these machines, one against the other, would admittedly be a major effort, but would seem to be worthwhile. If the machines were calibrated, research in one country would have more credibility in the other countries. This sharing of research would help forge a stronger bond between the countries. It might also represent a substantial savings in that the same problem would not have to be solved over and over again across the country or state borders.

# INNOVATIVE ASPHALT TECHNOLOGY

# INNOVATIVE ASPHALT TECHNOLOGY

## POSSIBLE USES OF EUROPEAN TECHNOLOGY IN THE UNITED STATES

Conventional, continuous-graded mix designs similar to those employed in the United States are used in Europe for construction, maintenance, and rehabilitation. All the countries visited by the EAST, however, make extensive use of special-purpose mixtures, particularly in surface courses, to enhance the performance of high-volume pavements. These mixtures are designed to control rutting and other distress under very heavy volumes of truck traffic. Many of these mixtures rely on modifiers to help achieve the enhanced level of performance needed.

Much of the EAST's time was spent examining these novel, special-purpose mix designs. Members inspected 27 field pavements incorporating the mixtures "on the ground" in Denmark, France, Germany, Sweden, and the United Kingdom. They also examined the operation of hot-mix plants producing these mixtures in Germany, France, Sweden, and the United Kingdom. Further, they rode over almost 1,200 miles of Interstate-type pavements in the company of personnel from road authorities, paving contractors, and material suppliers who provided extensive commentary on the design, construction, maintenance, and performance of pavements incorporating these special-purpose mixtures.

The EAST also visited research and operations laboratories belonging to national road authorities, contractor trade groups, and individual paving contractors and bitumen producers in each country. At these laboratories, the group discussed design features of the special-purpose mixtures, pavement design parameters, and advanced test methods and laboratory equipment for measuring the mechanical properties of asphalt mixtures.

This chapter mainly reports on the special-purpose mixtures. It is based primarily on the observation of pavements, both in-service and under construction, incorporating them. A site visit report (SVR) was prepared for each observed pavement feature. The SVR's are presented in appendix A. In addition, the observations of the EAST members were employed in preparing this chapter, supplemented by substantial and invaluable written and oral technical information provided by the relevant road authorities, paving contractors, and material suppliers.

In assessing the significance of the asphalt technology discussed in the following sections for the United States, the EAST members kept several factors in mind. First, European practice stresses regular maintenance of asphalt pavements to slow or prevent distresses, particularly rutting and fatigue and low-temperature cracking, that result from climate or an increase of traffic. Much of the maintenance and rehabilitation is carried out on pavements with little or no visible distress. These activities, including overlays and more substantial reconstruction, are performed on a schedule or are triggered by the results of periodic deflectometer or other instrumental measurements. This maintenance work is especially useful because all the high-performance pavements observed appear to have been placed on foundations that were in very good condition.

Second, the climatic conditions in the five countries are not as wide-ranging as those found in many regions of the United States. In particular, the high summer temperatures prevalent in much of the United States are uncommon in Denmark, Germany, Sweden, and the United Kingdom. Therefore, care must be taken in translating technology employed in these regions to areas of the United States with markedly different climates.

Third, these special-purpose mixtures often employ select materials. Hard, low-penetration grade bitumens' are routinely used. For the coarse aggregate, specifications often stipulate 100 percent crushed stone or rock, which may be transported hundreds of miles across national borders to obtain the correct petrographic properties. Manufactured sands and limestone fillers are generally required. Such modifiers as crumb rubber and polymers are also frequently used. Employment of these mixtures in the United States will probably require a similar strict attention to materials quality.

Fourth, typical traffic volumes, vehicle mixes, truck weights, and tire pressures are equal to or exceed those found in the United States. The special-purpose mixtures were observed almost exclusively on heavily-trafficked routes comparable to the United States Interstate and primary highways. Moreover, four-lane motorways are still common in Europe in situations where practice in the United States would dictate six- or eight-lane roadways. Thus, traffic demand on each lane of these special-purpose mixtures is comparable to that generally experienced in the United States.

Fifth, and last, European HMA production almost universally employs batch plants. The technology observed has been used rarely, if at all, with drum mixers, which are common in the United States. As a result, transferring the technology to United States practice will require careful consideration of possible changes necessitated by the differences in production methods. Typical European HMA production rates are much lower than those attained in routine United States operations. This circumstance should also be weighed in evaluating the applicability of these technologies to United States practice.

1 In conformity with European practice, the term "bitumen" will be used herein in place of the United States term, "asphalt cement." In this context, the European term "asphalt," as used in PA or SMA, generally denotes an asphalt aggregate mixture or the United States "asphalt concrete."

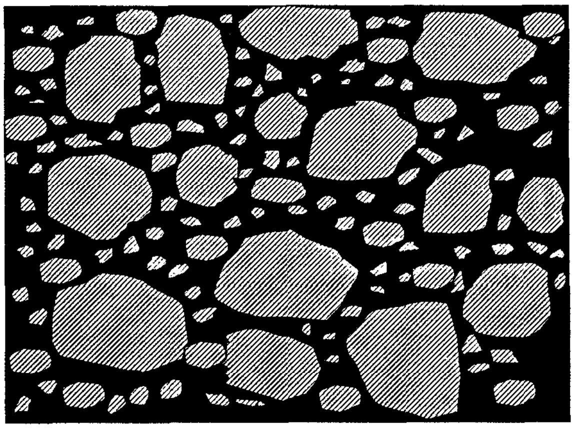
## STONE MASTIC ASPHALT

### General Description

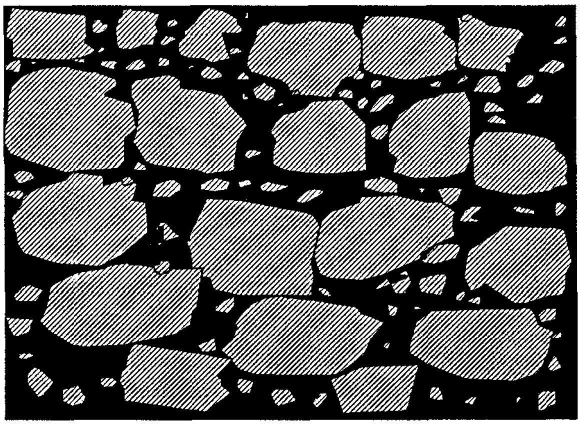
In the opinion of the EAST members, the special-purpose mixture with the greatest promise for use in the United States is SMA. It was developed in the 1960's in Germany as an overlay especially resistant to studded tire damage. The term *splittmastixasphalt* is used in the German ***Supplemental Technical Specifications and Guidelines on Asphalt Surface Courses (Zustzliche Technische Vertragsbedi ngungen und Richtlinien fur den Bau von Fahrbahndecken aus Asphalt,*** abbreviated ZTV bit-StB 84, published by Der Bundesminister FGr Verkehr, 1990 revision). This term is variously translated as "stone-filled mastic" or "grit mastic asphalt." (In the former East Germany, it was aptly termed "skeleton asphalt"). Today, SMA is widely employed in Germany, the Netherlands, and Scandinavia as an overlay or surface course to resist load-induced rutting and studded-tire damage.

Select materials are usually employed in SMA construction. A hard, low-penetration grade of bitumen is used. It is modified by the addition of cellulose fibers, mineral rock wool or, less often, polymers to prevent drainage of the mortar off the coarse aggregate during pavement construction. The coarse aggregate is typically 100 percent crushed rock or stone. The sand fraction contains a large amount of manufactured crushed sand that may be washed if it contains an unacceptable amount of fine particles.

To provide resistance to rutting and studded tire damage, SMA relies on a stone-on-stone skeleton. The point-

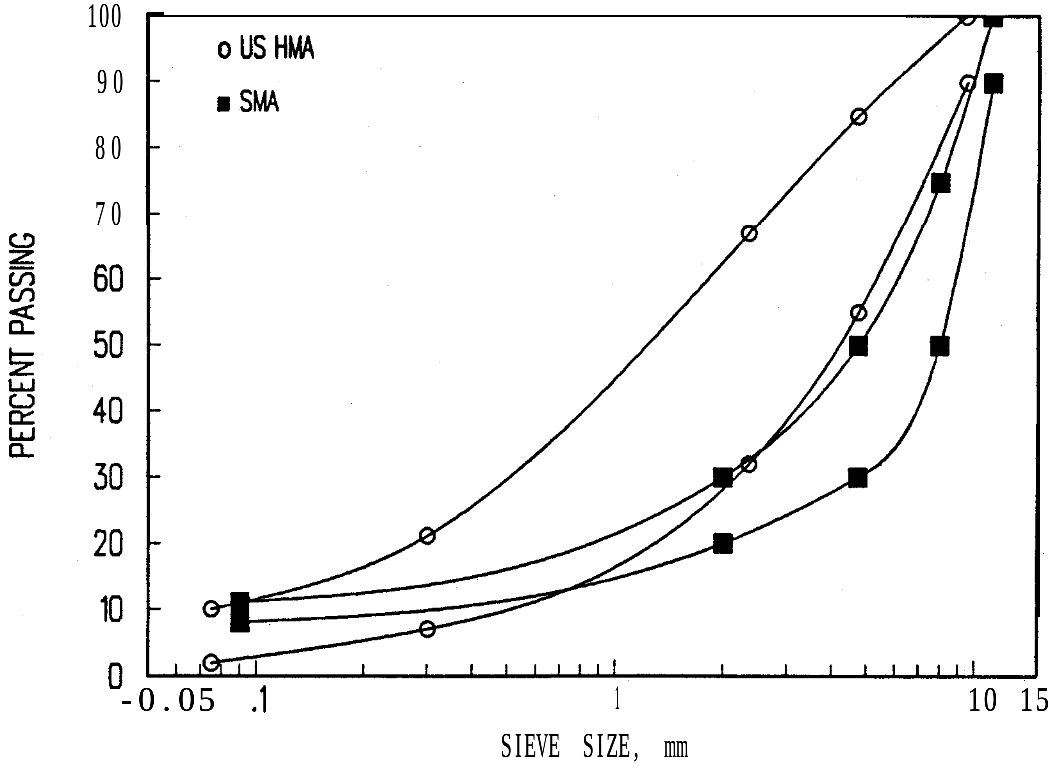


**DENSE GRADED PAVEMENT**



**STONE MASTIC ASPHALT**

**FIGURE 1**




to-point contact achieved in the stone skeleton provides an internal friction throughout the overlay that resists load-induced shear. The stone skeleton is filled and held together with a mastic composed of the bitumen, the sand fraction, and aggregate fines. The mastic is bitumen-rich and voidless so it provides a durable surface that is resistant to cracking. The stone skeleton must accommodate the mastic without disrupting the point-to-point contact of the coarse aggregate particles (those retained on the 2 mm sieve) or the overlay will be susceptible to distress.

To achieve the stone-on-stone skeleton, an aggregate blend rich in coarse material is used in SMA. Details of the SMA mix design vary somewhat from country to country, and from contractor to contractor, as will be seen in the following sections, but typical parameters have emerged. The coarse material (retained on the 2 mm sieve) makes up 70 to 80 percent of the weight of the aggregate; the top size of the coarse aggregate may range from 5 mm to 22 mm., but is typically between 11 and 16 mm. Filler material (defined as passing the 0.09 mm sieve) accounts for another 8 to 13 percent of the weight. The sand fraction, comprising the material sized between 0.09 and 2 mm, makes up only about 12 to 17 percent of the aggregate's weight. Figure 1 presents a typical 11.2 mm top size SMA gradation in comparison with a continuous, 3/8-in top size gradation representative of HMA practice in the United States.

The weight of the bitumen content of SMA is usually within the range of 6.5 to 7.5 percent by weight of the mixture. The filler-to-bitumen ratio of SMA far exceeds the upper limit of 1.2 percent recommended in the United States for conventional, continuously-graded mixtures.

Cellulose or mineral fibers are widely employed to stabilize the binder-rich SMA mixtures and prevent their separation during production and laydown. When cellulose fibers are employed as the modifier, they are added at a rate of about 0.3 weight percent of the mixture[2]. Such modifiers as carbon black and polymers are allowed as stabilizing additives, but the EAST members did not observe examples of their use.

The SMA is usually designed to have an air voids content of 3 percent. This target value provides an air voids content of less than 6 percent in in-situ pavements, as required by European specifications. Field compaction is needed primarily to orient the aggregate exposed in the upper part of the pavement; little additional densification occurs under the rollers. Because the mastic is not substantially compacted during construction, it must be rich in bitumen to obtain the essentially voidless character needed for satisfactory durability.

The stone skeleton must accommodate all the mastic while maintaining point-to-point contact. Therefore, little latitude is permissible in the production control of the aggregate gradation, bitumen content, or fiber content. For example, in Germany an &solute tolerance of 10 percent is allowed in the aggregate gradation (if the 8 to 11 mm fraction were specified at 20 percent, the allowable range would be 18 to 22 percent). For the filler, the tolerance is even stricter, ±5 percent.

Liljedahl (l990) gives an excellent discussion of the critical nature of SMA mixtures. Too much mastic will spread the coarse aggregate apart, leading to a pavement that is susceptible to shear. Too little mastic will create an unacceptably high air voids content, expose the bitumen to accelerated aging and moisture damage, and lead to a poorly-bound, distress-prone pavement.

In addition to its structural capabilities, an SMA pavement surface has a granular texture characterized by large, rough depressions. This surface offers good skid properties over time. The skid resistance of the SMA surface, however, may be lessened during approximately the first month of service until the initial thick binder film on the surface wears off under traffic, exposing the rough edges of the coarse aggregate particles. Bitumen-coated crushed sand (sized between 1 and 3 mm) is sometimes rolled into the hot SMA surface at a rate of 600 to 900 grams per square meter to provide added skid resistance until the surface film of binder is removed.

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2 Existing specifications usually allow the addition of cellulose fibers at concentrations up to 1.5 percent of the weight of the mixture, but concentrations greater than 0.3 percent are rarely used.

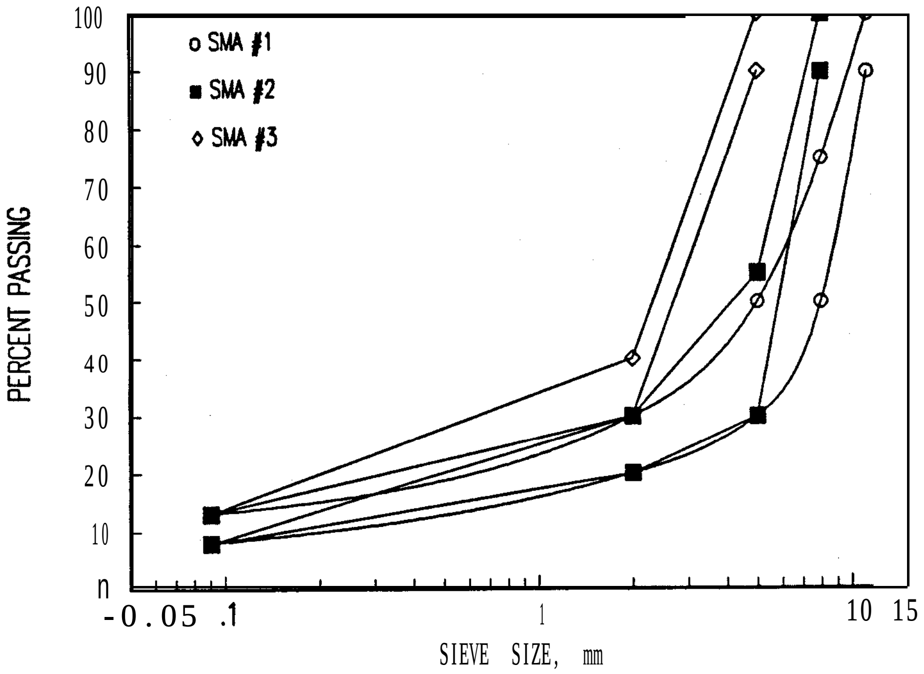
**Stone Mastic Asphalt in Germany**

**Design--The** German specification for SMA is contained on pages 47 and 48 of the publication entitled ***Supplemental Technical Specifications and Guidelines on Asphalt Surface Courses.*** Three SMA compositions are provided, differing in the top size of the aggregates (5,8 or 11 mm) and the grade of bitumen employed (penetration grades B65 or B80). Figure 2 compares the aggregate gradation limits for the three SMA compositions.

a top size of 11 mm. However, SMA mixes used for surface course rehabilitation generally employ a smaller top size (8 mm).

A bitumen content of 6.5 to 7.5 percent by weight of the mixture is specified except for the 5 mm top size aggregate mixture, where 7 to 8 percent is recommended. All mixtures require a stabilizing additive, usually cellulose fiber weighing about 0.3 percent of the mixture.

**FIGURE 2**




The recommended thickness of the SMA overlay varies with the top size of the aggregates. When the top size is 11 mm, the thickness ranges from 25 to 50 mm. A thickness of 15 to 30 mm would be suitable when the top size is 5 mm. The SMA overlay thickness is determined by the class of roadway it is placed on. For the Autobahns and other heavy-duty motorways, the standard appears to be a 40 mm overlay incorporating the SMA design for

Because of lower cost, higher possible mixing temperatures, and increased time available for paving, cellulose fibers are preferred to polymers as a stabilizing additive. Fibers have proven to be a conservative, secure choice for the SMA stabilizing additive because they help reduce the mix segregation that may result from small changes in the bitumen content during production. For example, 0.3 percent cellulose fibers provides an excellent margin of safety; under ideal conditions, as little as 0.1 percent might be adequate.

In theory, mix designs in the usual sense are not carried out in Germany for SMA or any other type of asphalt-aggregate mixture. Instead, the mix designs for the surface and base courses on a particular project are selected from a series of standard designs. These have been developed through experience for different classes of traffic volume. This approach requires careful selection of materials, tight control of the variables in the hot-mix production process and, generally, strict adherence to all requirements of the specification.

In practice, since the SMA specifications do allow some latitude in the details of the aggregate gradation and the bitumen and additive contents, the voids analysis procedure in the Marshall mix design method is sometimes used to narrow the specific job mix formula. For example, Marshall specimens are prepared at 50 blows per side for several bitumen contents mixed with a selected aggregate gradation at 135+5'C. The bitumen content that yields a Marshall air voids content of 3 percent is selected as the target value for the job mix formula.

Alternatively, road authorities in the German state of Lower Saxony recommend beginning with a bitumen content of 6.8 percent and checking to determine if the compacted mixture has an acceptable air voids content. In either case, further mechanical or engineering test requirements, such as Marshall stability, creep compliance, and resilient modulus, do not appear necessary for selection of the final SMA job mix formula.

Construction--Operationally, SMA construction in Germany does not present any unique difficulties compared with construction of conventional asphalt concrete overlays. In fact, some road authorities consider SMA easier to lay and compact than conventional mixes, especially in thin layers, and less sensitive to poor quality construction practices.

The EAST members witnessed a pavement reconstruction project and a maintenance overlay in Germany involving the use of SMA, and also observed SMA production at a hot-mix plant. The reconstruction project was on the A-65 Autobahn near Neustadt an der Weinstrasse (appendix A, SVR g-13-90, #2).

Substantial rutting had developed in the right-hand (driving) lane of the original pavement. No estimate of the average daily traffic (ADT) was given, but all the Autobahns observed carry heavy traffic. The average ADT for the Autobahn system is 39,000, with trucks comprising 20 percent of the total; by law, trucks are limited to the driving lane.

The lane had been milled to a depth of 38 cm; reconstruction was in progress, with conventional asphalt and cement-treated base courses and an asphalt binder course replacing the milled-out material. The EAST team observed asphalt base course construction. Both lanes of the Autobahn will be surfaced with a 40 mm SMA overlay over an impermeable membrane.

The members of the EAST observed production of SMA for the reconstruction project at a batch plant in Bitzfeld (SVR 9-14-90, #4). Operations appeared generally consistent with United States practice except for the addition of the cellulose fiber as a stabilizing additive for the SMA. The cellulose fibers, packaged in 1 kg polyethylene pressure-packs, were added by hand to the hopper carrying aggregate to the pug mill. The aggregate and fibers were dry mixed for 6 to 10 seconds, after which the bitumen was introduced. The normal mixing time was increased by a few seconds to ensure satisfactory blending of the materials. (The polyethylene film used for the fiber packages has a very low melting point and rapidly dissolves in the hot ingredients).

The maintenance project on Route 19 near Schwbisch Hall (SVR 9-14-90, #5) involved placement of a 25 mm SMA overlay on a heater-planed pavement surface. The SMA mix had a nominal aggregate top size of 8 mm. Again, an estimate of the ADT was not given. Route 19 is a rural route; on average, roads of this class in Germany have an ADT of about 3,000.

The existing pavement surface, which showed only random, minor distress, was recycled with a heater-planer unit. The SMA overlay was immediately placed with a conventional paver and compacted by two static, steel-wheeled rollers running in tandem. (Vibratory compaction is not recommended, at least after the first rolling pass, since it has been shown to draw bitumen to the pavement surface; rubber-tired rollers are also not recommended). The SMA occasionally showed some marking under the rollers. The compacted SMA surface appeared rich in bitumen. Stone chips were then rolled on for extra skid resistance.

**Cost and Serviceability--In** Germany, the bid price for an SMA overlay is generally about 120 percent of that for conventional asphalt concrete overlay, termed asphaltbeton in the ZTV bit-StB 84. When a polymer is employed in place of cellulose fiber as the stabilizing additive, the cost increases to 130 percent of conventional asphalt concrete. (Depending on the mix design, the cost of hot mix at the plant is $40 to $70 per ton in Germany; see SVR 9-12-90, #l).

A substantial service life is expected for this increased cost. On normally-trafficked Autobahns and heavily-trafficked federal highways (corresponding respectively to the United States Interstate and primary systems), SMA overlays are the surface course of choice. A normal service life of 10 to 15 years is expected. By contrast, ***asphaltbeton*** surface courses are recommended for normally-trafficked federal highways and lesser-trafficked local and regional road networks. A service life of 8 to 12 years is expected. All other things being equal, SMA is expected to yield up to 25 percent longer service than a conventional overlay.

**In-Service Pavements--A** good example of the use of an SMA surface course is described in SVR 9-12-90, #2. It describes a 6-year old SMA surface course the EAST team observed on the Barmbekerstrasse in Hamburg. This urban street has an ADT of 40,000, including 6 percent truck traffic. The entire pavement structure is 740 mm or about 29 inches thick and is built upon frost-proof sand. The pavement did not show any signs of distress. Hamburg road authority personnel indicated the typical service life for SMA in similar circumstances is 10 years.

The EAST team also rode over an extensive SMA surface on the A-7 Autobahn about 12 km north of Kassel in the state of Hessen. This pavement was about 2 years old; no distress of any significance was visible at Autobahn speeds of 55 to 60 miles per hour. The ride was smooth.

**Stone Mastic Asphalt in Sweden**

**Design--The** Swedish National Road Administration's (SNRA) term for SMA is ***HABS***; the Swedish term for conventional, continuously-graded asphalt concrete is ***HABT.*** The Swedish national specifications for SMA are contained in SNRA (Vgverket) publication **1988:42, Hard Asphalt Concrete (Stone-Filled) Wearing Courses** (Slitlager av **HABS),** December 1988.

In Sweden, SMA was introduced in the late 1960's to reduce pavement damage caused by studded tire use. Asbestos fibers were employed as the stabilizing additive (as also was the case in Germany at that time). Shortly, however, asbestos was prohibited because of health, safety, and environmental concerns. A corresponding hiatus in the use of SMA occurred until cellulose fibers were introduced in the early 1980's.

The principal function of HABS overlays in Sweden continues to be the reduction of studded tire damage. Swedish SMA design differs from the German design in several ways. First, nominal aggregate top sizes in Sweden are larger. Swedish gradations for SMA are based on top sizes of 12 mm (HABS 12) and 16 mm (HABS 16) compared with the German top sizes of 5,8 and 11 mm. (Swedish authorities are considering SMA designs based on a 22 mm top size). The gradation limits for the HABS 12 and 16 are shown in figures 3 and 4. Laboratory studies by the SNRA

**FIGURE 3**

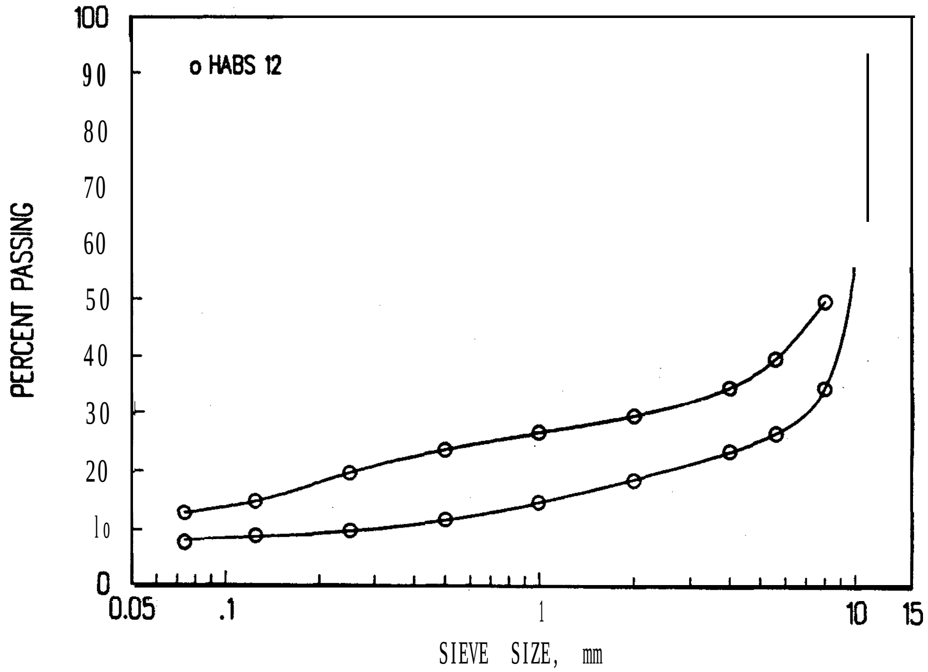
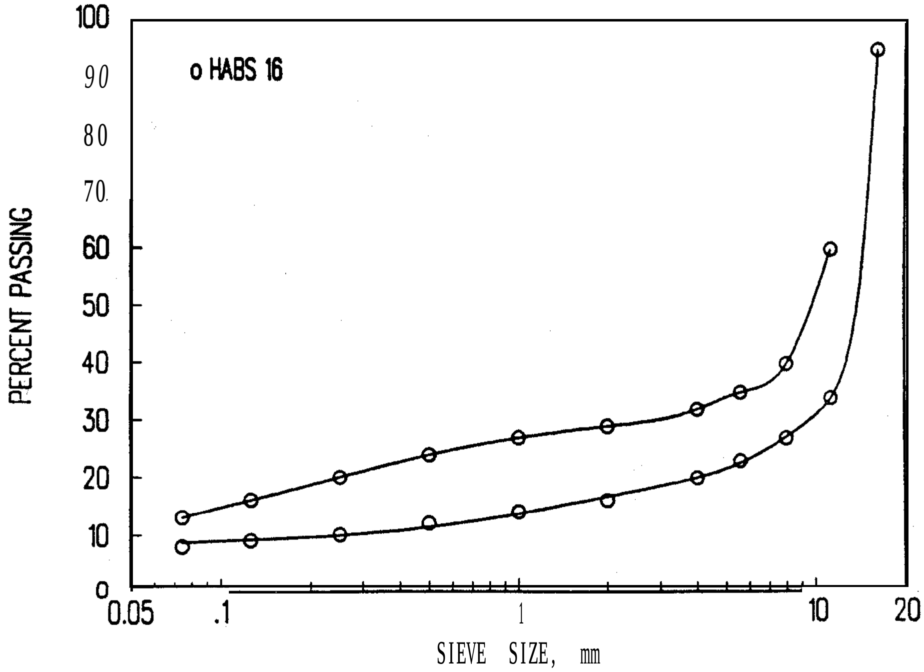


FIGURE 4




indicate that HABS 16 will yield as much as a 40-percent reduction in studded tire wear compared with HABS 12.

Second, the variety of stabilizing additives employed in Sweden is greater. Cellulose fibers are employed in loose form and in preformed pellets composed of equal parts by weight of fibers and bitumen. The latter form is easier to handle in hot-mix production operations and less dusty than the loose fibers. It would be essential for SMA production in drum mixers. In addition, mineral fibers are widely used, while fiberglass and plastic fibers are less common. The SMA specification also permits the use of powdered rubber and polymers.[3]

Third, and last, SMA is marketed by at least two major Swedish paving contractors under proprietary trade names: *Stabinor* available from Skanska Entreprenad AB and *Viacotop* from NCC Bygg AB (Nordic Construction Company). Both products conform to the SNRA specification, but differ in several ways that will be discussed in the following sections.

3 Field experiments are underway on the E-3 motorway in Goteborg to compare the performance of an SMA overlay containing Styrene-Butadiene-Styrene (SBS)-modified bitumen with an overlay using a conventional B85 bitumen. Apparently, cellulose fibers are used with both binders. After two winters, the two overlays exhibited little apparent difference. The monitoring will continue for several more years.

In Sweden, recommended SMA overlay thicknesses range from 34 to 43 mm for HABS 12, and 38 to 47 mm for HABS 16. The SMA overlays are advised for all Swedish roads with an ADT over 15,000 or where studded tire damage is the main cause of distress. In practice, this usually means all roads with an ADT of 4,000 or more, and particularly those in the southern part of the country where the traffic density is highest.

The Swedish specification advises a target bitumen content of 6.3 percent for HABS 16 and 6.6 percent for HABS 12; in both cases, a bitumen of grade B 85 (85 penetration grade is recommended). The use of a stabilizing additive is not required, but the contractor is given wide latitude to employ additives if they are judged to be warranted. The specification notes that when additives are used, the bitumen content may require adjustment above the suggested levels.

In addition to gradation requirements, the coarse aggregate must satisfy specific test limits for abrasion resistance, flakiness index, impact crush strength, and proportion of crushed material.

The voids analysis procedure of the Marshall mix design method is employed to develop the job mix formula for SMA mixes. In practice, an initial target value for the bitumen content is obtained by measuring the void space in the coarse aggregate (retained on the 2 mm sieve). With this quantity, the allowable volumes of the mastic and the air voids in the compacted mix can be calculated for a range of bitumen contents. Then, the bitumen content and the aggregate gradation are adjusted within the specified limits to achieve a job mix formula with a Marshall air voids content of 3 percent. The specification does not provide any requirements for Marshall properties other than the air voids content.

Many Swedish contractor personnel stressed the importance of the 2 mm sieve size in judging the acceptability of the SMA design and in the field control of the hot-mix production. While the specification permits the amount of aggregate passing 2 mm to vary between 16 and 29 percent for HABS 16 mixes or 19 and 30 percent for HABS 12 mixes (similar to the German specification), the contractor personnel strongly advocated a more stringent requirement of no more than 20 to 23 percent passing the 2 mm sieve.

Liljedahl (1990) demonstrates that allowing more than 23 percent of the aggregate to pass the 2 mm sieve (or, conversely, employing an aggregate gradation with less than 77 percent coarse aggregate) increases the mastic volume to a point where the necessary stone-on-stone contact of the coarse aggregate and, consequently, the rutting resistance of the SMA are lost. Additionally, he shows that the absolute necessity for stone-on-stone contact in the SMA mix also requires that the largest stones make up the bulk of the coarse aggregate. For example, for an HABS 16 mix, at least 70 percent of the aggregate should be in the 10 to 16 mm sizes.

**Construction--The EAST** team witnessed the construction of two SMA overlays in Sweden. They also visited a hot-mix plant near Goteborg that routinely produces SMA mix.

Both SMA overlay projects were on European Route E-6, a divided four-lane, limited-access motorway that runs north-south along the west coast of Sweden. The two projects were approximately 55 miles apart on the portion of the E-6 between Goteborg and Halmstad to the south. The ADT is about 13,000, with truck traffic comprising about 25 percent of the total; in the winter months 65 to 75 percent of the vehicles use studded tires. Compacted overlay thickness was specified at 38 mm for a general HABS 16 mix design.

The northerly project (SVR g-10-90, #5), near Varberg, was under construction by Skanska Entreprenad AB using its ***Stabinor SMA*** mixture. ***Inorphil*** mineral fibers were employed as the stabilizing additive, introduced at a rate of 8 percent by weight of the binder (0.5 percent by weight of the mixture). An 85-penetration grade bitumen (B85) was employed. Twenty percent of the stone (coarse aggregate) was described as "qualified'; that is, it meets the minimum requirements established in Slitlager av HABS for SMA coarse aggregate.[4]

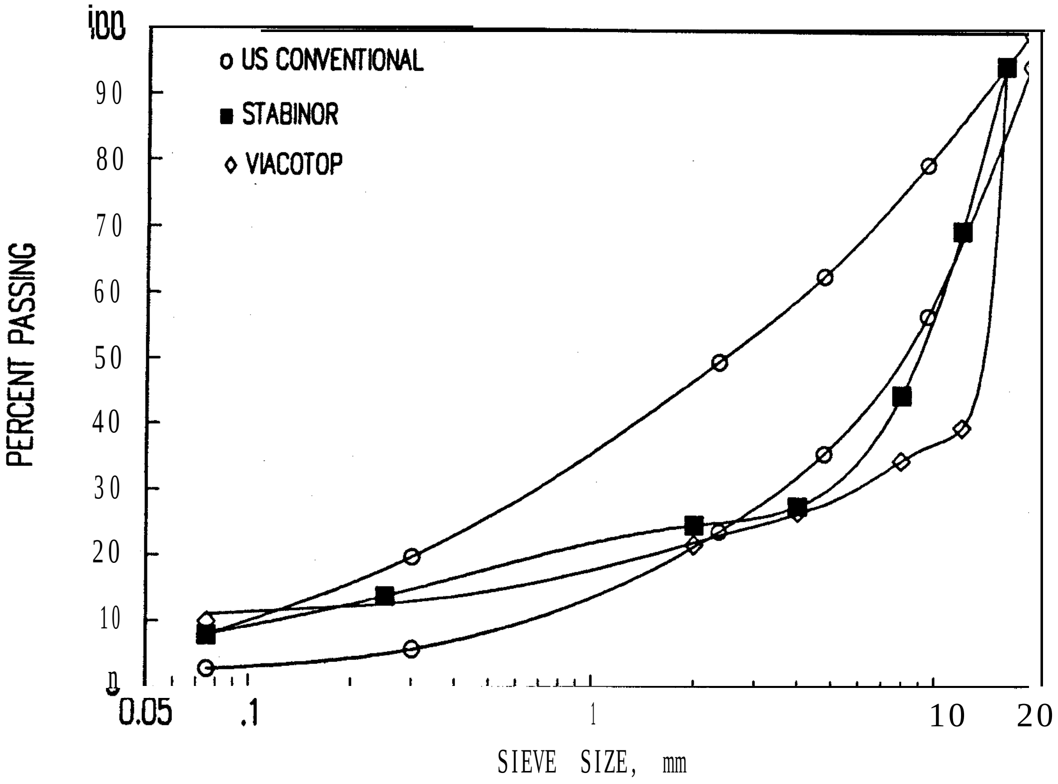
The Stabinor gradation used in this project is shown in figure 5, where it is compared with that of Viacotop as well as the recommended gradation limits for a conventional United States dense-graded asphalt concrete with a 16 mm (approximately 5/8-inch) top size. The gradation falls outside the limits presented in ***Slitlager av HABS*** for HABS 16 at the 8 mm sieve size and above. Based on Liljedahl's analysis (1990), this might be considered a "critical" mix since the void space in the coarse aggregate could be insufficient to accommodate the mastic and achieve stone-on-stone contact.

The original pavement at this location did not show substantial distress; however, photographs taken at the time of the visit show some studded tire wear in the wheel paths. The SMA was placed over a thin (12 to 16 mm) leveling course with a conventional Dynapac paver at a temperature of 160°C. Two steel-wheeled rollers followed close behind the paver; vibration was not used. The contractor personnel indicated that rolling is mainly intended to orient the stone skeleton in the overlay rather than to compact the mat substantially. Rolling is permitted until the mat temperature falls to 75'C; the second roller in the train was equipped with an infrared pyrometer for this purpose.

The southerly project (SVR g-10-90, #7) was near Bastad. As with the northerly pavement near Varberg, the existing pavement surface on the southerly project did not exhibit exceptional distress. The project was under construction by NCC Bygg AB using its trade named *Viacotop*

4 This implies that the quality requirement was waived by the road authority for the remainder of the stone. In Sweden, "qualified" stone intended for use in HABS overlays is generally quartzite or porphyry that must often be obtained from remote sources. For this project, the cost of the qualified stone is estimated at 46 Swedish kronor per square meter or about $0.75/square foot of roadway.

## FIGURE 5




SMA mixture. Cellulose-bitumen pellets were used as the stabilizing additive. They were added at a rate of 0.6 percent by weight of the mix, yielding a cellulose fiber content of 0.3 percent. The bitumen (grade B85) content of the Viacotop HABS 16 was 6.7 percent by weight of the mix. This was considerably higher than that used in Skanska Entreprenad AB's Varberg project, even considering that 0.3 percent is contributed by the cellulose pellets.

The aggregate gradation (figure 5) in this Viacotop mix conforms more closely than the Stabinor mix with the gradation limits presented in ***Slitlager av HABS*** for a typical HABS 16 mix. In particular, 60 perent of the aggregate is retained on the 12 mm sieve, compared with only 30 percent for the Stabinor mix. The amount passing the 2 mm sieve, the dividing line between the coarse aggregate and the sand and filler fraction, is only 22 percent, compared with 25 percent for the Stabinor (as noted earlier, many Swedish authorities prefer the lower figure at this sieve size). These differences in gradation allow the Viacotop mix to accommodate the increased bitumen content; in theory, this leads to lower compactive effort and increased durability of the SMA.

The SMA was laid with a conventional paver and rolling was accomplished by two 10-ton rollers. Roller marks were much less pronounced than for the Stabinor mix. The compacted pavement surface appeared rich in binder, almost to the point of flushing, but the road authority and contractor personnel reported that Viacotop has good friction properties when newly laid. Unlike the German practice, no stone chips or sand were rolled on either project to provide extra initial friction.

The batch plant in suburban Goteborg produces SMA as well as conventional HMA and porous asphalt mixes (SVR g-10-90, #4). No production was underway at the time of the visit. Unlike the German hot-mix plant described in the previous section, this plant has a mechanical system for dispersing both cellulose and mineral fibers into the pug mill.

This plant (of several in Sweden) is also capable of handling the cellulose pellets mechanically. The pellets are delivered in 700 kg sacks (1,543 pound). These are hoisted into a storage silo where an internal knife cuts them open, depositing the pellets in the silo. The pellets fall by gravity through a pipe to the same scale used to weigh filler. The weighed pellets are conveyed by a screw drive into the pug mill.

**Cost and Serviceability--In** Sweden, SMA hot mix (HABS) costs about 10 percent more than continuously-graded, dense hot mix (HABT in SNRA terminology) employed for overlays. The precise differential depends on the material used as the stabilizing additive.

A 20-percent increase in service life (measured in ADT of vehicles with studded tires) is a realistic expectation for SMA compared with dense-graded HMA overlays. The favorable Swedish experience has led to the use of SMA for most overlays on motorways, primary routes, industrial streets, congested urban intersections and bridges with an ADT greater than about 5,000. NCC Bygg AB alone placed almost 300,000 tons in 1990 or about 32 million square feet of overlay.

Personnel of the Goteborg city road authority indicated to the EAST team that SMA has become the overlay of choice in recent years for most of their road surfaces because of its enhanced resistance to rutting caused by increased traffic volumes and the action of studded tires. In Goteborg, traffic volumes increased dramatically year-by-year in the 1980's and typically 70 percent of the vehicles in the city use studded tires during the winter. Yet in the Tingstad tunnel, which EAST visited to see an in-service installation, city road authority personnel indicated that SMA overlays have experienced only 17 mm of rutting after 30 million vehicle passes compared with 25 to 30 mm for the previous HABT surface after 25 million vehicle passes.

**In-Service Pavements--The** EAST team observed a variety of in-service SMA pavements around Goteborg and on the E-6 motorway between Goteborg and Helsingborg.

In the eastbound lanes of the Tingstad tunnel in Goteborg (SVR g-10-90, #l), a ***Stabinor (HABS 12) SMA*** overlay constructed in 1985 was viewed at normal traffic speeds. The ADT is 100,000 over the six lanes of the tunnel. In addition to a mean rut depth of 17 mm, the pavement exhibited some rutting due to studded tires, but not uniformly through the length of the tunnel. Other types of distress were not visible. A 20-percent increase in service life is projected for the SMA overlay compared with the conventional HABT used previously.

A S-year old *Viacotop* (HABS 12) SMA overlay was observed on a four-lane urban street in the Stlhandskegatan district of Goteborg (SVR g-10-90, #2). Measured rut depth was 10 mm with a 30,000 ADT over four lanes. Little or no distress of any kind was noted at normal traffic speeds. This overlay had been constructed by the forces of the Goteborg Street and Highway Department.

A l-year old SMA pavement on the E-6 south of Varberg was inspected by the EAST team on foot (SVR g-10-90, #6). This overlay used an 18 mm top size aggregate; only local, unqualified stone was used. The pavement surface was wet from an earlier rain shower, and showed an irregular drying pattern that emphasized what appeared at first to be ravelling in areas away from the wheel paths. The United States contractors in the EAST, however, agreed that the condition more likely arose from mix segregation during construction than loss of aggregate during service. The wheel paths appeared normal, perhaps reflecting movement of the mastic to the surface under traffic. No other distress was noted.

On the E-6 motorway south of Goteborg, the SMA surface (HABS 16, built in 1988) had a smooth, almost flushed appearance. Aggregate was less apparent on the surface than on the section described previously. No distress of any consequence was noted on the pavement surface.

Further south on the E-6, an SMA overlay (HABS 12) constructed in 1987 was examined. No rutting or cracking was noted, but some aggregate pop-outs were apparent in the driving lane. The SNRA personnel with the EAST indicated that a 10- to 12-year service life was forecast, based on the little distress measured to date.

## Stone Mastic Asphalt in Denmark

The use of SMA is not as widespread in Denmark as it is in Germany and Sweden. The Danish Road Directorate indicated that a gap-graded asphalt concrete mix design, similar to the hot-rolled asphalt described in a later section on the United Kingdom, is used extensively to prepare rut-resistant surfaces on roadways subjected to heavy truck traffic.

However, the EAST team did see some interesting examples of in-service SMA pavements in Denmark. The most noteworthy is the modified SMA overlay inspected on the Helsingor (E-4) Motorway (40,000 ADT, 5 percent trucks) that runs north from Copenhagen (SVR g-11-90, #2). The SMA was the 40 mm wearing course of a 100 to 200 mm asphalt concrete overlay placed between 1988 and 1990 on the original 30-year old, distressed PCC pavement. The PCC had been either cracked and seated or completely removed, depending on its state of deterioration.

The contractor, Superfos Dammann-Luxol a/s, selected an SMA wearing course because of its good durability and resistance to deformation. A bitumen modified with both an SBS-type polymer and cellulose fibers was chosen as the binder to obtain a highly flexible, crack resistant pavement surface. The modified bitumen content was 6.9 percent by weight of the mix; SBS polymer comprised 6 percent of the binder. Cellulose fibers, which comprised 0.25 percent of the mix, cost $0.65 per pound or about $3.25 per ton of hot mix. The aggregate gradation generally falls within the SNRA's limits for HABS 12 mixes.

The driving lane presented a slightly flushed appearance in the wheel paths, but as noted for the E-6 motorway in Sweden (SVR 9-10-90, #6), perhaps this appearance signaled movement of the mastic to the surface under the action of traffic. By contrast, the passing lane had an even appearance. The only distress noted was slight rutting in the wheel paths of the driving lane.

The EAST members also examined an SMA surface course on the E-4 motorway on the way south from Copenhagen to Rodby, just north of the Route 37 interchange. This surface course was 2 years old and had flushed in the wheel paths of the driving lane. The Danish road authority personnel indicated that the flushing had reduced the skid resistance appreciably. It is suspected that the binder content of the SMA mix was too high.

## POROUS ASPHALT

### General Description

In general, PA may be considered the European equivalent of the open-graded asphalt friction courses (OGAFC) or open friction courses (OFC) used in the United States. Both are intended to provide a wearing course that rapidly drains rainwater from the pavement surface and reduces hydroplaning. For comparison, the original United States design method for OGAFC is given in Smith et al. (1974).

In Europe, PA is also used to reduce traffic noise where high-capacity roadways are in populated areas. In contrast with the United States, many European mix designs for wearing courses have a harsh macrotexture that generates substantial tire noise. Porous asphalt provides a way of absorbing and dissipating this noise within the pavement surface and is favored for use even where hydroplaning is not a significant concern. In addition, the French road authorities note that the open texture of the PA helps reduce reflected glare from headlights.

The EAST members observed PA wearing courses in France, Germany, and Sweden. France and Sweden have standard specifications for PA mixes (discussed later) and use PA routinely. In Germany, PA appears to be treated as an experimental feature, intended mainly as a noise reducer, but is in increasingly greater demand as public concern about traffic noise grows. (In the United Kingdom, ***porous macadam surfacing*** has been examined, but has not yet been adopted by specifying agencies; consistently demonstrating a favorable cost-to-benefit ratio for its use has not been possible).

The main characteristic of PA mixes is their high air void contents, in the range of 20 percent or more, which provide the "open" nature necessary for water drainage and noise muffling. These air void content values are obtained by using gap-graded aggregates or by reducing the proportion of fine aggregate and filler in the total continuous aggregate gradation to less than 20 percent of the weight; and, in either case, by employing binder contents in the range of 5 percent of the total mixture's weight.

Modified bitumens appear to be used exclusively in PA mixes. The EAST team saw examples of binders modified with cellulose and mineral fibers, polymers such as SBS latex, and even reclaimed tire rubber. As with SMA, the PA binder is modified to prevent its drainage during mix production and transport, but the modification is also intended to increase the durability of the mix when it is exposed ***in situ*** to air and water.

To be effective, PA surface courses must be linked with pavement drain systems. Germany and Sweden have construction requirements on the smoothness of the base or binder course under the PA surface as well as minimum transverse crossfall in the pavement to promote drainage through the PA surface to the drains.

All PA pavements experience a gradual decrease in drainage and noise reduction as they become filled over time with air- and water-borne debris, anti-icing abrasive, etc. This is particularly a problem in urban areas where low traffic speeds are not effective in flushing debris forcibly through the PA layer. None of the road authorities appears to have an effective maintenance procedure to reverse this trend so the useful service life of the PA is limited by how fast the air voids fill with debris. Another facet of this problem is that the open structure of PA pavements requires increased amounts of deicing chemicals and abrasive for effective snow and ice control, and the pavements are more difficult to keep free of frost and ice.

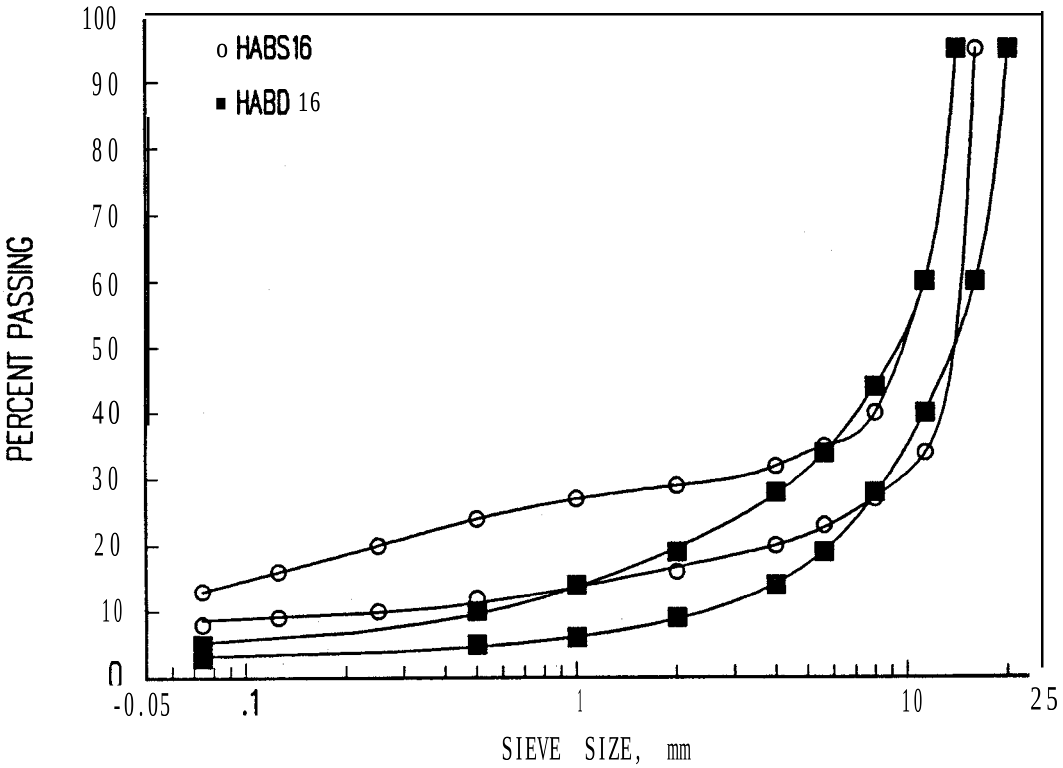
In the United States, the use of OGAFC has been hampered by unfavorable experience with the stripping and deterioration of underlying pavement courses. To address this problem, European practice requires placement of an impermeable membrane or seal layer directly under PA surface courses to prevent the intrusion of water into the underlying pavement structure.

## Porous Asphalt in Sweden

**Design, Cost and Serviceability--The** SNRA's term for PA is HABD, which is roughly translated ***as drainage asphalt concrete.*** The Swedish national specifications for PA are contained in SNRA (Vagverket) publication BYA ***84, Technical Specifications for Construction and General Advice (Byggnadstekniska foreskrifter och allmannna rad)*** , 1984 edition, pages 30 through 35. The specifications for HABD 12 and HABD 16 mixes are based on top aggregate sizes of 12 and 16 mm, respectively.

Figure 6 (found on the following page) compares the aggregate limits established for HABD 16 with those for the SMA mix HABS 16. The two gradations overlap substantially above the 4 mm aggregate size, but the proportion of fine aggregate

## FIGURE 6




and filler in the HABD 16 mix is substantially lower than that in the HABS 16 mix. Since the coarse aggregate (retained on the 2 mm sieve) gradation is similar for the two, the PA mix is expected to have the same stone-on-stone skeleton and resultant performance characteristics as the SMA.

A target bitumen content of 5.2 percent by weight of the mix is specified for both HABD 12 and 16, compared with 6.6 percent for Swedish SMA mixes. The SNRA notes, however, that even 5.2 percent is a high binder content in relation to the aggregate grading curve. Thus, HABD mixes have adequate resistance to changes in the binder caused by exposure to air, water, deicing chemicals, etc., but their overall durability is not expected to be as good as that of SMA. Bitumen grade and aggregate quality requirements for HABD mixes are similar to those discussed above for HABS mixes.

The use of modifiers is not specifically required by BYA 84 to prevent drainage of the binder from the PA mix during mix production and transport. However, if stabilizing additives are not used, the PA mix must be maintained at 120 to 135°C during construction to deter binder drainage. The specification does require the use of amine-type anti-strip agents to alleviate the damaging effects of moisture in the open structure of the PA

The thickness of the PA surface layer also is not specified. The PA course must be placed on an impermeable bituminous tack coat or membrane to prevent moisture damage to the underlying pavement.

The SNRA indicated that the cost of PA is similar to that of SMA, but that the durability of the PA is no better than that of conventional HMA. Indeed, in many cases, PA is much less resistant to studded tire damage than conventional HMA. Thus, the use of PA must be justified on a case-by-case basis where the benefits of noise reduction and water drainage outweigh the increased cost.

Measurements on PA pavements in Goteborg in the early 1980's indicated that the initial 4.8 dB(A) noise reduction fell to 0 dB(A) within 2 years of service. Similarly, the water drainage capacity of the pavements was found to decrease by 50 percent within 3 years. These decreases in serviceability were blamed on silting of the void spaces with debris and studded tire damage. The Goteborg road authority considers these levels of performance sufficient to justify PA use in certain instances.

Obviously, PA surfaces cannot be rehabilitated simply by overlaying. The old PA layer must be milled off, and the pavement must be recycled or sealed with bitumen. The SNRA does not allow, under any circumstances, the encapsulation of an old HABD layer between other types of bituminous courses.

**In-Service Pavements--The** EAST members observed in-service PA pavements in the Goteborg area and on the E-6 motorway between Goteborg and Helsingborg.

On the westbound lanes of Brackevagen (Route 159) in Goteborg (SVR g-10-90, **#3)**, a 43 ***mm-thick*** *Drainor* (HABD 16) PA overlay constructed in 1986 was viewed at normal traffic speeds. *Drainor* is the trade name for PA produced by the Skanska Entreprenad AB.

This PA mix contained 5.0 percent binder by weight of the mix; the binder was modified with *Inorphil* mineral fibers at a rate of 0.8 percent by weight of the binder to prevent binder drainage during construction.[5] Of the coarse aggregate, 55 percent was quartzite, a very hard mineral aggregate that does not crush during compaction and resists studded tire wear. The air voids content of the compacted mix at the time of construction was greater than 15 percent.

Personnel of the city road authority indicated that the measured mean rut depth was between 6 and 7 mm; ADT is 25,000 over the four lanes of the highway. The pavement was viewed at speed from the bus; little or no significant distress was visible. The pavement surface, however, appeared rough, with aggregate showing.

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5 Limited field experiments in Goteborg with PA mixes containing a binder modified with both mineral fibers and 6 percent styrene-butadiene thermoplastic suggest that polymer modification increases the durability of the binder against wear and weathering.

In Goteborg, only HABD 16 mixes are used; the HABD 12 mixes were found to have poor resistance to studded tire damage, lasting only about half as long as conventional HMA surface courses. The city road authority selects the use of new PA surface courses primarily to reduce traffic noise; in the city, water drainage is of secondary importance.

The EAST study team also drove over a PA surface course at the entrance to the Tingstad tunnel in Goteborg (see SVR 9-10-90). This surface course was placed in 1984 and has distinct ruts caused by studded tire wear. The city road authority personnel indicated that the rut depth was about 25 mm.

In addition, several sections of PA surfacing on the E-6 motorway between Goteborg and Helsingborg were examined. One section of unknown age was contiguous to an SMA surface course. After a moderate rainfall, much less water was visible on the PA than on the SMA surface. Another PA section (15,000 ADT) had been built in 1982 and recycled in 1988. The recycled mix had a compacted air voids content of 12 percent, compared with 15 percent in the original mix. No substantial degree of distress was noted.

**Porous Asphalt in Germany**

Germany does not yet have standard specifications for PA (termed ***Larmmindemde Asphalt)*** in Germany. The German road authorities consider it an experimental feature, but are under increasingly strong public pressure to use it to reduce traffic noise. As in Sweden, PA is employed to reduce traffic noise and to prevent hydroplaning by draining rainwater. Experimental pavements have already yielded 6 to 7 years of satisfactory performance.

Larmmindernde Asphalt mix designs are available with both 8 and 11 mm nominal aggregate top sizes. Mixes are designed to have an air voids content in excess of 20 percent. In practice, compacted Larmmindernde Asphalt pavements have air voids contents ranging from 15 to 25 percent. This percentage is achieved by using a very high proportion of coarse aggregate (retained on the 2 mm sieve), a low sand and mineral filler content, and a binder content of about 5 percent by weight of the mix.

The existing pavement is milled out, one lane at a time, to a depth of 70 mm. A new 70 mm-thick asphalt binder course is placed, followed by an impermeable seal coat. The seal coat is prepared by applying a polymer-modified cationic bitumen emulsion at a rate of 2 $kg/m^2$ and dressing it with chippings applied at 8 to 10 $kg/m^2$.

A 40 mm-thick Larmmindernde Asphalt surface layer is then applied. This employs an 11 mm top size coarse aggregate; 85 percent of the aggregate is retained on the 2 mm sieve. The mineral filler passing the 0.09 mm sieve represents a nominal 5 percent of the total aggregate. The binder is a polymer-modified cationic B65 bitumen emulsion containing 0.5 percent (by weight of the mix) cellulose fibers.

German practice uses polymer-modified bitumens exclusively in Larmmindernde Asphalt; this is done to increase binder-aggregate adhesion in the presence of copious amounts of air and water. Cellulose fibers are also added to the rnix to reduce binder drainage during construction. Larmmindernde Asphalt surface courses are always placed over some kind of impervious membrane or seal layer to protect the underlying pavement from water.

In Germany, the in-place cost of Larmmindernde Asphalt is about 100 percent more than a comparable HMA surface course. Given the cost, it is primarily used to reduce noise on highways with high velocity traffic, usually in or near residential areas. As in Sweden, filling of the void structure in the Larmmindernde Asphalt with debris gradually reduces its effectiveness, and two to three times the amount of deicing chemicals is needed for snow and ice control.

The EAST team saw several examples of this type of mix on the Autobahn system (SVR g-14-90, #'s 1,2, and 3). On the A-S 1 Autobahn near Freiberg in Breisgau, reconstruction was underway, including placement of a PA surface course on the entire pavement, shoulders, and all bridge decks. This is a very high capacity, four-lane freeway that had experienced substantial rutting; the current ADT is 90,000, with trucks totalling 33 percent of the traffic. It is noteworthy that Larmmindernde Asphalt is considered a viable remedy for pavements where load-induced rutting has been a problem.

On another project, only binder course construction was underway on the day of the visit (SVR g-14-90, #2) and the EAST members also observed a pavement section completed earlier in 1990 (SVR g-14-90, #3). The pavement section that had been completed in 1990 showed no apparent distress. The ride on the Larmmindernde Asphalt pavement was quiet, indicating its effectiveness, at least when new, at absorbing tire noise.

Several sections of Larmmindernde Asphalt surface course were also viewed by the EAST members on the A-6 Autobahn east of Heilbronn (SVR g-14-90, #l). The dates of construction are not known, but the team did not observe any visible distress and the ride was quiet. The Larmmindernde Asphalt mix designs used here were virtually the same as that employed in the A-81 construction discussed earlier; however, both 8 and 11 mm top size aggregate gradations were employed.

## Porous Asphalt in France

**Design, Application, and Cost--For** pavement surface maintenance, PA is one of several alternative strategies specified by the French Transport Ministry *(Ministere de L'Equipement et du Logement des Transports et de la Mer)* and its component agencies, particularly the Directorate of Roads *(Direction des Routes),* the Central Laboratory of Bridges and Roads *(Laboratoire Central des Ponts et Chaussees or LCPC),* and the Roads and Highways Engineering Department (Service D'Etudes Techniques des Routes et Autoroutes or *SETRA).*

Porous asphalt is classified with the various maintenance techniques that provide no structural effect; this classification places it in the same category as very thin asphalt concrete (to be discussed in the next chapter) and conventional chip seals.

It is employed to rehabilitate pavement surfaces while providing significant noise reduction and reduced hydroplaning.

On the French toll motorway system, PA comprises about 16 percent (22.4 million $ft^2$) of the surface courses. It is also used extensively on the national road system, comparable to the United States primary 'system. The toll motorways have ADT's between 7,000 and 50,000, with 15 to 20 percent trucks and maximum single axle loads of 13 metric tons.

General French requirements for PA mixes differ from Swedish and German requirements in two important ways: 1) a gap-graded aggregate blend is employed with little or no aggregate sized between 2 and 6 mm; and 2) the mineral filler content (passing the 0.09 mm sieve) is very small, usually 1 to 1.5 percent of the total aggregate.

Nominal aggregate top sizes of 10 and 14 mm are used; the coarse fraction (2 mm) typically makes up 85 percent of the total aggregate. Air voids contents are designed at about 22 percent. Binder compositions over a wide range are allowed, including pure bitumen, polymer-modified bitumen, rubber bitumen, and fiber-modified bitumen.

Major French paving contractors produce proprietary or trade named PA mixes to satisfy the general French PA specification. These mixes feature modified bitumens to provide perceived benefits in performance and durability. The EAST team did not receive information on the cost of these PA mixes in-place compared with conventional HMA overlays. In France, however, polymer-modified bitumens cost about 100 percent more than unmodified bitumen, and polyrner-modified HMA, as produced, about 20 percent more than conventional HMA.

**In-Service** Pavements--Members of the EAST inspected three in-service PA pavements around Nantes and Lyon.

A 25 mm-thick PA overlay on low-traffic volume, two-lane RN 23 in suburban Nantes was constructed in July 1989 (SVR 9-17-90, #2). The PA mix used was PERMFLEX, a proprietary product of the French paving contractor COLAS S.A. It employs the modified binder COLFLEX 253, an **SBS**[6] latex-modified bitumen. The binder content of the mix is 5.2 percent; the SBS latex comprised 5 percent by weight of the binder. Aggregate top size was 10 mm. Nominal air voids content was 23 percent.

The underlying pavement was prepared by application of a tack coat of polymer-modified bitumen emulsion. The PA overlay was placed with a conventional paver and compacted with steel-wheeled rollers. The overlay was placed thinner than usual to prevent frost build-up on the pavement during the winter months. The pavement had an open appearance, but no distress was apparent.

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6 SBS = styrene-butadiene-styrene block copolymer.

Another PERMFLEX overlay was inspected on Boulevard Dolon in Nantes (SVR g-17-90, #3). This was also constructed in July 1989. In this case, a two-layer pervious pavement was used: a 20-mm PA overlay basically identical to that employed on RN 23 over a 60 mm pervious bituminous macadam base course. This two-layer construction was used to provide the pavement with the capacity to store large volumes of rainwater temporarily.

The pervious base course, which uses an unmodified 60/70 penetration grade bitumen, has an aggregate top size of 14 mm and a binder content of 4.8 percent. A gap-graded aggregate was used, rich in 10 to 14 mm sizes, but with little mineral filler content. This heavily-trafficked urban route did not show any apparent distress after 1 year in service.

The A47 toll motorway south of Givois in suburban Lyon is a heavily-trafficked route to the French Riviera. In the summer, the traffic volume is on the order of 160,000 ADT. The EAST members inspected a 40 mm-thick PA overlay constructed in July 1989 (SVR g-18-90, #l). The PA mix used was DRAINOCHAPE FE, a proprietary product of the French contracting firm BEUGNET Technical Management. It employs a proprietary bitumen-rubber binder, FLEXOCHAPE E, also produced by BEUGNET. Reclaimed tire rubber treated with aromatic oil is used. The binder content of the PA mix is 6.6 percent. The reclaimed rubber content is 5 percent by weight of the binder. The gap-graded aggregate has a top size of 10 mm; 88 percent falls between 6 and 10 mm. A hard, crushed porphyry rock is used for the coarse aggregate.

This type of overlay is also placed with conventional pavers and compaction equipment. The hot mix plant, however, must be equipped with a special unit for precise production of the rubber-bitumen binder.

Inspection of this DRAINOCHAPE FE pavement showed it to be in excellent condition after 1 year of service. The pavement surface appeared fresh, without any visible distress.

The EAST members were also shown a 2-year old PA overlay on a steeply-sloped suburban street in the Lyon area. The overlay, which is approximately 45 mm thick, was produced with a polymer-modified bitumen and a gap-graded aggregate blend with a nominal 14 mm top size. The air voids content was 20 percent. During the summer of 1990, the air temperature had reached 40°C daily for several weeks and the pavement temperature 60°C. Remarkably, little or no visible distress was noted in the overlay.

## MODIFIED ASPHALTS AND ASPHALT-AGGREGATE MIXTURES

### General Remarks

The use of modified binders and bitumen-aggregate mixtures appears much more prevalent and routinely accepted in the European countries visited than in the United States. Although latex-modified asphalt cement and asphalt-rubber binder are used in substantial quantities in several American states, European practice seems to encompass larger volumes of material as well as a wide range of modifiers.

The group's impression was that the freer use of modified materials arises from several factors. First, the latitude given to paving contractors to design and produce pavements that meet specified warranty conditions, rather than the lowest first cost, encourages more experimentation by the contractors in the use of novel materials and mix designs.

Second, major differences in contracting practices permit much higher HMA prices in Europe than in the United States. As a result, the additional cost of modified materials is not as significant a factor in choosing the "best" system for the job at hand.

Third, European HMA production, almost exclusively by batch plants, is geared to relatively smaller daily volumes than in the United States. The additional plant units and production times for modified materials do not exact the same penalties in Europe as they would in the United States.

Last, the European paving contractors appear to take the main responsibility for the development and adoption of modified materials, and have a direct economic stake in their successful use. The promotion of new products by third parties, as is prevalent in the United States, seems much less common in Europe.

### Stone Mastic Asphalt and Porous Asphalt

The extensive use of a wide range of bitumen modifiers in SMA and PA mixes has been discussed in detail in sections II and III. The production of both types of mixes would appear to be difficult without modifiers. Moreover, the generally successful performance of the small sample of SMA and PA pavements observed by the EAST team suggests the additional cost and production time needed for the modified mixes are justified.

### Verv Thin Asphalt Concrete (France)

Very thin asphalt concrete (VTAC) is another of the alternative strategies specified for pavement surface maintenance by the French Transport Ministry.

In addition to providing enhanced skid properties, VTAC is intended to seal and renew existing pavement surfaces. It is considered a paver-laid alternative to slurry seals, and does not affect the pavement structurally.

A VTAC overlay consists of a gap-graded aggregate combined in most cases with a modified bitumen binder. The aggregate top size is 10 mm; 83 percent of the aggregate is in the 6 to 10 mm range, with 15 percent between 0.09 and 2 mm. The remainder of the mixture is limestone filler.

A variety of modifiers are used, including polymers, rubber, and fibers. Depending on the modifier selected, the binder content can vary from 5.7 to 6.7 percent by weight of the mix. The air voids content of VTAC is high, generally in the range of 15 percent.

The East members inspected two examples of VTAC treatments. The first was on route RD 68 between Ste-Lute and Thouare (SVR g-17-90, #l). A 15 mm VTAC overlay had been placed on this two-lane secondary road in July 1990.

The overlay mix is trade named *COLRUG,* a proprietary product of the French paving contractor, COLAS S.A. *COLRUG* uses 5-percent SBS latex as the bitumen modifier. The overlay appeared fresh and in excellent condition; EAST members did not note any distress.

The second VTAC overlay was on route N 165,30 km west of St. Nazaire; this is a four-lane, divided freeway carrying a high traffic volume. The 10-mm thick overlay was placed in *1988* using the *MEDIFLEX* proprietary mix produced by SCREG Routes Group. Like COLRUG, *MEDIFLEX* uses a binder modified with 5-percent SBS latex. This overlay also appeared in excellent condition; close examination did not reveal any overt distress.

**Paver-Laid Chip Seal (France)**

Paver-laid chip seal is another maintenance strategy permitted under French Ministry of Transport specifications. This technique is not intended to provide any structural effect, and its use is confined to pavements that are not deformed.

The chip seal is constructed with a binder layer of polymer-modified bitumen emulsion. Hot precoated chips (6 to 10 mm) with a 17 to 1 blend of sand and bitumen are applied. A single, self-propelled unit sprays the binder layer and immediately applies the chips. The chip seal is then smoothed by a rubber-tired roller.

Three benefits are claimed for this paver-laid chip seal: 1) use of a modified binder and precoated chips virtually eliminates loose chips and allows immediate opening to traffic; 2) noise levels are lower than for conventional chip seals; and 3) it is suitable for a variety of traffic volumes.

The members of the EAST inspected a paver-laid chip seal constructed in July 1989 on route RN 171 near La Baule (SVR g-17-90, #7). This is a four-lane highway with an ADT of 25,000. The *NOVACHIP* chip seal system marketed by SCREG Routes Group was used in the construction. The binder layer was an emulsified, 60/70 penetration grade bitumen modified with 5-percent *Neoflex* (an

SBS latex). The binder was applied at a rate of 0.95 kg/m*; the chips were placed at a rate of 25 to 30 kg/m2.

The pavement had an open look, without any apparent distress except for some minor tearing along the centerline of the driving lane. Considering the traffic volume and loads, the group judged the performance to be impressive.

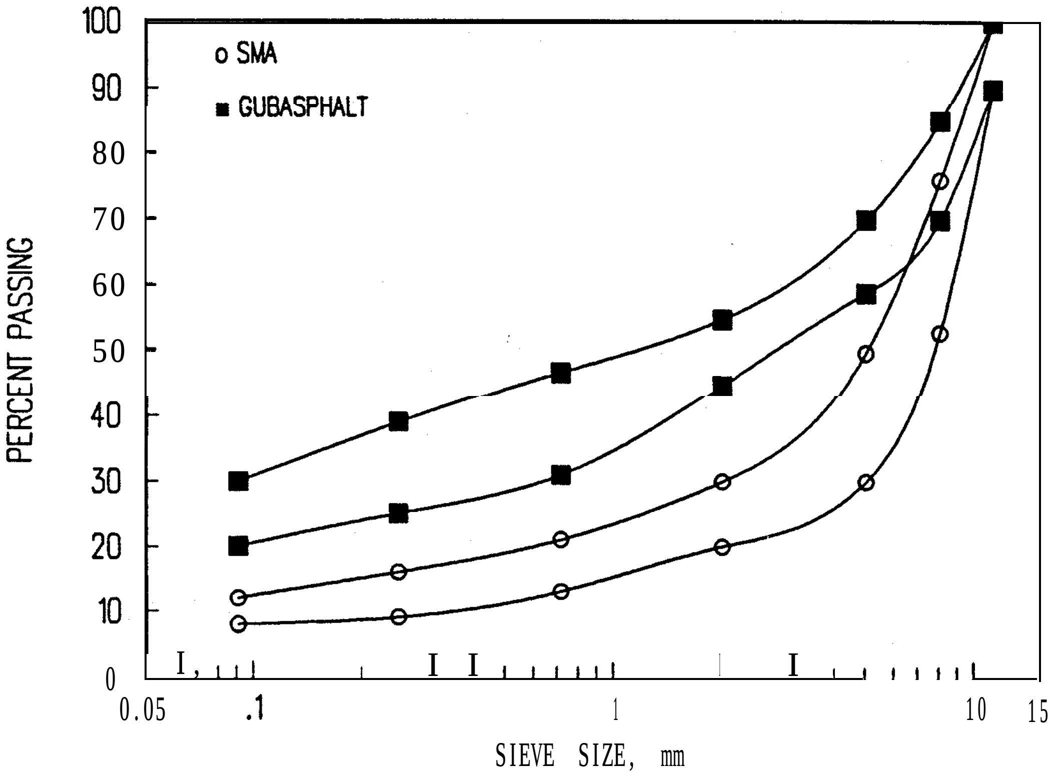
## Gussasphalt (Germany)

**Design, Cost, and Serviceability--The** term "Gussasphalt" is difficult to translate precisely, but may be best approximated as floated or pourable asphalt or bitumen mastic. In Germany, Gussasphalt is considered a premium paving mix intended for surface and wearing courses bearing the highest traffic volumes and highly channelized truck traffic.

Gussasphalt is placed at 200 to 250°C (390 to 480°F) with a special screed on a specially-prepared pavement surface. It may also be poured from buckets and "floated" with hand tools in a manner similar to PCC. No compaction is required; therefore, one $m^2$ of Gussasphalt surface course can be laid with the same quality as 1 million $m^2$. The fresh Gussasphalt surface is dressed with excess chippings at a rate of about 15 kg/m*; these are rolled into the hot surface with a heavy steel-wheeled roller. The German specification for Gussasphalt is contained in the ZTV bit-StB 84, pages 47, 48, 50 and 51.

Figure 7 compares the gradation limits for a German 0/11S Gussasphalt mix with those for the German 0/11S SMA mix. As can be seen, the Gussasphalt aggregate gradation is relatively rich in the middle

**FIGURE 7**



fraction (0.09 to 2 mm) and mineral filler ( 0.09 mm) content compared with SMA. In different terms, the coarse aggregate fraction (retained on the 2 mm sieve) is typically 55 percent for Gussasphalt compared with 80 percent for SMA; the mineral filler fraction is a maximum of 30 percent for Gussasphalt compared with only 15 percent for SMA.

The bitumen content of Gussasphalt mixes may range from 6.5 to 8.5 percent by weight of the mix, depending on the top size of the aggregate used and the result of a specific permeability test. A low-penetration grade of bitumen is required, typically B 25 (25 penetration) or B 45. Given the high bitumen content combined with the rich gradation, in-place air voids contents are close to 0.0 percent. This is the essential characteristic of Gussasphalt; it prevents the penetration of oxygen and the aging of the bitumen.

Pavement structures incorporating Gussasphalt surface courses must be massively designed to distribute the loads transferred through the Gussasphalt courses; otherwise, pavement rutting may eventually develop through deformation of the underlying courses. Well-designed Gussasphalt pavements, however, are expected to perform satisfactorily for 15 years or more, and service lives of 20 years or more do not appear uncommon.

This longevity does not come without costs. Typically, the bid price of a Gussasphalt overlay is almost 200 percent that of a conventional HMA overlay. Gussasphalt surfaces are much noisier than either SMA or conventional HMA surfaces. Most important, the high temperatures required for Gussasphalt mixing and paving operations might lead to air quality concerns in the United States.

**In-Service Pavements--The** EAST team closely inspected two in-service Gussasphalt pavements, one in the city of Hamburg (SVR g-12-90, #3) and the other in Lower Saxony (SVR g-12-90, #4).

The Gussasphalt pavement in Hamburg was placed on the Behringstrasse in 1973. This four-lane city street has a 40,000 ADT with 6 percent heavy trucks; it is one of several routes leading to and from a vehicular tunnel under the Elbe River.

The 40 mm thick Gussasphalt surface course was placed over an 80 mm HMA binder course and 400 mm of treated base material on a frost-proof sand subbase. The Gussasphalt overlay is in excellent condition; only slight rutting was noted here and there on the section of pavement inspected.

The Gussasphalt surface course in Lower Saxony was on the A-7 Autobahn north of Kassel. This four-lane facility has a maximum seasonal ADT of 80,000, of which 17 to 20 percent are trucks. The 40 mm Gussasphalt surface course was placed in May 1990 over an 80 mm HMA binder course and a 180 mm asphalt base course. The binder in the Gussasphalt was modified with Trinidad Lake asphalt at a rate of 33 percent by weight of the binder or about 2.2 percent by weight of the mixture.

The pavement did not show any apparent distress. The surface appeared rough, but this is considered normal because of the rolled-in chips. The wheel paths had a smoother overall appearance. Some areas appeared ravelled, but this may also be related to the rolled-in chips.

The EAST team examined other Gussasphalt pavements briefly at locations on the A-7 and A-61 Autobahns. These were 10 to 20 years old and were in satisfactory condition. In several cases, the Gussasphalt was rutted in the driving lane; this was explained as a failure in the underlying binder course. On the A-3 Autobahn, the group observed a 10 year old Gussasphalt overlay on a PCC pavement. Other than some transverse cracking, this pavement was also in satisfactory condition.

## Hot-Rolled Asphalt and Bitumen Macadam (United Kingdom)

**Mixture Designs--For** heavy duty service on motorways and other trunk routes carrying high traffic volumes and substantial truck traffic, the typical pavement structure in the United Kingdom includes various types of hot-rolled asphalt and bitumen macadam.

Hot-rolled asphalt is the general term for a gap-graded mixture meeting British Standard BS594. The bitumen-filler mortar and the sand fraction provide mechanical strength; the bitumen content provides cohesion. A hard, low penetration grade bitumen is used as the binder.

Dense bitumen macadam (DBM) is a general term for a continuously-graded mixture meeting United Kingdom Department of Transport specification CL.930. Nominal aggregate top sizes of 1.5, 1.0, and 0.75 inches are specified. Compared with HRA, a DBM employs a softer bitumen and lower fines content. It depends markedly on mechanical interlock of the aggregate for strength and resistance to load-induced stresses.

A mixture designated 30%-HRA is used for wearing courses. The bitumen content is about 8 percent; a 50 penetration bitumen is used. Of the mineral aggregate, 30 percent is crushed stone retained on the #7 sieve; the top size aggregate is nominally 0.5 in. Another 55 percent is sand and 10 percent is limestone mineral filler (passing the #200 sieve). Design air voids are about 4 percent. The mixture is dressed with precoated inch chips rolled into the surface at a rate of 12 to 13 $kg/m^2$ to improve durability and skid resistance. 30%-HRA is considered a functional alternative to SMA with the bitumen content providing the necessary cohesive element in the mix.

A mixture termed 60%-HRA is used for road base layers. This mixture has a bitumen content of about 5.6 percent and it also employs a 50 penetration-grade bitumen. Sixty percent of the mineral aggregate is crushed stone retained on the #7 sieve; the nominal top size aggregate is in.

Dense bitumen macadam and its variants are employed principally for road base and subbase course. For example, heavy duty bitumen macadam (HDM) has a continuously-graded aggregate with a top size of 1.5 inches, but has a bitumen content of 3.5 percent compared with 4.0 to 4.5 percent for DBM. A DBM that uses a

50 penetration grade bitumen in place of the usual 100 to 200 penetration grade is termed DBM 50.

At smaller thicknesses than DBM, pavement layers of HDM and DBM 50 provide equal service. All other things being equal, relative thicknesses of 1.00, 0.90, and 0.88 for DBM, DBM 50 and HDM, respectively, provide equal resistance to traffic loads.

**Structural Design Incorporating HRA and DBM Mixes--A** currently favored pavement structure for heavy service on motorways and trunk roads uses a 30%-HRA wearing course, an HBM upper road base, and a 60%-HRA lower road base over a substantial combination of bound and unbound subbase and subgrade courses. This structure is designed to provide resistance to deformation in the upper courses while simultaneously providing resistance to tensile stresses in the bottom layers.

Severe rutting of HRA wearing courses did not occur during the unusually hot summer of 1990 when pavement temperatures as high as 50°C (122'F) were common throughout the United Kingdom, although this temperature is near the (ring and ball) softening point of the bitumens used.

**Construction--The EAST** team observed construction of heavy duty pavements on two motorway projects in the United Kingdom: reconstruction of the M-l motorway near junction 27 north of Nottingham (SVR g-20-90, #l) and construction of a new section of the M-40 north of Oxford (SVR g-20-90, #2).

Reconstruction of the southbound lanes of the M-l was prompted by deflection measurements; the existing northbound lanes showed little apparent distress. The motorway was constructed in 1969 and overlaid in 1981 with a 40 mm HRA wearing course. Traffic volume is 60,650, including 25 percent trucks.

Major reconstruction was taking place in the left-hand driving lane (#l of three) where 300 mm of the existing pavement was milled out with a cold planer. The milled-out material was replaced by four pavement layers, including a 40 mm 30%-HRA wearing course, 215 mm of HDM upper road base, 125 mm of 60%-HRA lower road base, and 100 mm of DBM subbase, for a total depth of 380 mm over the existing 300 mm graded limestone subgrade.

The EAST members witnessed construction of the upper road base on the #l lane. Two conventional pavers with fixed screeds were in use; laydown temperature was 160°C on a cold, windy and intermittently rainy day. Daily tonnage was about 5,500, requiring 100 haul trucks to continuously supply hot-mix for the pavers. The total reconstruction of 9 km of six-lane pavement will cost about $8 million or about $34.25 per square yard.

The M-40 extension is completely new construction. This six-lane facility will have an initial pavement 510 mm in depth comprised of a 40 mm 30%-HRA wearing course, a 195 mm HDM upper road base, a 125 mm 60%-HRA lower road base, and a 150 mm subbase prepared from better quality crushed rock. This structure is placed on a prepared subgrade of 600 mm of crushed rock.

The EAST team also observed construction of an HRA wearing course on the #3 outer passing lane. Laydown was with a conventional paver at 160 to 170°C. After compaction of the HRA, the crew immediately applied 20 mm of precoated chips with a chip spreader at a rate of 12 to 13 $kg/m^2$ and rolled with three rollers to achieve firm anchoring.

The HRA wearing course mix was being produced on site, but road base mixes were hauled almost 2 hours from a remote location to take advantage of better quality aggregate. Up to 20,000 tons of road base mix was being laid each week.

**OTHER SPECIAL, PURPOSE MIXES**

In Germany, an application of a Ralumac slurry seal was observed by the EAST team (SVR g-13-90, #l). This proprietary system, which is used in the United States, employs a latex-modified, emulsified bitumen.

In Denmark, the EAST members witnessed taxiway reconstruction at the Kastrup Airport, Copenhagen (SVR g-11-90, #l). The HMA binder course that was being laid was modified with a combination of *Microfil* carbon black, hydrated lime, and cellulose fibers. The carbon black was intended principally to flatten the temperature-viscosity response of the binder; it also has been found to slow the aging of the bitumen during hot-mix production.

Personnel of the Copenhagen Airports Authority noted that both SBS latex and EVA[7] had been employed as modifiers in earlier reconstruction projects, but had presented problems with bitumen compatibility and separation. Furthermore, the SBS and EVA-modified pavements failed under heavy, static tire loads.

Two other special-purpose overlay systems based on SBS latex-modified bitumens were observed in France. BETOFLEX is a proprietary, deformation-resistant overlay for bridge decks. A 1 year-old overlay was inspected on the Anne de Bretagne Bridge in Nantes (SVR g-17-90, #4).

Construction of a two-layer overlay specially designed to prevent reflective cracking was observed on route RN 165 near Sautron (SVR g-17-90, #6). Both the SAFLEX wearing course and the RUFLEX binder course use SBS latex-modified bitumen.

7 EVA = Ethylene Vinyl Acetate.

## MIXTURE DESIGN TECHNIQUES AND TEST APPARATUS

### Novel Mixture Design Techniques

**Germany--As** noted in the section on SMA in Germany (page 72), mix designs for the surface and base courses on each project in Germany are selected from a series of standard designs. These have been developed through experience for different traffic volume classes. However, the Marshall mix design method is used extensively for voids analysis and the selection of target bitumen contents.

This approach requires careful selection of materials, tight control of all variables in the hot-mix production process and, generally, a rigorous adherence to all requirements of the specification. It also demands strict attention to pavement drainage requirements and universal provision of frost-proof foundations for all classes of pavement structures.

During construction, the contractor is required to conduct quality control measures according to the specifications for the project. Furthermore, loose mix samples are taken on behalf of the State road authority from the hopper of the paver and checked for satisfactory bitumen content and aggregate gradation by an independent, third-party laboratory. Cores are also taken from the new pavement to determine that requirements for compaction, air voids content, and bond between layers have been met.

France--In France, the LCPC mix design system is universally employed by the central road authority and the paving contractors. Compactors and a battery of sophisticated mechanical engineering test equipment are used to measure the performance characteristics of the trial mixes (resistance to rutting, fatigue cracking, and moisture sensitivity). The two types of compactors in use are gyratory, which is similar to equipment used by the U.S. Army Corps of Engineers, and rolling wheel. (Resistance to low-temperature cracking is not specifically addressed).

**General Procedures--The** procedure varies according to the knowledge available on the mix to be used. If the mix has been used with the same material composition, the gyrator-y shear testing machine is used for verification to assure the mixture's workability has not changed. If one or two of the material components are new, verification is performed regarding workability using the gyratory shear testing machine; the DURIEZ test similar to the U.S. immersion-compression procedure, is used for compressive strength and resistance to immersion.

If the mix design employs materials of unknown performance, a complete battery of tests is performed, including verification of mixture workability by gyratory shear testing, compressive strength and resistance to immersion in water, wheel tracking test, and direct tension test. On occasion, when an asphalt contractor develops a new proprietary mix, the complex modulus and fatigue tests are used instead of the direct tension.

Initial screening of candidate mix designs is done by compaction with the gyrator-y shear testing machine to select a trial mix within the desired air voids content range. Empirical relationships have been developed that correlate the laboratory air voids content to that found in actual pavements. A rubber-tired, rolling wheel compactor is then used to prepare plate or slab specimens from which cylindrical and trapezoidal beam specimens may be cut for mechanical engineering testing.

The rutting, stripping and load-related fatigue characteristics of trial mixes are determined with sophisticated wheel-tracking and direct tension testing equipment. These results are compared with a database of similar measurements on field pavement specimens to gauge the suitability of the trial mix design.

**Permanent Deformation and Moisture Sensitivity--For** permanent deformation, a wheel-tracking test is used. It measures the rut created by the repeated passage of a wheel over a prismatic asphalt concrete sample. The French strongly believe that the laboratory simulation of the rutting phenomenon must approach actual pavement stress conditions so the result obtained can provide one of the selection criteria for a mix design.

The equipment provides for testing two samples simultaneously at a fixed temperature. **To** evaluate rutting sensitivity, consideration is given not only to the rut depth occurring after a certain number of cycles at a specified void content at the job site, but to the cross-section of the rutted specimen and the sensitivity of this curve to a variation in air void content. The equipment also allows the specimen to be conditioned by exposure to water so that moisture sensitivity can be estimated.

**Fatigue Cracking--Because** tests for fatigue cracking characterization are costly and time consuming, they are carried out only for research. The first type of fatigue test is an imposed displacement alternating bend test. Four trapezoidal-shaped test samples may be tested simultaneously. This test consists of maintaining constant displacement amplitude and frequency for the free end of the test sample. During the test, continuous reduction of the stiffness modulus from accumulated fatigue damage is recorded. This is reflected in a reduction in the force required to maintain constant displacement amplitude. The test is continued until the initial force required to impose displacement is reduced by one-half.

**A** trend has emerged in France toward shear fatigue testing. This test is also run at imposed strain amplitudes. The shear fatigue test provides results showing less scatter than the bending fatigue test. It also takes more effective account of the types of load to which thin surface courses and interlayers are subjected. In connection with current research, this test is being used in France to study the capacity of asphalt concretes for self-repair during periods at rest and the laws of damage accumulation.

A single-axle direct tensile load test has been developed for comparing the fatigue resistance thickness design of asphalt concretes, where the critical stress in the pavement layer concerned may be assimilated to a tensile load. Strain, the form of which is parabolic over time, is applied. It is first applied in a minor strain field to define the moduli dependent on time and temperature. Then it is applied in a major strain field to the point of rupture to deduce a linearity loss. Definition of a simplified test procedure incorporating several tests and carried out on a single sample substantially reduces cost and makes it possible to use the test in routine mix design.

**United** Kingdom--In the United Kingdom, the Marshall design method is used by some county road authorities while others rely on standard recipe designs that have performed well. Historically, use of the Marshall design method began because pavements constructed with recipe mixes experienced severe rutting during the extremely hot sumrner of 1976.

This situation has led to a proliferation of “standard” rnix designs--more than 200 variations, extant, that met the umbrella specification requirements for HRA and DBM discussed on page 94.

The University of Nottingham has developed a more performance-oriented design method that characterizes the mechanical behavior of trial mixes using repeated load indirect tensile, uniaxial creep, and repeated load axial tests. Compaction of cylindrical trial specimens employs a specially-adapted vibratory hammer called a PRD or percentage refusal density apparatus.

**Test Specimen Fabrication and Compaction--Although** roller compaction (rolling wheel device) simulates site compaction equipment, this device is not considered suitable for the routine manufacture of specimens necessary for a widely acceptable method of mix design.

The University of Nottingham has identified a procedure that uses the PRD test apparatus to manufacture test specimens, make the use of large aggregate easier, and introduce a kneading compactive effort. The procedure involves a 6-inch diameter split mold and a vibrating hammer. The PRD test is widely used in the United Kingdom to determine the degree of compaction of materials laid on site. Therefore, this test apparatus was adopted as the laboratory procedure.

By varying the time and the temperature at which the specimen is compacted, a range of PRD’s for each mix formulation can be obtained. Initially, three levels of compaction conditions are used to achieve 100,96 and 93 PRD.

**Volumetric Analysis--The** -volumetric proportions of the materials are important parameters that influence the mechanical performance of mixes. Ranges for these parameters are specified as part of the mix design process and as a preliminary step before mechanical testing.

The control variables used are: VMA, voids in the mineral aggregate;Vv, voids in the mix; and **VB,** volume of asphalt in the mix (similar to VFA in United States practice). For mixes compacted to 100 PRD, the mix properties should be within the following limits to maintain satisfactory fatigue strength: VMA, 13 to 18 percent; Vv, 3 to 8 percent; and $V_B$, 8 percent or greater.

**Mechanical Engineering Tests--Mixes** that meet the established volumetric property criteria are then subjected to mechanical engineering tests to estimate their probable performance in pavements. These tests require special equipment, which is necessary to assess end product performance of bituminous mixtures.

The equipment advocated for this purpose is the Nottingham Asphalt Tester, which is an all-in-one test apparatus capable of performing indirect tensile tests, static load creep tests, repeated load axial tests, and fatigue tests. For design, two tests are used: the indirect tensile test to obtain elastic stiffness and the unconfined repeated load axial test to assess resistance to deformation.

The indirect tensile test is performed first because it is non-destructive. Values of elastic stiffness should not be less than 2,000 MPa at 20°C. Generally, specimens with satisfactory volumetric proportions will have elastic stiffnesses in excess of this value.

The unconfined repeated load axial test has adopted the conditions of the static creep test (100 kPa load at 40°C applied for 1 hour), but the load is pulsed onto the specimen at a frequency of 0.5 Hz. The test is terminated at 3,600 cycles or earlier if specimen failure appears irnminent. Precise interpretation of results from this test is not yet possible. The results, however, will clearly rank materials in order of their deformation resistance and engineering judgment will help in the decisionmaking process. At this stage, satisfactory mixes should not exhibit more than 1 percent strain at the end of the test.

Tests for fatigue strength are not recommended; this testing requires an excessive number of test specimens for reliable results. The minimum $V_B$ of 8 percent is designed to avoid mixes that may be susceptible to cracks. The fatigue strength of the optimum mix formulations may be checked by using a prediction method involving the softening point of the binder and the volume of binder in the mix **(VB).** This method is considered to be of use when the results are combined with pavement design calculations using the mechanistic approach.

The final check is the durability of the selected mix. The indirect tensile test is performed on a specimen at the optimum mix formulation after immersing the specimen in water for 24 hours at 25’C. If the elastic stiffness is within 70 percent of its pre-immersed original value, the mix is satisfactory. If it fails this criterion, the binder content must be increased.

## NOVEL TEST APPARATUS

**Compaction Devices--As** discussed in the “General Remarks” found on page 90, the use of gyratory and rolling-wheel compaction devices in European mix design and analysis systems. A compaction device similar in size and capabilities to the well-known U.S. Army Corps of Engineers device and termed a Gyratory Shear Compacting Press is employed in the LCPC design method. The device is commercially available from the French manufacturer MAP, with a retail cost in France of 230,000 Ffr (about $43,000).

The LCPC method also requires the use of a rubber-tired rolling wheel compactor, termed a Plate Compactor. This device mounts single or dual 0.415 m diameter by 0.109 m wide tires, and can achieve a loading pressure of 700,000 Pa. It requires the use of an 80 kg batch mixer and produces compacted slabs in 20 minutes. Maximum slab size is 0.6 m long, 0.4 m wide and 0.15 m high. Cylindrical specimens are typically cored horizontally from the slab, allowing specimen lengths near 0.6 m. This apparatus is also available from MAP at a cost of about 250,000 Ffr ($46,000).

In the United Kingdom, both the TRRL and the University of Nottingham have one-of-a-kind rolling wheel compaction devices that are used principally for research studies. These employ a partial segment of steel wheel, similar to those employed on steel-wheeled pavement rollers, to provide the compactive effort needed for slab production. These are not presently available from commercial sources.

The PRD test apparatus employed for laboratory compaction in the University of Nottingham (or Brown-Ackroyd) Mix Design System is a cornmercially-available vibratory hammer that produces 6-inch diameter cylindrical mix specimens in split steel molds. This type of vibratory hammer is used extensively by the highway community in the United Kingdom for soil tests, a fact that should facilitate its adoption in a laboratory mix design and field quality control system.

Compared with current practice in the United States, the gyrator-y and rolling wheel compaction devices discussed here represent substantial increases in equipment costs and complexity of operations. In particular, the rolling wheel compactors produce large, massive slab specimens; high-volume batch mixers are needed to produce the HMA required, and forklift trucks are necessary to move the specimens. Finally, the rolling wheel compactors produce slabs from which the actual test specimens must be cored or sawn, depending on the test configuration.

**Mechanical Engineering Test Devices--The** LCPC design method discussed on page 97 employs two engineering test devices that are unknown in routine U.S. mix design practice.

The Pavement Rutting Tester is a wheel tracking device in which two rubber-tired wheels are driven in back-and-forth motion over a rectangular slab prepared in the laboratory or cut from a field pavement.

The dependence of the rut depth in the specimen with material types, number of loading cycles, tire pressure, wheel load, temperature, and moisture conditioning can be determined. An extensive data base is available to relate the measured rut depths obtained in the test to those expected in actual field pavements. This apparatus is available commercially from the French manufacture MAP at a cost of 250,000 Ffr ($46,000).

Wheel-tracking test devices of various sizes and degrees of complexity are also used in the United Kingdom for research studies and to calibrate, for field performance, the results of such other methods as static and dynamic creep tests. These devices are not used directly in mix design and analysis systems. They generally employ pneumatic rubber-tired wheels like the LCPC device, but in some instances, steel wheels or hard rubber-tired wheels are used.

The LCPC method further incorporates the use of the Fatigue Bend Machine for Bituminous Mixes. This machine carries out fatigue tests on trapezoidal beam specimens cut from laboratory-compacted slabs or actual pavements. The beam is loaded repeatedly at a nominal excitation frequency of 25 Hz. For various material combinations and temperatures, the dependence of the number of load cycles to specimen failure or some predetermined reduction in stiffness modulus is determined. This method also is calibrated to an extensive data base of French pavement performance, but because of its complexity, is run only when completely new or unfamiliar materials and mix designs are evaluated. Commercially, this apparatus is available for about $50,000.

Similar devices are used in many research laboratories in the United States and Europe.

The Nottingham Asphalt Tester, which was discussed on page 99, combines several test devices into one computer-controlled assembly. The apparatus is capable of performing indirect tensile tests, static load creep tests, repeated load axial tests, and fatigue tests. For the Brown-Ackroyd mixture design procedure, only two test procedures are routinely used: the indirect tensile test to obtain elastic stiffness and the unconfined repeated load axial test to assess resistance to deformation.

The functions contained in the Nottingham Asphalt Tester are used extensively around the world for research studies, but have never before been integrated into a complete design procedure in this way. Many of the individual pieces of test equipment, particularly the indirect tensile test device, are available in state highway agency laboratories in the United States.

Agencies considering adoption of this design procedure, but that do not have any of the component apparatus available, can obtain the complete Asphalt Tester from commercial sources in the United Kingdom for approximately $140,000.

## REFERENCES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# APPLICATION OF FINDINGS

# APPLICATION OF FINDINGS

As described throughout this report, the EAST's mission of identifying potentially promising asphalt technologies and contract administration practices was considered by all participants to be an overwhelming success. But identifying new technologies is not enough. The successful adaptation of those findings for possible use in the United States will be the determining factor in measuring the mission's success.

While immediate implementation of the findings is desired, caution must be exercised. The United States cannot just "hit the ground running" with Europe's methods. For special reasons, these technologies may work well in Europe and not as well or as efficiently in the United States. Cultures are different. For example, one noticeable fact in Europe is the limited amount of litigation in the transportation industry. In Europe, a close and extensive working relationship exists between government and private industry. While this situation may be due partly to legislation or regulation, it does exist and offers more opportunities than in the United States for cooperative ventures in the development and implementation of technology. For these and other reasons, patience and persistence are paramount in adapting the EAST's findings for use in the United States through carefully designed experimental plans.

After returning from Europe, members of the EAST met to consider, first, which European technologies should be focused on initially and then to develop a plan for the application of their findings. After considering all the possibilities, the study team identified four general areas and several specific areas:

- **Asphalt Pavement Mixtures:**
  Stone Mastic Asphalt
  Porous asphalt
  Modified Binders
- **Laboratory Equipment**
  Mix Design Equipment
  Laboratory Compaction
  Rut Tester
- **Innovative Contracting Practices**
  Lane Rental
  Contractor Warranties/Guarantees
- **Research**

The members then developed an experimental plan for implementing their findings:

## ASPHALT PAVEMENT MIXTURES

### Stone Mastic Asphalt

Stone Mastic Asphalt is a special purpose, rut resistant surface pavement mixture of coarse aggregates held together by an asphalt-filler-stabilizer mastic. The FHWA's Office of Technology Applications has been assigned the lead in coordinating evaluation of this technology, adapting it to this country's needs and construction characteristics, and implementing it in the United States. To accomplish these assignments, the Office prepared a work plan that describes a series of field tests in five or more States; collection and refinement of existing information to include a followup European trip; material, mix design, and construction evaluation; and a detailed study of SMA's mechanical and physical properties.

Existing reports and data on SMA have been reviewed and a Technology Synthesis on the subject has been released. The technical fact-finding visit focused on SMA in Germany and Sweden was completed in late April. Inquiries during the visit focused on mixture design and controls for material and construction. Samples of SMA materials planned for projects in this country will be provided to European experts for evaluation.

A Technical Advisory Committee (TAC) has been established and information on the technology distributed. Membership in the TAC includes representatives from seven States, FHWA, SHRP, NAPA, The Asphalt Institute, and the National Center for Asphalt Technology (NCAT). The seven States are Colorado, Georgia, Michigan, Missouri, Texas, Virginia, and Wisconsin. A formal meeting of the TAC will be scheduled to coincide with the construction of an initial State field project.

Proposals have been received for field projects in Georgia and Michigan. Construction is scheduled for mid to late summer. An additional project is being planned in Wisconsin, with several other States expressing interest in constructing SMA pavements, pending results of the pilot projects.

Material sources have been identified for the Michigan pilot project. The State's and the FHWA's laboratories have begun preliminary material and design investigations. Laboratory activity will also examine the effectiveness and composition of such SMA stabilizers as cellulose, mineral fibers, and various polymer/elastomer modifiers.

The NCAT has submitted a proposal to establish SMA's characteristics and evaluate its sensitivity to changes in its components. This effort, lasting 3 months, will primarily concentrate on the material being used in the Michigan pilot project.

Initial and periodic post construction evaluations will be performed on the Georgia and Michigan pilot projects. Data from additional field projects along with State, FHWA, and industry laboratory research will be pooled and analyzed for eventual national implementation of SMA.

## Porous Asphalt

European PA pavements are similar to the open-graded friction courses used in the United States. They provide a pavement surface that drains rainwater rapidly, thus reducing the incidence of hydroplaning. European PA also provides a means of absorbing and dissipating noise. The use of modified asphalt cements (cellulose, mineral fibers, and polymers) in the European PA allows for increased asphalt film thickness, thus reducing aging while enhancing durability.

Use of open-graded friction courses with modified asphalts, similar to the European PA, is being examined for possible field evaluation and implementation. Projects are planned for the summer of 1991 in several States using this methodology.

### Modified Asphalt Binders

European practice routinely uses a wide range of modified asphalt cements in construction of roadway wearing surfaces. The Office of Technology Applications is examining an approach and formulating guidelines for a study on asphalt modification. The guidelines will include uniformity in the classification of modifier types, test methods for evaluating the modifiers, life-cycle cost effectiveness, methods of acceptance, and potential specifications.

Evaluation and implementation of these modifications will, in part, take place through our efforts in the areas of SMA and PA.

## LABORATORY EQUIPMENT

### Mix Design Equipment

Representatives from the FHWA, the Colorado Department of Highways, and the NAPA will jointly investigate the flexible pavement design testing technologies used in Europe. They developed a work plan that addresses equipment acquisition, installation, staffing, training, test and evaluation, and ultimate implementation in this country.

The work plan focuses on mix design systems from France and the United Kingdom. The French system incorporates two types of compactor, namely gyrator-y (similar to equipmentused by the U.S. Corps of Engineers) and rolling wheel, as well as a series of mechanical tests to measure trial-mix performance characteristics. The University of Nottingham in the United Kingdom has developed an asphalt tester that is an all-in-one test apparatus capable of performing indirect tensile, static load, creep, repeated axial load, and fatigue tests. The evaluation of these two systems will include examination of the various methodologies, rationales, and equipment. These systems will then be used in developing and testing methodologies for mixture design in this country.

### Compaction Devices

The FHWA will evaluate such European compaction testing devices as the rolling wheel compactor and the British vibratory hammer. Data generated on these devices will be compared with existing United States compaction methodology (Marshall), gyrator-y compaction devices (Corps of Engineers and Texas), and modified Marshall hammers.

### Rut Tester

The French wheel tracking device will be evaluated and compared with current rut prediction methodologies, as evidenced in the current Asphalt Aggregate Mixture Analysis System. Comparisons will also be made with the Georgia rut-test device being evaluated in six States.

## INNOVATIVE CONTRACTING PRACTICES

The TRB established Task Force A2T51 in 1987 to address innovative contracting practices. That task force was charged with soliciting, studying, and compiling information on the practices under which the United States and foreign agencies contract for construction as they affect quality, progress, and costs; call attention to practices that inhibit quality construction and ways to counter them; and suggest ways for improving contracting processes with attendant quality improvement in construction. The members of Task Force A2T51 plan to publish a report on innovative contracting practices in 1991. The report will contain significant findings on bidding, materials, quality, and insurance/bonding.

In 1989, Task Force A2T51 asked the FHWA to establish a mechanism for assisting State departments of transportation (DOT) in evaluating and validating some of the Task Force's early findings. The FHWA established Special Experimental Project 14 to address the call. Now that the project has been announced, the FHWA is seeking--and strongly encouraging--additional State DOT interest.

A number of activities the members of the EAST observed in Europe are supportive of Task Force A2T5 l's findings, including time/lane rental bidding, contractor responsibility factors (quality and performance), design/build, performance-based specification and testing, alternate bids, regional testing/product evaluation centers, and warranties/guarantees.

Moreover, the proposed Surface Transportation Assistance Act of 1991, which the President submitted to the Congress in February, contains provisions directly related to one of the group's findings. The bill would, for the first time, allow State DOT's to request warranties/guarantees from contractors on Federal-aid projects.

## RESEARCH

Research is another area where the European practice may offer an opportunity for enhancement of the U.S. industry/government/academic research and development relationship. In Europe, government and industry have extensive research facilities, and the results are marketed aggressively. In some countries, in fact, research and marketing are joint ventures between government and industry.

The FHWA and the State DOT's must take a fresh look at the way research is conducted in the United States. The research process must be realigned to strengthen our competitiveness in international markets. It must be adrninistered to strengthen and foster innovation, instead of deterring or stifling the quest for innovation, as is the case with some current practices.

Contracting practices in the United States, in contrast with those in Europe, tend to discourage contractors from operating large-scale research facilities. One primary reason is size. European countries generally work with a few large contractors. Another reason is the opportunity in Europe to reward innovation through such contracting practices. as design/build and warranties/guarantees. Regardless of the differences, research and development must be given as high a priority in the United States as it is in Europe if economic competitiveness in the world market is to be maintained.

In addition, the United States needs more cooperative research between government and private sector laboratories. Such an arrangement could lead to lower research and development costs by minimizing duplication of specialized scientific expertise and expensive laboratory facilities and equipment. To this end, efforts are underway through AASHTO's Research Advisory Cormnittee to identify the capabilities and facilities of the United States highway community through an inventory of academic, government, and industry resources. This inventory is the first step toward a national consortium of highway research laboratories similar to research laboratories in Europe. In addition, fostering a cooperative, collaborative environment among industry and government is important if the United States is to fully use the capabilities and results of the national research and development resources without significant concerns about ownership turf.

# ACRONYMS, DEFINITIONS and TECHNICAL TERMS

# ACRONYMS, DEFINITIONS and TECHNICAL TERMS

## ACRONYMS

**AASHTO**
American Association of State Transportation Officials
444 North Capitol Street, NW., Suite 225
Washington, D.C. 20001
Phone (202) 624-5800

FHWA
Federal Highway Administration
400 Seventh Street, SW.
Washington, D.C. 20590
Phone: (202) 366-0660

NAPA
National Asphalt Pavement Association
NAPA Building, 5 100 Forbes Boulevard
Lanham, Maryland 20706-44 13
Phone: (301) 73 l-4748

SHRP
Strategic Highway Research Program
818 Connecticut Avenue, NW., Suite 400
Washington, D.C. 20006
Phone: (202) 334-3774

TAI
The Asphalt Institute
Research Asphalt Drive
P.O. Box 14052
Lexington, Kentucky 405 12-4052
Phone: (606) 288-4960

TRB
Transportation Research Board
2101 Constitution Avenue, NW.
Washington, D.C. 20037
Phone: (202) 334-2989

## DEFINITIONS/TECHNICAL TERMS

***ANAS - Azienda Nazionale Autonoma delle Strada*** - the National Road Board, an asphalt plant (in Italy)

BAST - ***Bundesanstalt fur Strassenwesen*** - the Federal Highway Research Center (in Germany)

DBM - Dense Bitumen Macadam

EVA - Ethylvinyl Acetate

HABS - Swedish term for SMA

HABT - Swedish term for conventional, continuously-graded asphalt concrete

HMA - Hot-Mix Asphalt

HRA - Hot Rolled Asphalt

LCPC - ***Laboratoire Central des Ponts et Chaussees*** - the Central Laboratory of Bridges ad Roads (in France)

PA - Porous Asphalt

PCC - Portland Cement Concrete

SBS - Styrene-Butadiene-Styrene

SMA - Stone Mastic Asphalt

TRRL - Transportation Road Research Laboratory

# APPENDIX A

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE *9-10-90* # *1*

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***STONE MASTIC ASPHALT (SMA): Tradename Stabinor produced by skanska AR.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Tingstad Tunnel (east side), Route E6, Gothenborg Sweden***

DATE OF CONSTRUCTION 1985 LENGTH ____ (mi/km) # OF LANES 3 ***(east bound)***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALS*** |
|---|---|---|---|
| WHEN OPENED | | | ACTUAL |
| CURRENT | ***100,000 (6 lanes)*** | | DESIGNED |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***38 mm overlay of 80 stabinor 12 (80 $kg/m^2$, 12 mm top size).***

ASPHALT CONTENT *6.6* (% OF MIX) AIR VOIDS CONTENT *3.0* (%)

MODIFIER TYPE ***Mineral Fiber*** MODIFIER CONTENT *0.8* (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***TOP SIZE: 12mm; 50 % Quartzite typical gradation: 26% passing 2mm, 30 % passing 4mm, 50% passing 8mm, 10% filler passing 0.075mm (#200 sieve).***

| DISTRESS TYPE | EXTENT OR FREQUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | 17mm | | |
| LONGITUDINAL CRACKING | X | | |
| TRANSVERSE CRACKING | X | | |
| RAVELLING | X | | |
| ALLIGATOR CRACKING | X | | |
| BLOCK CRACKING | X | | |
| POTHOLES | X | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***High traffic volume precluded stopping bus to view pavement. However, rutting due to studded tires was apparent in some areas, not in others. Pavement generally had a roughly-textured, overall appearance. No other distress of consequence apparent at speed of 50 to 70 km/hr.***

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*Stabinor is the tradename for SMA produced by Skanska AB. Mineral filler, tradename Inorphil, is used as modifier.*

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

*To date, SMA has taken 20 percent more traffic than the conventional HMA overlay previously used which lasted 5 years before rehabilitation was necessary.*

*At 5 years service, HMA had a rut depth of 25mm compared to 17 mm for SMA. A 20 percent increase in service life for SMA compared to HMA is projected.*

**APPLICABILITY TO U.S. PRACTICE:**

*High*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Increased. Swedish authorities justify increased first cost by longer service life.*

**35 mm PHOTOS:** NO___ YES___ ROLL #___ NEGATIVE #'S________
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO___ YES___ CASSETTE #___

**REPORTER(S):** ________________________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE 9-10-90 # 2

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***STONE MASTIC ASPHALT (SMA): Tradename Viacotop produced by the Swedish paving contractor NCC.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Stalhanskegatan., Gothenborg, Sweden***

DATE OF CONSTRUCTION ***198.5*** LENGTH ____ (mi/km) # OF LANES ***2 (east bound)***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALS*** |
|---|---|---|---|
| WHEN OPENED | | ACTUAL | |
| CURRENT | ***30,000 (4 lanes)*** | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***38 mm overlay of 80 viacotop 12 (80 $kg/m^2$, 12 mm top size).***

ASPHALT CONTENT 6.8 (% OF MIX) AIR VOIDS CONTENT 2.5 (%)

MODIFIER TYPE ***Cellulose fibers*** MODIFIER CONTENT 0.3 (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***TOP SIZE: 12mm; 50 % Quartzite; typical gradation: 22% passing 2mm, 31 % passing 4mm, 38% passing 8mm, 10.5% filler passing 0.075mm (#200 sieve).***

| DISTRESS TYPE | EXTENT OR FREQUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | 10mm | | |
| LONGITUDINAL CRACKING | X | | |
| TRANSVERSE CRACKING | X | | |
| RAVELLING | X | | |
| ALLIGATOR CRACKING | X | | |
| BLOCK CRACKING | X | | |
| POTHOLES | X | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***High traffic volume precluded stopping bus to view pavement. Pavement viewed at speed showed little or no apparent distress.***

DRAINAGE FACILITIES:

COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):

*Viacotop **is** the tradename **for** SMA produced by NCC. Cellulose fiber is used as modifier.*

OTHER REMARKS:

*Paving was done by the Gothenborg Street and Highway Department.*

POST-VISIT DEBRIEFING NOTES:

APPLICABILITY TO U.S. PRACTICE:

*High.*

COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:

35 mm PHOTOS: NO___ YES___ ROLL #____ NEGATIVE #'S________
VIDEOTAPE: NO___ YES___ CASSETTE #___
AUDIOTAPE: NO___ YES___ CASSETTE #___

REPORTER(S): ____________________

FHWA/AASHTO/NAPA SITE VISIT REPORT **DATE 9-10-90 # 3**

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Porous Asphalt (PA): Tradename Drainor produced by Skanska AB.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Brackevagen, Route 159, Gothenberg, Sweden***

DATE OF CONSTRUCTION ***1986*** LENGTH ____ (mi/km) # OF LANES ***2 (westbound)***

| | ACTUAL ADT | % TRUCKS | | EALS |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | ***25,000 (4 lanes)*** | | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***43 mm overlay of 90 Drainor 16 (90 kg/m², 16 mm top size).***

ASPHALT CONTENT '5.0 (% OF MIX) AIR VOIDS CONTENT >1.5 (%)[1]

MODIFIER TYPE ***Mineral Fiber*** MODIFIER CONTENT *0.8* (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
***TOP SIZE: 16mm; 55 % Quartzite; typical gradation: IO-15% passing 2mm, 20-24% passing 4mm, 36-42% passing 8mm, 60% passing 11.3mm, 4-6% filler passing 0.075mm (#200 sieve).***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | 6-7mm | | |
| LONGITUDINAL CRACKING | X | | |
| TRANSVERSE CRACKING | X | | |
| RAVELLING | X | | |
| ALLIGATOR CRACKING | X | | |
| BLOCK CRACKING | X | | |
| POTHOLES | X | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Pavement uses 16mm maximum stone size to increase resistance to studded tires. Pavement has a rough-looking surface; lots of aggregate show. Pavement was viewed at speed from bus; little or no significant distress was visible.***

1. Nominal

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*Drainor is the tradename for porous asphalt produced by Skanska AB. Mineral filler (Inorphil) is used as modifier.*

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

*80 Drainor 12 showed inadequate resistance to studded tires. 90 Drainor 16 is about as resistant to studded tires as conventional HMA.*

**APPLICABILITY TO U.S. PRACTICE:**

*Uncertain*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*In Sweden, PA costs about as much as SMA, but resists wear comparably to HMA. PA costs are justified on a case-by-case basis where noise reduction and water drainage are- required.*

**35 mm PHOTOS: NO___ YES___ ROLL #____ NEGATIVE #'S_________**
**VIDEOTAPE: NO YES___ CASSETTE #____**
**AUDIOTAPE: NO- YES CASSETTE #____**

**REPORTER(S):** ____________________

FHWA/AASHTO/NAPA SITE VISIT REPORT **DATE** *9-10-90* *#* *4*

## DESCRIPTIONOFNOVELTECHNOLOGY:

*"Vikan" Asphalt Hot Mix Plant*

## LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

*Near Gothenberg, Sweden*

## DETAILS OF OPERATION:

*This is a 240 ton/hour batch plant employed to produce HMA, SMA and PA. The plant can handle both cellulose and mineral jibers which are dispersed mechanically into the pugmill. Fibers may also be used in pelletized form with asphalt cement as the binder. It is not necessary to coat the fibers with asphalt cement in the pug mill.*

OTHER REMARKS:

POST-VISIT DEBRIEFING NOTES:

APPLICABILITY TO U.S. PRACTICE:

COSTS RELATIVE TO CURRENT U.S. PRACTICE:

35 mm PHOTOS: NO ___ YES ___ ROLL # ___ NEGATIVE #'S ________
VIDEOTAPE: NO ___ YES ___ CASSETTE # ___
AUDIOTAPE: NO ___ YES ___ CASSETTE # ___

REPORTER(S): ________________________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-12-90 # 1

**DESCRIPTION OF NOVEL TECHNOLOGY:**

*Hot mix plant - Permanent Batch Operation*
*(Operated by Hamburg Asphalt Geschag)*

**LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):**

*Nordersted, Germany (Northern Suburb of Hamburg)*

**DETAILS OF OPERATION:**

1. *Very compactly organized-operations are "enclosed" to a large degree.*
2. *Employs 15 hot aggregate bins.*
3. *Much of the process heat is supplied by recylced waste gases.*
4. *Much high quality stone is imported from Norway.*
5. *Has two drums for heating aggregate. In the first, virgin aggregate is heated and screened. Hot waste gases are directed to the second drum (at 300°C) to heat RAP to 120°C. Particulate matter from virgin aggregate is trapped in heated RAP or in a baghouse filter when RAP is not being used in mix operations.*
6. *Aggregate is stored in hot bins at 180°C. The use of 16 hot bins allows mix designs to be varied rapidly. The plant is computer-controlled and can produce 160 different mix designs at present. Mix recipes in computer can be altered only at central oftice; plant operators can only select among stored designs. Total hot bin storage is 360 tons; filler is stored in separate bin.*
7. *RAP is used in base course mixes up to 50% (20% in Hamburg), and in surface course mixes up to 15%. No RAP is used in SMA.*
8. *Aggregate is heated and screened at night. Hot-mix is prepared in 2.5 ton batches. Production rate is about 160 tons/hr. Yearly production is near 100,000 tons. Mix cost at plant varies from $40 to 70.*
9. *Mixing time is 20-30 seconds per batch for virgin materials, 50 seconds for mixes with RAP content. Total hot mix storage capacity is 560 tons in eight storage silos.*
10. *A 60-80 pen grade asphalt cement is used. No rejuvenating agents are employed in recylced mixes.*
11. *Plant operating tolerances are ±0.1-0.2% for asphalt content, ±0.3% for aggregate gradation.*
12. *There is no strict control of the final asphalt properties in recycled mixes. However, stockpiles of RAP are sampled every 300 tons to check gradation, asphalt content and ring-and-ball softening point of the binder, RAP stockpiles are blended to maintain an average R&B softening point of 70°C for the recovered asphalt cement.*
13. *When SMA mixes are produced, cellulose fibers are added through the filler bin.*
14. *Plant staff is 6 persons.*

OTHER REMARKS:

POST-VISIT DEBRIEFING NOTES:

APPLICABILITY TO U.S. PRACTICE:

COSTS RELATIVE TO CURRENT U.S. PRACTICE:

35 mm PHOTOS: NO ___ YES ___ ROLL # ___ NEGATIVE #'S ________
VIDEOTAPE: NO ___ YES ___ CASSETTE # ___
AUDIOTAPE: NO YES CASSETTE # ___

REPORTER(S): ____________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-IO-90 # 5

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***SMA Under Construction (SKanska AB Stabinor)***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***European Route E-4 near Varberg, Sweden, KP 51500***

DATE OF CONSTRUCTION 9-10-90 LENGTH ____ (mi/km) # OF LANES ***Divided 4-lane***

| | ACTUAL ADT | % TRUCKS | EALs | |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | 13,000 | 25 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***2" (uncompacted) SMA overlay: 90 Stabinor 16, compacted to 38mm.***

ASPHALT CONTENT *6.1* (% OF MIX) AIR VOIDS CONTENT *3-4* (%)

MODIFIER TYPE *Inorphil* MODIFIER CONTENT *8* (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***TOP SIZE: 16mm; 20% qualified stone (46 kr/m²); nominal gradation: 25% passing 2mm, 28% passing 4mm, 45% passing 8mm, 70% passing 12mm, 8% passing 0.075mm (#200 sieve).***

| DISTRESS TYPE | EXTENT OR FREQUENCY: LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | | | |
| LONGITUDINAL CRACKING | | | |
| TRANSVERSE CRACKING | | | |
| RAVELLING | | | |
| ALLIGATOR CRACKING | | | |
| BLOCK CRACKING | | | |
| POTHOLES | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***New; construction in progress. Asphalt cement grade: B85.***

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*Stabinor is the tradename for SMA produced by Skanska AB. Mineral filler, trade named Inorphil, is used as modifier.*

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

*SMA was placed with conventional paver at 160°C. Compaction was accomplished with two steel-wheeled rollers. No vibration was employed. Rollers operated close behind the paver.*

*Rolling is intended to orient stone skeleton; little compaction of the mat is expected. SMA is placed over a thin, I2-16mm, leveling course.*

*The air temperature at construction was about 60°F, sky partly cloudy and wind at about 10 to I5 mph. Rolling can continue until mat temperature falls to 75°C. Second roller is equipped with infrared thermometer.*

**APPLICABILITY TO U.S. PRACTICE:**

*High*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

**35 mm PHOTOS:** NO___ YES___ ROLL #____ NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO YES CASSETTE #___

REPORTER(S) :______________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE *9-10-90* # 6

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***SMA***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***European Route E-4 South of KP 51500 (see #5)***

DATE OF CONSTRUCTION *1989* LENGTH ____(mi/km) # OF LANES *Divided 4-lane*

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALs*** | |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | ***13,000*** | 25 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

ASPHALT CONTENT-(% OF MIX) AIR VOIDS CONTENT -(%)

MODIFIER TYPE MODIFIER CONTENT -(% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Probably similar to datasheet #5 (9-10-90); however only local stone used; no qualified (select) material imported Top size: 18mm.***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HTGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | X* | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

* SEGREGATION

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Viewed northbound lanes. Pavement wet from earlier rain. Pavement showed irregular drying pattern caused by mix segregation. Pavement appeared very porous in randomly-spaced locations in between wheel paths. Wheel paths appeared normal, perhaps due to movement of mastic under traffic.***

(form continued on reverse side)/26 JUNE 90

DRAINAGE FACILITIES:

COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):

OTHER REMARKS:

POST-VISIT DEBRIEFING NOTES:

***Pavement distress appeared to be ravelling. However, U.S. contractors on team agreed that distress resulted from mix segregation during construction.***

APPLICABILITY TO U.S. PRACTICE:

COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:

35 **mm** PHOTOS: NO ___ YES ___ ROLL # ___ NEGATIVE #'S ________
VIDEOTAPE: NO ___ YES ___ CASSETTE # ___
AUDIOTAPE: NO ___ YES ___ CASSETTE # ___

REPORTER(S): ______________________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE 9-10-90 # 7

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***SMA under construction (NCC Viacotop)***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***European Route E-6, just North of Bastad, Sweden***

DATE OF CONSTRUCTION ***9-10-90*** LENGTH____(mi/km) # OF LANES ***Divided 4-lane***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | | ***EALs*** |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | | | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***38rnm thick (compacted) SMA overlay: 90 Viacotop 16.***

ASPHALT CONTENT 6.7* (% OF MIX) AIR VOIDS CONTENT 3_(%)

MODIFIER TYPE ***Cellulose Pellets*** MODIFIER CONTENT *0.3* (% OF MIX) (0.6% Fibers + Binder) * Includes 0.3% from fiber pellets

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: 16mm; nominal gradation: 22% passing 2mm; 27% passing 4mm, 33% passing 8mm, 40% passing 12mm, 95% passing 16mm, 10% filler passing 0.075mm (#200 sieve).***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | | | |
| LONGITUDINAL CRACKING | | | |
| TRANSVERSE CRACKING | | | |
| RAVELLING | | | |
| ALLIGATOR CRACKING | | | |
| BLOCK CRACKING | | | |
| POTHOLES | | | |
| * SEGREGATION | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***New; construction in progress. Asphalt cement grade: B85.***

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*Viacotop is the tradename for SMA produced by NCC. This job employed pelletized cellulose fibers as a modifier.*

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

*The binder content is considerably higher for this project than for the Stabinor project reported in #5 (9-10-90). However this mix is reported to hae good friction properties when newly laid.*

*Rolling was accomplished with two steel-wheeled rollers (10 metric tons each).*

*Pavement surface appeared rich in binder, almost to the point of flushing. However, the roller marks were much less pronounced than for the Stabinor mix. This mix appears much more stable.*

**APPLICABILITY TO U.S. PRACTICE:**

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

**35 mm PHOTOS:** NO___ YES___ ROLL #___ NEGATIVE #'S__________
**VIDEOTAPE:** NO___ YES___ CASSETTE #____
**AUDIOTAPE:** NO___ YES___ CASSETTE #____

**REPORTER(S):** ____________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-11-90 # 1

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Runway and Taxiway Rehabilitation Projects at Copenhagen Airport: a) EVA - Modified AC overlay on PCC (Accuplast Seal) b) Open graded A/C filled with superplasticized PCC (Densiphalt); c) Microfil-Modified AC overlay; d) Recycled 40 year old AC pavement.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Klastrup Airport, Copenhagen, Denmark***

DATE OF CONSTRUCTION 9-11-90 LENGTH ____ (mi/km) # OF LANES ***Divided 4-lane***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | | ***EALs*** |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | N/A | | DESIGNED | N/A |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***c) Taxiway Reconstruction: Binder course and open-graded surface course. Binder course consists of HMA. Modified with carbon black (Microfil), hydrated lime (1.5% of mix) and cellulose fibers (0.25%)***

ASPHALT CONTENT 6.5 (% OF MIX) AIR VOIDS CONTENT 4 (%)

MODIFIER TYPE *Microfil* MODIFIER CONTENT 12-15- (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***c) Top size: 20mm. Binder course employs conventional dense-graded aggregate.***

| DISTRESS TYPE | EXTENT OR FREQUENCY: LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | | | |
| LONGITUDINAL CRACKING | | | |
| TRANSVERSE CRACKING | | | |
| RAVELLING | | | |
| ALLIGATOR CRACKING | | | |
| BLOCK CRACKING | | | |
| POTHOLES | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***a) EVA - Modified AC overlay: No visible distress. Another section developed rutting from heavy static tire loads.***

(fom continued on reverse side)

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*Microfil is the tradename for a commercial carbon black product produced by Cabot Corporation.*

**OTHER REMARKS:**

*c) Microfil-Modified AC overlay: SBS rubber and EVA polymer have also been tried as modifiers, but these present bitumen compatibility and separation problems. Also, SBS and EVA-modified pavements have failed under heavy static tire loads.*

**POST-VISIT DEBRIEFING NOTES:**

*c) Microfil-Modified AC Overlay:*
*The carbon black is employed to flatten the temperature susceptibility response of the 60 pm PDA-refined Danish bitumen. Carbon black apparently increases the compaction effort required to achieve satisfactory density The roller complement employed here was double that needed for unmodified HMA. Both steel-wheeled and pnuematic-tired rollers are used. The pneumatic-tired rollers are held off the pavement for 24 hours; this finish rolling is designed to improve durability. Compaction was intended to achieve* $\geq$*98% of Marshall density at 4% air voids.*

*Microfil appears to slow aging of HMA during production. It also flattens the response of Marshall stability and flow to changes in binder content. It has been employed with bitumens up to 120 pen. Cost in Denmark is about $1 per kg.*

**APPLICABILITY TO U.S. PRACTICE:**

*Uncertain.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Increased due to modifier cost and changes in construction practices.*

**35 mm PHOTOS: NO___ YES  ROLL #___  NEGATIVE #'S________**
**VIDEOTAPE: NO YES  CASSETTE #___**
**AUDIOTAPE: NO YES  CASSETTE #___**

**REPORTER(S) :**______________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE ***9-11-90*** **# 2**

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***SBS - Modified SMA overlay on a cracked and seated, 32-year old PCC pavement.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Helsingor Motorway (European Route E4) North from Copenhagen, Denmark***

. DATE OF CONSTRUCTION ***1988-90*** LENGTH ***44***(mi/km) # OF LANES ***Divided 4-lane***

| | ACTUAL ADT | % TRUCKS | EALs |
|---|---|---|---|
| WHEN OPENED | | | ACTUAL |
| CURRENT | 40,000 | 5 | DESIGNED N/A |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***40 mm SMA over 60mm HMA binder course over either cracked and seated PCC slabs or 100 mm HMA base course where poor PCC was replaced.***

ASPHALT CONTENT ***6.9*** (% OF MIX) AIR VOIDS CONTENT -(%)

MODIFIER TYPE ***SBS/Cellulose Fibers*** SBS CONTENT 6 (% OF BINDER)

FIBER CONTENT 0.25(% ***OF MIX)***

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***82% crushed rock, 15% luxovit (burned flint, light stones), 2.75% filler, 0.25% fibers. Nominal gradation: 22% passing 2mm; 28% passing 4mm, 53% passing 8mm, 93% passing 11.2mm, 100% passing 16mm, 7.2% jiller passing 0.075mm (#200 sieve).***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | Slight | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | **None** | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Slight flushed appearance in wheel tracks of driving lane. Passing lane has very even appearance.***

DRAINAGE FACILITIES:

COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):

OTHER REMARKS:

*Binder course is 50% recycled HMA.*

*Cellulose fibers cost 10 kr/kg ($0.65/lb).*

*SMA binder is modified with SBS to increase flexibility.*

POST-VISIT DEBRIEFING NOTES:

APPLICABILITY TO U.S. PRACTICE:

*High.*

COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:

*First costs increased by addition of cellulose fibers and SBS.*

35 **mm** PHOTOS: NO___ YES___ ROLL #____ NEGATIVE #'S________
VIDEOTAPE: NO___ YES___ CASSETTE #___
AUDIOTAPE: NO___ YES___ CASSETTE #___

REPORTER(S): ____________________

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***SMA Surface Course on a heavily trafjiced urban street.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Barmbekerstrasse, Hamburg, Germany***

DATE OF CONSTRUCTION 1984 LENGTH-(mi/km) # OF LANES 4 ***(undivided)***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALs*** | |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | 40,000 | 6 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***40 mm SMA over 40mm HMA binder course over 140mm asphalt base course over 520mm of treated base material on frost-proof sand. This pavement section is intended for intermediate traffic loads.***

ASPHALT CONTENT-(% OF MIX) AIR VOIDS CONTENT -(%)

MODIFIER TYPE ***Cellulose Fibers*** MODIFIER CONTENT (% ***OF MIX)***

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: 11mm. 70 to 80% of aggregate is crushed material. Remainder consists of manufactured and natural sands and filler. Nominal gradation: 90-100% passing 11.2mm, 50- 75% passing 8mm, 30-50% passing 5mm, 20-30% passing 2mm and 8-13% passing 0.09mm.***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***As noted, no distress is apparent of a significant nature. Hamburg roads and streets agency personnel indicated that typical service life for SMA in these circumstances is 10 years.***

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

**APPLICABILITY TO U.S. PRACTICE:**

*High.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*In Germany, SMA costs about 20 percent more than conventional HMA.*

**35 mm PHOTOS: NO___ YES___ ROLL #___ NEGATIVE #'S________**
**VIDEOTAPE: NO___ YES___ CASSETTE #___**
**AUDIOTAPE: NO___ YES___ CASSETTE #___**

**REPORTER(S):** ____________________

FH.WA/AASHTO/NAPA SITE VISIT REPORT DATE 9-12-90 # 3

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Gussasphalt Surface Course on a heavily trafficed urban street.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Behringstrasse, Hamburg, Germany***

DATE OF CONSTRUCTION 1973 LENGTH-(rni/km) # OF LANES ***4 (undivided)***

| | ACTUAL ADT | % TRUCKS | | EALs |
|---|---|---|---|---|
| WHEN OPENED | 40,000 | ACTUAL | | |
| CURRENT | 40,000 | 6 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***40 mm Gussasphalt over 80mm HMA binder course over 160mm HMA over 400mm of treated base material on frost-proof sand. This pavement section is intended for the highest traffic loads.***

ASPHALT CONTENT 7-8 (% OF MIX) AIR VOIDS CONTENT 0 (%)

MODIFIER TYPE _ MODIFIER CONTENT (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: 12mm. Nominal gradation: 90 to 100% passing 11.2mm, 70-80% passing 8mm, 45-55% passing 2mm and 20-30% passing 0.09mm. Aggregate consists of crushed stone, manufactured or natural sand and filler.***

| DISTRESS TYPE | EXTENT OR FREQUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None to slightly | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Excellent considering its long service life. Gussaphalt typically yields a service life of years or more compared to 12 years for SMA.***

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**

*Gussasphalt is a pourable HMA that is placed at 300°C (575°F) with a special screed. It can also be poured from buckets and "floated" with hand tools similar to PCC. No compaction is required. It is covered with excess chipping at a rate of 1.5 kg/m$^2$ which are rolled in with a very heavy roller.*

**POST-VISIT DEBRIEFING NOTES:**

**APPLICABILITY TO U.S. PRACTICE:**

*Low. Its use probably would be prohibited almost every where due to air pollution regulations. High.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*In Germany, Gussaphalt costs almost two times as much as conventional HMA.*

**35 mm PHOTOS:** NO YES___ ROLL #___ NEGATIVE #'S________
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO___ YES___ CASSETTE #___

**REPORTER(S):** ________________________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE ***9-12-90*** **#** 4

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Gussasphalt Surface Course***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Autobahn A-7, North of Kassel, Lower Saxony, Germany***

DATE OF CONSTRUCTION ***5-1990*** LENGTH-(mi/km) # OF LANES 4 (divided)

| | ***ACTUAL ADT*** | ***% TRUCKS*** | | ***EALS*** |
|---|---|---|---|---|
| WHEN OPENED | 50,000 | 17-20 | ACTUAL | |
| CURRENT | ***50,000 (mean)***<br>80,000 (maximum) | 17-20 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***40 mm Gussasphalt Surface Course over 80mm HMA Binder course over 180mm asphalt base course.***

ASPHALT CONTENT *6* (% OF MIX) AIR VOIDS CONTENT *0* (%)

MODIFIER TYPE ***Trinidad Lake Asphalt*** MODIFIER CONTENT 2 (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: llmm. Nominal Gradation: 90 to 100% passing 11.2mm, 70-85% passing 8mm, 45-55% passing 2mm, and 20-30% passing 0.09mm. Aggregate consists of crushed stone, manufactured and natural sand, and mineral filler.***

| DISTRESS TYPE | EXTENT OR FREOUENCY | | | |
|---|---|---|---|---|
| | | LOW | MEDIUM | HIGH |
| RUTTING | None | | | |
| LONGITUDINAL CRACKING | None | | | |
| TRANSVERSE CRACKING | None | | | |
| RAVELLING | None | | | |
| ALLIGATOR CRACKING | None | | | |
| BLOCK CRACKING | None | | | |
| POTHOLES | None | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Surface appeared rough, but this is normal*** due ***to the rolled-in chippings. Wheel paths have a smoother overall appearance. There were isolated paths that appeared to be ravelled, but may be related to the rolled-in chippings.***

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**

*Gussasphalt is a pour-able HMA that is placed at 300°C (575°F) with a special screed. It can also be poured from buckets and "floated" with hand tools in a manner similar to PCC. No compaction is required. It is covered with excess chipping at a rate of 15 $kg/m^2$, these are rolled into the surface with a very heavy roller.*

**POST-VISIT DEBRIEFING NOTES:**

**APPLICABILITY TO U.S. PRACTICE:**

*Low due to environmental problems.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*In Germany, Gussaphalt costs almost two times as much as conventional HMA.*

**35 mm PHOTOS:** NO YES ROLL #___ NEGATIVE #'S________
**VIDEOTAPE:** NO YES___ CASSETTE #___
**AUDIOTAPE:** NO YES CASSETTE #___

**REPORTER(S):** ________________________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-13-90 # 1

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Ralumac Slurry Seal***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Highway P38 westbound between Autobahn A-65 and Neustadt and der Weinstrasse, Rheinland - Pfalz, Germany.***

DATE OF CONSTRUCTION 9-13-90 LENGTH-(mi/km) # OF LANES 2

| | ACTUAL ADT | % TRUCKS | | EALs |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | 12,500 | | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***Ralumac slurry seal (Microsurfacing) applied at a nominal thickness of 8mm to fill existing ruts in pavement and provide a level surface.***

ASPHALT CONTENT *N/A* (% OF MIX) AIR VOIDS CONTENT *N/A* (%)

MODIFIER TYPE ***Latex rubber/emulsifier*** MODIFIER CONTENT *(% OF MIX)*

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
***Top size: 5mm. 8mm top size has been used on east-bound lane surfaced earlier in day.***

| DISTRESS TYPE | EXTENT OR FREQUENCY | | |
|---|---|---|---|
| | LOW | MEDIUM | HIGH |
| RUTTING | N/A | | |
| LONGITUDINAL CRACKING | N/A | | |
| TRANSVERSE CRACKING | N/A | | |
| RAVELLING | N/A | | |
| ALLIGATOR CRACKING | N/A | | |
| BLOCK CRACKING | N/A | | |
| POTHOLES | N/A | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***The existing pavement had been deeply rutted. A first layer of Ralumac was applied to fill the ruts. Then a second complete layer 8mm thick was applied. Traffic was permitted onto surface also immediately; however, it typically takes several days for all the water in the emulsion to evaporate. Ralumac is considered to have more structural value than other slurry seals. A useable service life of 2-3 years is expected for this Microsurfacing.***

(form continued on reverse side)

DRAINAGE FACILITIES:

COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):

***Ralumac is a proprietary product of Raschig AC, Ludwigshafen, Germany.***

OTHER REMARKS:

POST-VISIT DEBRIEFING NOTES:

APPLICABILITY TO U.S. PRACTICE:

***This product is widely used in US.***

COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:

35 mm PHOTOS: NO YES___ ROLL #____ NEGATIVE #'S________
VIDEOTAPE: NO___YES CASSETTE #___
AUDIOTAPE: NO YES CASSETTE #___

REPORTER(S): ____________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE *9-13-90* # 2

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Reconstruction of a rutted pavement with SMA surface course. (At time of visit, asphalt base course was being laid).***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Autobahn A-65 (Northbound), North of Neustadt an der Weinstrasse Interchange, near KP 117,100, Rheinland - Pfal., Germany.***

DATE OF CONSTRUCTION *9-13-90* LENGTH ___ (mi/km) # OF LANES *4 (divided)*

| | ACTUAL ADT | % TRUCKS | | EALs |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | | | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***Driving (Right-Hand) Lane: 35mm SMA over stress-absorbing membrane interlayer over 80 mm HMA binder course over 100 mm asphalt base course over 200 mm cement-treated base.***

ASPHALT CONTENT *7.5** (% OF MIX) AIR VOIDS CONTENT *3.0** (%)

MODIFIER TYPE *Cellulose fibers* MODIFIER CONTENT 0.3* (% OF MIX)
* Nominal
AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
***Top size: 11 mm. TYPICAL GRADATION: 90-100% Passing 11.2mm, 50-75% passing 8mm, 30-50% passing 5mm, 20-30% passing 2mm and 8-13% filler passing 0/09mm. Crushed rock or stone composes 75% of aggregate, natural and manufactured sand 15% and mineral filler 10%.***

| DISTRESS TYPE | EXTENT OR FREQUENCY | | | |
|---|---|---|---|---|
| | | LOW | MEDIUM | HIGH |
| RUTTING | N/A | | | |
| LONGITUDINAL CRACKING | N/A | | | |
| TRANSVERSE CRACKING | N/A | | | |
| RAVELLING | N/A | | | |
| ALLIGATOR CRACKING | N/A | | | |
| BLOCK CRACKING | N/A | | | |
| POTHOLES | N/A | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:
***Rutting had occurred in driving lane of original pavement. This lane was milled out to a depth of 38cm and reconstructed with the pavement section described above. SMA and SAM will extend across entire pavement width. This type of reconstruction was necessitated by the fact that substantial overlays would have blocked the existing drainage system.***

(form continued on reverse side)/26 JUNE 90

DRAINAGE FACILITIES:

COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):

OTHER REMARKS:

POST-VISIT DEBRIEFING NOTES:

APPLICABILITY TO U.S. PRACTICE:

COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:

35 mm PHOTOS: NO ___ YES___ ROLL #____ NEGATIVE #'S________
VIDEOTAPE: NO___ YES___ CASSETTE #___
AUDIOTAPE: NO___ YES___ CASSETTE #___

REPORTER(S): ____________________________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-14-90 # 1

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Danasphalt (Porous Asphalt) overlay on pavement and shoulders***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Autobahn A-6, east of Heilbronn, Baden - Wurttemberg, Germany.***

DATE OF CONSTRUCTION _ LENGTH-(mi/km) # OF LANES-

| | ACTUAL ALIT | % TRUCKS | | EALs |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | | | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

ASPHALT CONTENT 5.0 (% OF MIX) AIR VOIDS CONTENT 18 ( %) (Marshall Design)

MODIFIER TYPE Polymer-modified ***emulsion and 0.5% cellulose fibers*** MODIFIER CONTENT (% ***OF MIX)***

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
***Top size: 8 and 11 mmin different sections. Nominal gradation: 85% retained on 2mm, 5% filler passing 0.09 mm. Binder is polymer-modified cationic emulsion of a B65 - grade bitumen. Cellulose fibers are added to reduce drainage during construction.***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:
***Viewed several sections of porous asphalt overlays intended to reduce hydroplaning and traffic noise.***

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**
*Porous asphalt surface courses on main lines are self-cleaning due to the action of high-speed traffic.*

**POST-VISIT DEBRIEFING NOTES:**

*<u>No standard mix design</u> has been established yet for porous asphalt by the German road authorities. Riding surface is very quiet.*

**APPLICABILITY TO U.S. PRACTICE:**

*Uncertain. Use of impermeable seal layer under porous asphalt might eliminate some of the problems experienced in the U.S. with open-graded asphalt courses.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**
*In Germany, porous asphalt costs 100% more than conventional HMA.*

**35 mm PHOTOS:** NO___ YES___ ROLL #___ NEGATIVE #'S________
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO___ YES___ CASSETTE #___

**REPORTER(S):** ____________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-14-90 # 2

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

*Surface course on reconstructed pavement, including bridge decks. Dranasphalt (Porous Asphalt).*

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

*Autobahn A-81, south of Heilbronn, Baden - Wurttemberg, Germany, near KP 561.0.*

DATE OF CONSTRUCTION 9-14-90 LENGTH-(mi/km) # OF LANES-

| | ACTUAL ADT | % TRUCKS | EALs | |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | 90,000 | 33 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
*35mm Dranasphalt over 40mm (seal layer prepared with polymer-modified asphalt emulsion over existing pavement milled-out pavement.*

ASPHALT CONTENT 5.0 (% OF MIX) AIR VOIDS CONTENT 18 ( %) (Marshall Design)

MODIFIER TYPE Polymer-modified *emulsion and 0.5% cellulose fibers* MODIFIER CONTENT (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
*Top size: 11 mm. Nominal gradation: 8.5% retained on 2mm, 5% filler passing 0.09 mm. Binder is polymer-modified cationic emulsion of a B65 - grade bitumen. Cellulose fibers are added to reduce drainage during construction.*

| DISTRESS TYPE | | EXTENT OR FREQUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|---|
| RUTTING | | | | |
| LONGITUDINAL CRACKING | | | | |
| TRANSVERSE CRACKING | | | | |
| RAVELLING | | | | |
| ALLIGATOR CRACKING | | | | |
| BLOCK CRACKING | | | | |
| POTHOLES | | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:
*Reconstruction of rutted pavement subjected to very high traffic volume and channelized truck traffic.*

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

*Box drains installed 40 mm into the binder course, extending through the seal layer to contact the porous asphalt.*

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**
*Group witnessed construction of asphalt binder course. Three rollers follow closely upon paver. Two pneumatic-tired rollers provide breakdown, followed by a single steel-wheeled roller. Porous asphalt is also compacted with normal rollers without vibration.*

**POST-VISIT DEBRIEFING NOTES:**

*No standard mix design has been established yet for porous asphalt by the German road authorities. This project involves the reconstruction of an existing pavement structure. Existing pavement is milled out, one lane at a time, to a depth of 70mm. A new 70 mm polymer-modified asphalt emulsion seal layer and a 35mm porous asphalt surface course. The seal layer is designed to prevent the intrusion of water into the pavement structure underlying the porous asphalt. The seal layer and the porous asphalt extend across the pavement and the shoulders; it consists of polymer-modified cationic asphalt emulsion, applied at 2 $kg/m^2$, dressed with chippings applied at 8 to 10 $kg/m^2$.*

**APPLICABILITY TO U.S. PRACTICE:**

*Uncertain. Use of impermeable seal layer under porous asphalt might eliminate some of the problems experienced in the U.S. with open-graded asphalt courses.*

**COSTS RELATIVE, TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**
*In Germany, porous asphalt costs 100% more than conventional HMA.*

**35 mm PHOTOS:** NO___ YES ROLL # NEGATIVE #'S________
**VIDEOTAPE:** NO___ YES___ CASSETTE #____
**AUDIOTAPE:** NO YES CASSETTE #____

**REPORTER(S):** ______________________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE 9-14-90 # 3

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Dranasphalt (Porous Asphalt) Surface Course.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Autobahn A-81 northbound, near Freiberg in Breisgan, Baden - Wurttembetg, Germany, near KP 561.0.***

DATE OF CONSTRUCTION ***1990*** LENGTH-(mi/km) # OF LANES ***6 (divided)***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | | ***EALs*** |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | 90,000 | 33 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***35mm Dranasphalt over 40mm seal layer over 70 mm asphalt binder course.***

ASPHALT CONTENT 5.0 (% OF MIX) AIR VOIDS CONTENT *18* ( %) (Marshall Design)

MODIFIER TYPE ***Polymer-modified B65 Bitumen in Cationic emulsion cellulose fibers*** MODIFIER CONTENT (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
***Top size: 11 mm. Nominal gradation: 85% retained on 2mm, 5% filler passing 0.09 mm. Binder is polymer-modified B65 bitumen in cationic emulsion. Cellulose fibers are added to reduce drainage during construction.***

| DISTRESS TYPE | EXTENT OR FREQUENCY | | | |
|---|---|---|---|---|
| | | LOW | MEDIUM | HIGH |
| RUTTING | None | | | |
| LONGITUDINAL CRACKING | None | | | |
| TRANSVERSE CRACKING | None | | | |
| RAVELLING | None | | | |
| ALLIGATOR CRACKING | None | | | |
| BLOCK CRACKING | None | | | |
| POTHOLES | None | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:
***No apparent distress. Pavement is very quiet.***

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

*No standard mix design has been established yet for porous asphalt by the German road authorities, Impermeable seal layer is always applied under porous asphalt. The layer is nominally 40mm thick It is composed of a polymer-modified B65 bitumen cationic emulsion applied at 2 $kg/m^2$ and dressed with stone chipping applied at 8 to IO $kg/m^2$.*

**APPLICABILITY TO U.S. PRACTICE:**

*Uncertain Use of impermeable seal layer under porous asphalt might eliminate some of the problems experienced in the U.S. with open-graded asphalt courses.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**
*In Germany, porous asphalt costs 100% more than conventional HMA.*

**35 mm PHOTOS:** NO___ YES___ ROLL # NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO___ YES___ CASSETTE #___

**REPORTER(S):** ______________________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE ***9-14-90*** **#** 3

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Dranasphalt (Porous Asphalt) Surface Course.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Autobahn A-81 northbound, near Freiberg in Breisgan, Baden · Wurttemberg, Germany, near KP 561.0.***

DATE OF CONSTRUCTION ***1990*** LENGTH-(mi/km) # OF LANES 6 ***(divided)***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | | ***EALs*** |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | ***90,000*** | ***33*** | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***35mm Dranasphalt over 40mm seal layer over 70 mm asphalt binder course.***

ASPHALT CONTENT 5.0 (% OF MIX) AIR VOID CONTENT *18*(%) (Marshall Design)

MODIFIER TYPE ***Polymer-modified B65 Bitumen in Cationic emulsion cellulose fibers*** MODIFIER CONTENT (% ***OF MIX)***

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
***Top size: 11 mm. Nominal gradation: 85% retained on 2mm, 5% filler passing 0.09 mm. Binder is polymer-modified B65 bitumen in cationic emulsion Cellulose fibers are added to reduce drainage during construction***

| DISTRESS TYPE | EXTENT OR FREOUENCY | | |
|---|---|---|---|
| | LOW | MEDIUM | HIGH |
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:
***No apparent distress. Pavement is very quiet.***

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

***No standard mix design*** ***has been established yet for porous asphalt by the German road authorities. Impermeable seal layer is always applied under porous asphalt. The layer is nominally 40mm thick. It is composed of a polymer-modified B65 bitumen cationic emulsion applied at 2 $kg/m^2$ and dressed with stone chipping applied at 8 to 10 $kg/m^2$.***

**APPLICABILITY TO U.S. PRACTICE:**

***Uncertain. Use of impermeable seal layer under porous asphalt might eliminate some of the problems experienced in the U.S. with open-graded asphalt courses.***

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**
***In Germany, porous asphalt costs 100% more than conventional HMA.***

**35 mm PHOTOS:** NO__ YES__ ROLL #__ NEGATIVE #'S________
**VIDEOTAPE:** NO__ YES__ CASSETTE #___
**AUDIOTAPE:** NO__ YES__ CASSETTE #___

**REPORTER(S):** ________________________________________

**FHWA/AASHTO/NAPA** **SITE VISIT REPORT** DATE 9-20-90 # 1

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Reconstruction of the MI motorway to strengthen pavement and extend its service life (original construction: 1968).***

LOCATION **(COUNTRY,** LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):
Motorway Ml southbound, near junction 27, north of Nottingham, Nottinghamshire, United Kingdom.

DATE OF CONSTRUCTION 1990 LENGTH-(mi/km) ***#*** OF LANES ***6 (divided)***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | | ***EALs*** |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | 90,000 | 33 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***35mm Dranasphalt over 40mm seal layer over 70 mm asphalt binder course.***

ASPHALT CONTENT 5.0 (*%* OF MIX) AIR VOIDS CONTENT *18*(*%*) (Marshall Design)
***Polymer-modified B65***
MODIFIER TYPE ***Bitumen in Cationic emulsion*** MODIFIER CONTENT (% ***OF MIX)***
***cellulose fibers***
AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
***Top size: II mm. Nominal gradation: 85% retained on 2mm, 5% filler passing 0.09 mm. Binder is polymer-modified B65 bitumen in cationic emulsion. Cellulose fibers are added to reduce drainage during construction.***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:
***No apparent distress. Pavement is very quiet.***

DRAINAGE FACILITIES:

COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):

OTHER REMARKS:

POST-VISIT DEBRIEFING NOTES:

***No standard mix design*** ***has been established yet for porous asphalt by the German road authorities. Impermeable seal layer is always applied under porous asphalt. The layer is nominally 40mm thick. It is composed of a polymer-modi'ed B65 bitumen cationic emulsion applied at 2 $kg/m^2$ and dressed with stone chipping applied at 8 to 10 $kg/m^2$.***

APPLICABILITY TO U.S. PRACTICE:

***Uncertain. Use of impermeable seal layer under porous asphalt might eliminate some of the problems experienced in the U.S. with open-graded asphalt courses.***

COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:
***In Germany, porous asphalt costs 100% more than conventional HMA.***

35 mm PHOTOS: NO ___ YES ROLL # ____ NEGATIVE #'S ________
VIDEOTAPE: NO ___ YES CASSETTE # ____
AUDIOTAPE: NO ___ YES CASSETTE # ____

REPORTER(S): ______________________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE 9-20-90 # 1

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Reconstruction of the Ml motorway to strengthen pavement and extend its service life (original construction: 1968).***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Motorway MI southbound, near junction 27, north of Nottingham, Nottinghamshire, United Kingdom.***

DATE OF CONSTRUCTION 9-20-90 LENGTH 9 (mi/km) # OF LANES 6 ***(Divided)***

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALs*** |
|---|---|---|---|
| WHEN OPENED | | | ACTUAL |
| CURRENT | 60,650 | 25 | DESIGNED |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***Maximum reconstruction taking place in inner (slow) lane; center and outer lanes are receiving lesser reconstruction. Inner lane pavement structure: 40mm hot-rolled asphalt (HRA) wearing course over 215mm heavy duty bitumen macadam upper road base over 125 mm HRA lower road base.***

ASPHALT CONTENT * (% OF MIX) AIR VOIDS CONTENT * (%)

MODIFIER TYPE * MODIFIER CONTENT * (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
*

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | | | |
| LONGITUDINAL CRACKING | | | |
| TRANSVERSE CRACKING | | | |
| RAVELLING | | | |
| ALLIGATOR CRACKING | | | |
| BLOCK CRACKING | | | |
| POTHOLES | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:
***Original pavement in northbound lanes shows little apparent distress. Motorway was built in 1968 and overlaid in 1981 with a 40 mm HRA wearing course. Decision to reconstruct was based upon deflection measurements. It was noted that the condition of the northbound lanes would require less reconstruction than witnessed for the southbound lanes.***

* See reverse and attached sheet.

**DRAINAGE FACILITIES:**
*Filter drains on verges (shoulders) and medians. These are being excavated and replaced with fresh limestone chippings.*

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*None*

**OTHER REMARKS:**

1. *Lanes milled out to required depths with a cold planer: 30mm on inner lane, 100mm on center lane, none on outer lane.*
2. *The old laydown of upperoad base on inner lane. Pavers have fixed screeds. Two pavers lay about 5,500 tons of mix per day. Laydown accomplished at 160°C.*

*(continued on attachment)*

**POST-VISIT DEBRIEFING** *NOTES:* *Details of Reconstruction:*

| | INNER (#1) LANE | CENTER (#2) LANE | OUTER (#3) LANE |
|---|---|---|---|
| Wearing Course (10yr service life) | 4omm 30% Hot-rolled Asphalt | 40mm 30% Hot-rolled Asphalt | 40MM 30% Hot-rolled Asphalt |
| Upper road base (resists rutting) | 115mm + 100mm Heavy duty bitumen macadam | 60mm 60% Hot-rolled asphalt base course | 60mm 60% Hot rolled Asphalt base course (Existing Surface) |
| Lower road base (resists tensile stresses) | 125mm 60% Hot-rolled Asphalt | EXISTING PAVEMENT STR | UCTURE |
| Subgrade/ Subbase | #100mm dense-graded Macadam over $200 to 300mm continuously graded limestone on a stiff marl. | | |

**APPLICABILITY TO U.S. PRACTICE:**
*Uncertain. This pavement structure should be compared to usual U.S. designs for similar cirumstances, to determine if equal or improved pavement service can be achieved at comparable costs.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Total project cost about $8,000,000 for reconstruction of 9 km (5.4 miles) of 6-lane pavement. This works our roughly to an average of $34.25 per square yard.*

**35 mm PHOTOS:** NO___ YES___ ROLL #___ NEGATIVE #'S______
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO YES CASSETTE #___

**REPORTER(S):** ____________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE 9-17-90 # 1

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Ultrathin Asphalt Wearing Course.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***RD 68 between Ste-lute and Thouare, Loire Atlantique, France***

DATE OF CONSTRUCTION 7-90 LENGTH _ _(mi/km) # OF LANES 2

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALs*** |
|---|---|---|---|
| WHEN OPENED | | | ACTUAL |
| CURRENT | ***Low*** | | DESIGNED |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***15 mm overlay laid with conventional paver.***

ASPHALT CONTENT 5.4 (% OF MIX) AIR VOIDS CONTENT 15 (%)

MODIFIER TYPE ***SBS Latex*** NOMINAL CONTENT 5 (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: 10mm. Usual gap-gradation: 83% between 6 and 10mm, 15% between 0.09 and 2mm, 2% limestone filler passing 0.09mm***

| DISTRESS TYPE | EXTENT OR FREQUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | I | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Excellent, fresh-appearing overlay on secondary road,***

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*This overlay is tradenamed COLRUG;it is marketed by the French contractor COLAS (S.A). It may be considered a proprietary formulation designed to satisfy the LCPC requirements for a very thin asphalt concrete overlay.*

**OTHER REMARKS:**
*The underlying pavement surface is prepared for COLRUG with a tack coat of polymer-modified asphalt emulsion. In this case, a COLAS proprietary product, EMULCOL, was used.*

**POST-VISIT DEBRIEFING NOTES:**
*These very thin asphalt overlays are used as an alternative to slurry seals to provide surface maintenance without changing the structural capacity of the pavement.*

**APPLICABILITY TO U.S. PRACTICE:**
*May provide alternative to slurry and chipseals. Systems such as COLRUG have the advantage of being laid with conventional pavers.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Comparable to slurry seals.*

**35 mm PHOTOS:** NO YES___ ROLL #____ NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #____
**AUDIOTAPE:** NO YES CASSETTE #____

**REPORTER(S):** ______________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-17-90 # 2

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Very thin pervious asphalt wearing course.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***RN 23, Le Chemin Nantais, Loire Atlantique, France***

DATE OF CONSTRUCTION 7-89 LENGTH _ _(mi/km) # OF LANES 2

| | ACTUAL ADT | % TRUCKS | | EALs |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | Low | | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***25 mm porous asphalt overlay.***

ASPHALT CONTENT 5.2 (% OF MIX) AIR VOIDS CONTENT 23 (%)

MODIFIER TYPE ***SBS Latex*** NOMINAL CONTENT 5 (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: 10mm. Gap-gradation: 86.5% between 6 and 10mm, 12% between 0.09 and 2mm, 1.5% filler passing 0.09mm.***

| DISTRESS TYPE | EXTENT OR FREQUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:
***Very open appearance; no visible distress.***

DRAINAGE FACILITIES:

COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):

*This overlay is tradenamed PERMFLEX; it is marketed by the French contractor COLAS S.A. It is proprietary formulation designed to satisfy the LCPC requirements for a thin porous asphalt overlay.*

OTHER REMARKS:
*The underlying surface was prepared by application **of** a tack coat **of** polymer-modified asphalt emulsion. In this case, a COLAS S.A. product EMULCOL, was used.*

POST-VISIT DEBRIEFING NOTES:
*These thin porous overlays are used **for** surface maintenance; they provide no additional structural capacity. The usual thickness is 40mm; the overlay here is thinner than normal to prevent frost buildup in the winter months.*

*The binder used in PERMFLEX is COLFLEX 253, a proprietary SBS latex-modified asphalt produced by COLAS S.A.*

*This overlay is placed with a conventional paver.*

APPLICABILITY TO U.S. PRACTICE:

*May provide a possible alternative to slurry and chip seals.*

COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:

*Uncertain. In France, polymer-modified HMA costs 20% more than conventional HMA.*

35 mm PHOTOS: NO ___ YES ___ ROLL # ___ NEGATIVE #'S ________
VIDEOTAPE: NO ___ YES ___ CASSETTE # ___
AUDIOTAPE: NO ___ YES ___ CASSETTE # ___

REPORTER(S): ____________________

FH.WA/AASHTO/NAPA SITE VISIT REPORT DATE 9-17-90 # 5

**DESCRIPTION OF NOVEL PAVEMENT FEATURE:**

*FILAFLEX: A reinforced bituminous membrane, made in-situ.*

**LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):**

*Demonstrated on a parking area at a hot-mix plant west of Nantes, Loire Atlantique, France.*

**COMMERCIAL SOURCE (IF PROPRIETARY):**

*Filaflex is a patented process of SCREG Routes Group.*

**DETAILS OF OPERATION:**

*This is an in-situ manufacturing process to produce a stress absorbing membrane interlayer made up of a film of polymer-modified asphalt binder strengthened by continuous polyester-fiber threads.*

*It is designed for maintenance of cracked asphalt and PCC pavements. It is intended as an impervious, crack-resistent base for asphalt wearing courses.*

*A single, large self-propelled machine sprays polymer-modifted asphalt emulsion or binder and immediately spreads chopped polyester threads on the binder. The binder is sprayed at 0.9 to 1.5 $kg/m^2$ while the threads are spread at 50 to 150 $g/m^2$.*

*Spreader trucks follow the main unit within 2 minutes, spreading 4/6 or 6/10 granite chips at a rate of 4 to 6 liters per $m^2$.*

(form continued on reverse side)

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

1. *The spreader truck tires pressed the chips into the polyester threads and the bituminous emulsion employed for the demonstration.*

2. *There was some pick-up of threads and emulsion on the truck tires.*

3. *The self-propelled binder/thread laydown unit costs about $600,000.*

4. *Since 1988, about one million $m^2$ of FILAFLEX has been successfully laid according to the manufacturer.*

**APPLICABILITY TO U.S. PRACTICE:**

*Uncertain.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Considered competitive in France to other maintenance treatments designed to control reflective cracking.*

**35 mm PHOTOS:** NO___ YES___ ROLL #____ NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #____
**AUDIOTAPE:** NO___ YES___ CASSETTE #____

**REPORTER(S):** ______________________________

FHJVA/AASHTO/NAPA SITE VISIT REPORT DATE 9-17-90 # 4

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

*Deformation-resistant overlay for bridge decks.*

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

*Anne de Bretagne Bridge, Nantes, Loire Atlantique, France*

DATE OF CONSTRUCTION 7-89 LENGTH _ _(mi/km) # OF LANES 4

| | ACTUAL ADT | % TRUCKS | EALS |
|---|---|---|---|
| WHEN OPENED | | | ACTUAL |
| CURRENT | Heavy | ***High*** | DESIGNED |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***60mm BETOFLEX overlay on PCC bridge deck***

ASPHALT CONTENT 5.5 (% OF MIX) AIR VOIDS CONTENT -(%)

MODIFIER TYPE ***SBS Latex*** NOMINAL CONTENT 5 (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: 14mm. Coarse aggregate and sand form continuously - graded blend. Filler content (passing 0.09mm) is 7.5% of total.***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***No apparent distress.***

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*Betoflex is a proprietary product of COLAS S.A.; it employs the COLFLEX 253 polymer-modified asphalt binder produced by COLAS.*

**OTHER REMARKS:**

*BETOFLEX is a deformation-resistant HMA designed for very heavy traffic loads on deformable support.*

**POST-VISIT DEBRIEFING NOTES:**

**APPLICABILITY TO U.S. PRACTICE:**

*Uncertain. Further investigations may be warranted.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Uncertain. In France, polymer-modified HMA costs 20% more than conventional HMA.*

**35 mm PHOTOS:** NO___ YES___ ROLL #____ NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #____
**AUDIOTAPE:** NO YES CASSETTE #____

**REPORTER(S):** ______________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-20-90 # 2

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***M40 Motorway construction***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Extension of the M40 motorway north from oxford, Oxfordshire***

DATE OF CONSTRUCTION ***1989-1990*** LENGTH - -(mi/km) # OF LANES 6

| | ***ACTUAL ADT*** | ***% TRUCKS*** | | ***EALs*** |
|---|---|---|---|---|
| WHEN OPENED | | ADT | ACTUAL | |
| PREDICTED | | 3000 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***40mm hot-rolled asphalt wearing course over 195mm heavy duty bitumen macadam upper road base over 125mm hot-rolled asphalt lower road base over 150mm better qualify crashed rock over 600mm crashed rock***

ASPHALT CONTENT 6.8 (% OF MIX) AIR VOIDS CONTENT - (%)

MODIFIER TYPE _ MODIFIER CONTENT 5 (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):*

***Top size: 14mm. Nominal composition: 70% Crashed Stone (retained on #7 sieve). 27-28% sand passing #7 sieve, retained on #200); and 2-3% limestone filler.***

* For HRA wearing course

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | | | |
| LONGITUDINAL CRACKING | | | |
| TRANSVERSE CRACKING | | | |
| RAVELLING | | | |
| ALLIGATOR CRACKING | | | |
| BLOCK CRACKING | | | |
| POTHOLES | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

1. *HRA wearing course employs 50 penetration grade asphalt cement.*

2. *HRA wearing course is batched on site. It is dressed with 20mm coated chippings applied at 12-13 kg/m².*

3. *Wearing course is laid at 160-l 70°C.*

4. *Road base mixes are hauled from 2 hours distance in order to take advantage of the best quality aggregate. About 20,000 tons of these mixes are laid each week Road base mixes were designed to purpose rather than batched to recipe. The upper road base was required to meet a refusal density criterion of 93%.*

**APPLICABILITY TO U.S. PRACTICE:**

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

**35 mm PHOTOS:** NO___ YES___ ROLL #___ NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO___ YES___ CASSETTE #___

**REPORTER(S):** ______________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE *9- 14-90* # *5*

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***SMA Overlay on heater-planed pavement surface.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Route 19, South of Schwabisch Hall, Baden- Wurttemberg, Germany***

DATE OF CONSTRUCTION ***9-14-90*** LENGTH_ _(mi/km) # OF LANES *2*

| | ***ACTUAL ADT*** | ***% TRUCKS*** | | ***EALS*** |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | | | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):

***25mm SMA overlay on heater-planed pavement.***

ASPHALT CONTENT *6.8* (% OF MIX) AIR VOIDS CONTENT *2-4* (%)

MODIFIER TYPE ***Cellulose fibers*** MODIFIER CONTENT *0.3* (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.): *

***Top size: 8mm. Nominal gradation: 90 · 100% passing 8mm, 30 to 55% passing Smm, 20-30% passing 2mm and 8-13% filler passing 0.09mm.***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | | | |
| LONGITUDINAL CRACKING | | | |
| TRANSVERSE CRACKING | | | |
| RAVELLING | | | |
| ALLIGATOR CRACKING | | | |
| BLOCK CRACKING | | | |
| POTHOLES | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Existing pavement showed some minor distress.***

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

**OTHER REMARKS:**

*This is considered an alternative to other possible overlay treatments.*

**POST-VISIT DEBRIEFING NOTES:**

*Paving train consisted of a heater-planer, a paver serviced from the front by a dump mix truck, and two steel- wheeled rollers.*

*The heater-planer heated the old pavement surface and planed it off to a predetermined depth. SMA was immediately placed and compacted. After rolling, surface of SMA looked very rich in binder so stone chippings were rolled on for extra friction. Mix occasionally showed some marking under the rollers.*

*Heater-planer technique is used only once due to large decrease in bitumen penetration. Next rehabilitation (in 2-3 years) will involve scarification and removal of pavement surface.*

**APPLICABILITY TO U.S. PRACTICE:**
*High.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*In Germany, SMA costs 50% more than conventional HMA.*

**35 mm PHOTOS:** NO___ YES___ ROLL #____ NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #____
**AUDIOTAPE:** NO___ YES___ CASSETTE #____

**REPORTER(S):** ____________________

FI-IWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-17-90 # 3

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Porous Pavement for noise reduction and rain water flow.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***Boulevard Dolon, Nantes, Loire Atlantique, France***

DATE OF CONSTRUCTION 7-89 LENGTH _ _(mi/km) # OF LANES 4

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALs*** | |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | | | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***20rnm Pervious Asphalt Wearing Course over 60mm pervious bituminous Macadam base course.***

ASPHALT CONTENT * (% OF MIX) AIR VOIDS CONTENT * (%)

MODIFIER TYPE * . MODIFIER CONTENT * (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
*

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***The 80 mm thickness is greater than usual for pavements of this type to provide the capacity to temporarily store significant volumes of rainwater.***

* See reverse

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*Permflex is a proprietary thin pervious asphalt produced by COLAS S.A. COLFLEX 253 is an SBS latex-modified asphalt binder produced by COLAS S.A.*

*Pervious pavement is designed to reduce traffic noise and control flow of rain water.*

*Both courses employ gap-graded aggregate.*

**POST-VISIT DEBRIEFING NOTES:**

| | Wearing course | Base course |
|---|---|---|
| Asphalt Content | 5.2% COLFLEX 253 | 4.8% 60/70 Bitumen |
| Air Voids Content | 20% | 20% |
| Modifier Type | SBS Latex | None |
| Modifier Content | 5% Nominal | - |
| Aggregate Gradation: | | |
| Coarse | 86.5% 6mm - 10 mm | 84% 10mm - 14mm |
| Sand | 12% 0.09mm - 2mm | 14.5% 0.09mm - 3mm |
| Filler | 1.5% passing 0.09mm | 1.5% passing 0.09mm |

**APPLICABILITY TO U.S. PRACTICE:**

*Uncertain, but may warrant investigation as alternative to open-graded friction courses and porous pavement.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Unknown. In France, polymer-modified HMA costs 20% more than conventional HMA.*

**35 mm PHOTOS:** NO YES___ ROLL # NEGATIVE #'S________
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO___ YES___ CASSETTE #___

**REPORTER(S):** ____________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE *9-17-90* # *6*

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Construction of a special overlay to prevent reflective cracking.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***RN 165, Sautron, Loire Atlantique, France***

DATE OF CONSTRUCTION 9-17-90 LENGTH__ (mi/km) # OF LANES *4*

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALs*** |
|---|---|---|---|
| WHEN OPENED | | | ACTUAL |
| CURRENT | High | | DESIGNED |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***30mm special wearing course over a 15mm special, anti-reflective cracking binder course.***

ASPHALT CONTENT * (% OF MIX) AIR VOIDS CONTENT * (%)

MODIFIER TYPE * MODIFIER CONTENT * (% OF MIX)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):
*

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | | | |
| LONGITUDINAL CRACKING | | | |
| TRANSVERSE CRACKING | | | |
| RAVELLING | | | |
| ALLIGATOR CRACKING | | | |
| BLOCK CRACKING | | | |
| POTHOLES | | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

* See table on reverse

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*The binder course is a proprietary product of COLAS S.A. called SAFLEX. The wearing course is a proprietary COLAS S.A. product called RUFLEX.*

**OTHER REMARKS:**

*The wearing course uses a gap-graded aggregate. It contains no large aggregate (top size is about 3/8 inch), but the modified binder is formulated to prevent rutting. Rolling with steel-wheeled rollers left no roller marks or evidence of significant compaction.*

**POST-VISIT DEBRIEFING NOTES:**

| | Wearing course | Base course |
|---|---|---|
| Asphalt Content | 5.6% COLFLEX 253 | 9.5% COLFLEX 253 |
| Air Voids Content | | |
| Modifier Type | SBS LATEX | SBS LATEX |
| Modifier Content | 5% Nominal | 5% NOMINAL |
| Aggregate Gradation: | | |
| Coarse | 65% 6mm · 10mm | 46% 0 · 2mm<br>35% 2mm · 4mm |
| Sand | 35% 0 · 2mm | 17% 0 · 3mm ROLLED SAND |
| Filler | | 2% Limestone |

**APPLICABILITY TO U.S. PRACTICE:**

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

**35 mm PHOTOS:** NO___ YES___ ROLL #___ NEGATIVE #'S________
**VIDEOTAPE:** NO YES___ CASSETTE #___
**AUDIOTAPE:** NO YES CASSETTE #___

**REPORTER(S):** ________________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE *9-17-90* # *7*

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Chip seal constructed with modified asphalt emulsion and hot, pre-coated chips.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***RN 171 Eastbound, near La Baule, Loire Atlantique, France.***

DATE OF CONSTRUCTION 7-89 LENGTH 3.5 (mi/km) # OF LANES *4*

| | ACTUAL ADT | % TRUCKS | EALs | |
|---|---|---|---|---|
| WHEN OPENED | | | ACTUAL | |
| CURRENT | 25,000 | 10 | DESIGNED | |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***Paver-laid chip seal. Binder layer of polymer-modified 60/70 penetration-grade asphalt emulsion applied at 0.95 kg/m²; chipss spread at a rate of 25 kg/m².***

ASPHALT CONTENT N/A (% OF MIX) AIR VOIDS CONTENT *N/A (%)* NOMINAL

MODIFIER TYPE ***Neoflex (SBS Latex)*** MODIFIER CONTENT *5* (% OF BINDER)

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***6mm to 10mm chips precoated with 25 weight percent of hot sand-asphalt (5.5 % asphalt, 94.5% sand).***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Pavement had an open look There was no apparent distress except for some minor tearing alone the centerline of the driving lane. Considering the traffic volume and loads, the performance was judged as very impressive.***

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*The system employed for this project is tradenamed NOVACHIP, It is a proprietary product of SCREG Routes Group and conforms to the general LCPC specifications for paver-laid chipseal.*

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

*Paver-laid chip seals are intended for surface maintenance without structural effect. They seal the surface and increase skid resistance, but are substantially less noisy than conventional chip seals. It is claimed that loose chips are virtually eliminated due to the precoating and use of modified binder.*

*NOVACHIP is laid with a purpose-built, self-propelled unit that sprays the binder, spreads the hot, pre-coated chips and smooths the chip seal. Additional rolling is accomplished by a rubber-tired roller and a steel-wheel roller acting in tondem. This system can be applied at a rate of 3500 $m^2/hr$ at forward speeds of 0.7 mph. The paver costs approximately $800,000; there are five in operation in France.*

**APPLICABILITY TO U.S. PRACTICE:**
*May provide alternative maintenance treatment for high-volume interstate and primary routes. Some similarity to chip seals applied with modified asphalt binders in Texas and New Mexico.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Probably higher. Costs may be offset by improved performance.*

**35 mm PHOTOS: NO YES___ ROLL # NEGATIVE #'S ________**
**VIDEOTAPE: NO___ YES___ CASSETTE # ___**
**AUDIOTAPE: NO YES CASSETTE # ___**

**REPORTER(S):** ________________________________

FHWA/AASHTO/NAPA SITE VISIT REPORT DATE 9-17-90 # 8

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Very thin asphalt concrete overlay for surface maintenance.***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***N 165, 30 km West of St. Nazaire, France.***

DATE OF CONSTRUCTION ***1988*** LENGTH _ _(mi/km) # OF LANES 4

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALs*** |
|---|---|---|---|
| WHEN OPENED | | | ACTUAL |
| CURRENT | ***High*** | | DESIGNED |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***1 Omm wearing course overlaid on existing pavement.***

ASPHALT CONTENT 6 (% OF MIX)' AIR VOIDS CONTENT 15 (%)[1]

MODIFIER TYPE ***(SBS Latex,)*** MODIFIER CONTENT 5 (% OF MIX)'

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: 10mm. Usual gap-gradation: 83% between 6 and 10mm, 15% between 0.09 and 2% limestone filler passing 0.09mm.***

| DISTRESS TYPE | EXTENT OR FREOUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Excellent. No visible distress.***

1 Nominal

(form continued on reverse side)/26 JUNE 90

**DRAINAGE FACILITIES:**

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*This overlay is tradenamed MEDIFLEX. It is a proprietary product of SCREG Routes Group,*

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

*These very thin asphalt concrete overlays are employed as an alternative to slurry seals to provide surface maintenance without changing the structural capacity of the pavement.*

*They are laid with conventional pavers.*

**APPLICABILITY TO U.S. PRACTICE:**

*May provide an alternative to slurry and chipseals. They offer the advantage of being laid with conventional paving equipment.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*In France, comparable to slurry seals.*

**35 mm PHOTOS:** NO___ YES___ ROLL #___ NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #___
**AUDIOTAPE:** NO___ YES___ CASSETTE #___

**REPORTER(S):** ____________________

**FHWA/AASHTO/NAPA SITE VISIT REPORT** DATE 9-18-90 # 1

DESCRIPTION OF NOVEL PAVEMENT FEATURE:

***Very thin Porous Asphalt Overlay***

LOCATION (COUNTRY, LOCAL GOVERNMENT UNIT, HIGHWAY #, MILEPOST):

***A47 Motorway South of Givois (Suburban Lyon), France.***

DATE OF CONSTRUCTION 7-89 LENGTH ____ (mi/km) # OF LANES 4

| | ***ACTUAL ADT*** | ***% TRUCKS*** | ***EALs*** |
|---|---|---|---|
| WHEN OPENED | | | ACTUAL |
| CURRENT | ***80,000 winter***<br>***160,000 Summer*** | | DESIGNED |

BRIEF DESCRIPTION OF PAVEMENT STRUCTURE (# OF LAYERS, LAYER THICKNESSES, etc):
***40mm overlay on existing pavement surface.***

ASPHALT CONTENT 6.6 (% OF MIX) AIR VOIDS CONTENT 20 (%)

MODIFIER TYPE ***Reclaimed tire rubber treated with aromatic oil and catalyst.*** MODIFIER CONTENT 5 (% OF BINDER)[1]

AGGREGATE DESCRIPTION (GRADATION, MATERIAL TYPES, etc.):

***Top size: 10mm. Gap-gradation: 88% between 6mm and 10mm, 11% between 0.09 and 2mm, 1 % filler passing 0.09mm. Aggregate is exclusively crushed porphyry.***

| DISTRESS TYPE | EXTENT OR FREQUENCY LOW | MEDIUM | HIGH |
|---|---|---|---|
| RUTTING | None | | |
| LONGITUDINAL CRACKING | None | | |
| TRANSVERSE CRACKING | None | | |
| RAVELLING | None | | |
| ALLIGATOR CRACKING | None | | |
| BLOCK CRACKING | None | | |
| POTHOLES | None | | |

NARRATIVE DESCRIPTION OF PAVEMENT CONDITION:

***Appears fresh and in excellent condition. There is no apparent distress.***

(form continued on reverse side)/26 JUNE 90

[1] Nominal

**DRAINAGE FACILITIES:**
*Adequate drainage must be provided to allow water flow through and out of the pavement surface.*

**COMMERCIAL SOURCE (IF PROPRIETARY FEATURE):**

*This project used a proprietary product DRAINOCHA PE marketed by BEUGNET Technical management. The asphalt-rubber binder is also a proprietary product, FLEXOCHAPE E, produced by BEUGNET.*

**OTHER REMARKS:**

**POST-VISIT DEBRIEFING NOTES:**

*This product is designed to meet the general LCPC specification for porous asphalt overlays.*

*The overlay is placed with a conventional paver.*

**APPLICABILITY TO U.S. PRACTICE:**
*May provide a possible alternative to slurry and chip seals.*

**COSTS RELATIVE TO CONVENTIONAL U.S. CONSTRUCTION PRACTICE:**

*Uncertain. In France, modified HMA costs 20% more than conventional HMA.*

**35 mm PHOTOS:** NO___ YES___ ROLL #___ NEGATIVE #'S_________
**VIDEOTAPE:** NO___ YES___ CASSETTE #____
**AUDIOTAPE:** NO___ YES___ CASSETTE #____

**REPORTER(S):** ______________________________