tion of Soils and Aggregates for County Roads. Highway Extension and Research Project for Indiana Counties, Purdue Univ., West Lafayette, IN, County Highway Series No. 13, Dec. 1971.
2. D.G. Shurig, J.E. Hittle, E.J. Yoder, and W.H. Goetz. Field Investigation of County Road Bases and Subgrades. Highway Extension and Research Project for Indiana Highways, Purdue Univ., West Lafayette, IN, County Highway Series No. 14, Jan. 1977.
3. High Load Penetrometer Soil Strength Tester. Commercial Airplane Division, Boeing Company, Renton, WA, Document D6-2455, 1971.
4. D.J. VanVuuren. Rapid Determination of CBR with the Portable Dynamic Cone Penetrometer. The Rhodesian Engineer, 1969.
5. B. Clegg. An Impact Device for In-Situ Base Course Evaluation. Univ. of Western Australia, Nedlands, 1975.

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Surfacings for Low-Volume Roads in the Third World

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This paper is a review of planning criteria for use in deciding when to provide low-volume roads with permanent surfacings and appropriate techniques for asphalt surfacings on such roads in the third world. Planning criteria involve benefit/cost studies, changes in road user costs (mainly in vehicle operating costs) balanced with the costs of the road improvement, and subsequent changes in road maintenance costs. Pavement deterioration under traffic is influenced considerably by climate, by the road-making materials and methods employed, and by the care taken in pavement maintenance. The choice of bituminous surfacing technique has a considerable influence and the thesis developed is that the pursuit of high stability and good load distribution properties, both desirable in bituminous mixtures on heavily trafficked roads and airfields, has militated against the flexibility that is a prime requirement for asphalt surfacings on low-volume roads. Types of surfacing with this property of flexibility are reviewed.

As the building of main road networks of Third World countries is moving toward completion, emphasis in their road-building programs is changing toward the construction, improvement, and maintenance of secondary and feeder roads that are being built as an essential component of agricultural development schemes. Most of these feeder roads carry very light traffic and are built of earth and gravel. The secondary roads often make up more than half of the total network and generally carry traffic within the range 30-500 vehicles/day. Most of these secondary roads also have surfacings of earth or gravel and there are great pressures to provide them with permanent bituminous surfacings. These pressures are generated by the desire to maintain a free and unencumbered passage for vehicles in wet weather and to remove the nuisances of dust and corrugated bumpy surfacings in dry weather. They are often exacerbated by the incapacity of local road maintenance organizations to provide even minimum routine maintenance on the earth and gravel roads. This paper has two objectives; one is to review criteria for deciding when it is desirable to provide such roads with permanent surfacings of asphalt or concrete and the other is to consider appropriate techniques for bituminous surfacings on such roads.

CRITERIA FOR PROVIDING ROADS WITH PERMANENT SURFACINGS

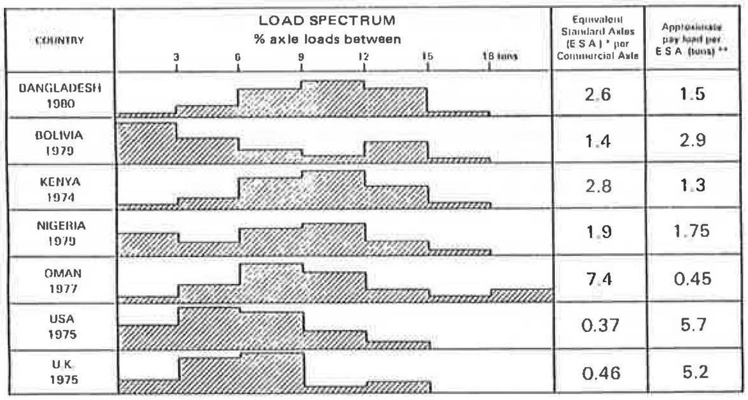
To the transport economist the criterion for providing roads with permanent surfacings is that of minimizing total transportation costs. Vehicle operating costs are normally reduced substantially following the provision of a permanent surface and the calculation is usually undertaken as a benefit/cost study, with the benefits expressed as a rate of return on the investment necessary to upgrade the road. To the politician the criterion may lie at least partly in the perceived gratitude of constituents. Between them there is the uneasy seat of those charged with allotting scarce capital resources among all the different heads of government expenditure. Our stand must be with the transport economist, and in taking this stand we are not functioning as lobbyists--we are seeking to provide a factual basis for making wise decisions on what resources should be devoted to road works and how these resources should be most effectively used.

The basis for benefit/cost calculations concerning the upgrading of roads from earth or gravel to bituminous-surfaced is well established. The basic information required for such calculations consists of data on traffic flow and predictions of likely future growth on costs of the various procedures of road construction and maintenance, on pavement deterioration under the combined effects of traffic and weather, and on the influence of road conditions, particularly of pavement roughness on vehicle operating costs. Typically, in open African savannah such calculations will indicate that rates of return exceed the opportunity costs of capital with present traffic flow between 150 and 400 vehicles/day. Somewhat lower traffic thresholds are to be expected in hilly country and in wet climates. It is always desirable to make sure that local circumstances have been fully considered in assembling the data and in the assumptions that have to be made. Some of the pitfalls are indicated briefly below.

The data on traffic flow must include a realistic estimate of the spectra of vehicle and axle loading. Enforcement of vehicle-loading regulations is generally weak in Third World countries. Overloading beyond the rated capacity of trucks is commonplace and the axle loading spectra are frequently heavier than on main roads in industrialized countries (Figure 1). There is evidence that the fourth power law derived from the American Association of State Highway Officials (AASHO) Road Test--that damage to a pavement is proportional to the fourth power of the wheel load--applies at least approximately on lightly constructed bituminous pavements. Designs on the assumption that legal loading limits are not exceeded can lead to pavement deterioration 10 times more rapid than was intended.

Construction costs will vary from one locality to another. At one locality they will be affected

Figure 1. Typical axle load spectra for commercial vehicles.



* Equivalent Standard Axle (ESA) = 18,000lb (8200kg)
** This column indicates the payload per unit of pavement damage

considerably by the geometric standards selected for the paved roads and by the extent of road widening and relocation deemed to be necessary. Computer programs are available for the rapid comparison of the rate of return as it is affected by changes in standards of geometric design. The British road transport investment model (RTIM), based on experience in East Africa (1), can be used to compare designs with different specified standards. The World Bank's highway design and maintenance model (HDM) (2) has the potential to make optimum use of specific design components.

Whether such studies are undertaken manually or with the assistance of computer models, it is essential that the relations employed be validated by local experience. This applies with the relation used between vehicle operating costs and road conditions and even more so with the assumptions made on pavement deterioration.

Information on the effects of road conditions on vehicle operating costs is sparse, particularly on the most relevant aspect for this type of study--the effects of road roughness on vehicle operating costs. In effect, at this time only three sources are used: the classic study by Moyer and Winfrey, completed in the 1930s; a synthesis of data and judgment by de Weille published by the World Bank in 1966 (3); and a study undertaken by the British Transport and Road Research Laboratory (TRRL) in cooperation with the Kenya Ministry of Works and the World Bank in the early 1960s (4). Further studies, with World Bank and United Nations Development Program (UNDP) assistance, are in progress in Brazil and India, and these should soon yield useful data. Even on roads that carry no more than 100 vehicles/day, the investment in providing and operating the vehicles considerably exceeds the investment in construction and maintenance of the road. It is odd to find so little research undertaken on the effects of road conditions on vehicle operating costs, particularly in view of the huge and continuing investment in research on pavement design.

Pavement deterioration is affected by many things. Traffic loading is of course always an important factor. On earth and gravel roads the nature of the road material, the climate, and the frequency and nature of maintenance are important influences. These are often known as matters of local experience; but they need to be made numerate in order both to plan the maintenance of such roads in the most effective way and to produce credible cost/benefit studies to establish when the provision of a permanent surface is warranted.

The system can be beaten in various ways, some more laudable than others. For instance, a district engineer who is both competent and cunning will concentrate efforts on improving the drainage and layout of a road and perhaps neglect the maintenance of the gravel running surface. He or she thus generates pressures for the upgrading of the pavement (by both popular clamour and inflated vehicle operating costs) and at the same time completes work that will reduce the capital cost of the upgrading. In the Third World such cunning is as yet rare. It is more common to find highway departments struggling, often with indifferent success, to build up effective road maintenance organizations.

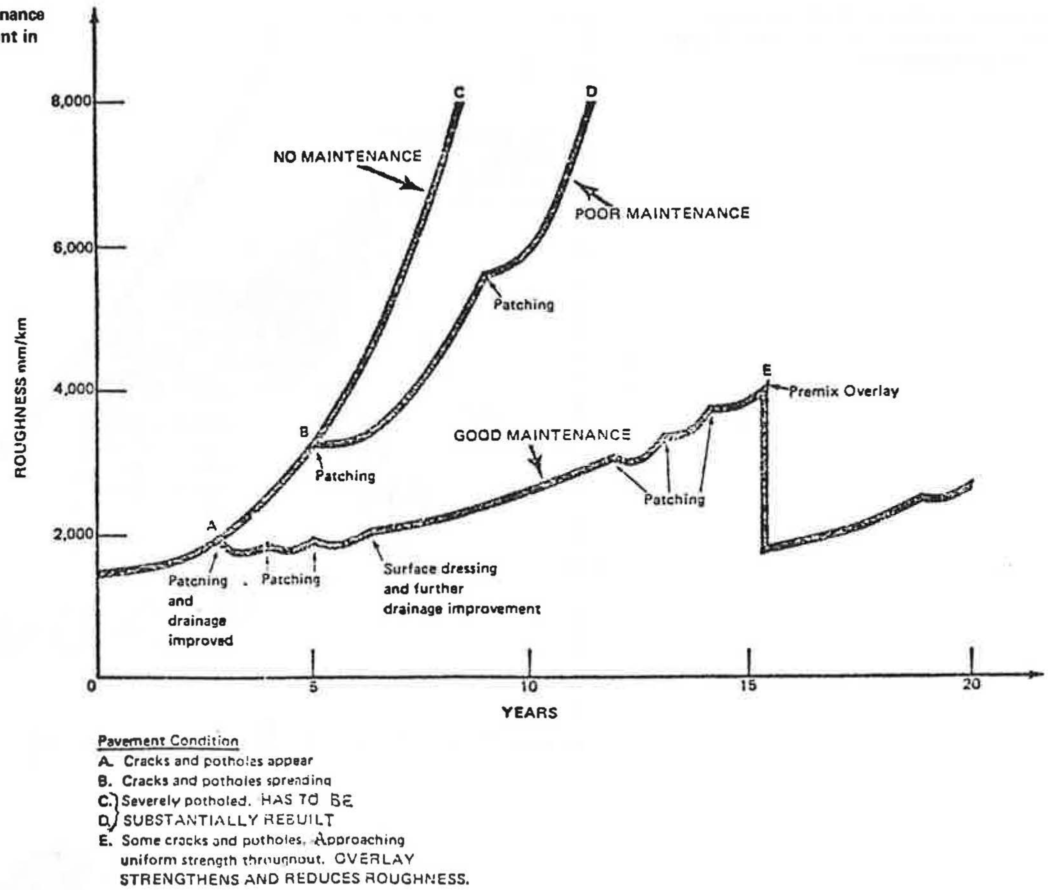
Bituminous pavements are normally designed with the intention that the next major capital investment in strengthening, and possibly widening, will not be required for some 10-20 years. Normal routine maintenance is presumed, and on more lightly trafficked roads that have lightly constructed pavements this maintenance inevitably involves the correction of some faults and omissions in construction; for instance, to correct weaknesses in drainage that become apparent and to repair potholes where construction faults occur. Figure 2 shows the effects of different maintenance policies on pavement deterioration.

The efforts made by both governments and aid donors to build up effective road maintenance organizations have not as yet been markedly successful and it is evident that the neglect of maintenance is leading to considerable waste of resources in both inflated vehicle operating costs and increased expenditure on the roads. This poses a dilemma that is becoming more serious as the focus of effort moves from main roads to secondary roads. We cannot expect the relatively high technologies of detailed soil and hydrological surveys of risk analysis in design and careful control during construction to be commonly available in improving and maintaining secondary roads. With lower levels of technology used in construction, it will be increasingly difficult to keep such roads in serviceable condition. The answer that is sought must be simple and more robust.

BITUMINOUS SURFACINGS

The evolution of bituminous surfacings has taken different paths in different parts of the world. For instance, the paramount bituminous premixes in the United States (asphaltic concrete), Great Britain (rolled asphalt), and the Federal Republic of Germany (Gussasfalt) are different materials in both composition and performance. The easy explanation that they were evolved to meet different needs conceals a fascinating story that is too long to

Figure 2. Effects of maintenance on light bituminous pavement in wet or monsoon climate.



recount here. The relevant point is that the Third World has not had the time or the necessary pressures for bituminous surfacings to be evolved that are manifestly adapted to their needs. They have had to use imported technologies, sometimes inherited from a colonial power, more often nowadays imported by foreign consultants who use experience from their home countries.

This can produce some odd anomalies. For instance, in Egypt bituminous roads are surfaced with asphaltic concrete and the same material is used for pavement maintenance. Surface dressing (chip and seal) is practically unknown. Twenty degrees of latitude to the west, in Tunisia, almost all the bituminous roads are surfaced with single- or double-surface dressings and the pavements are maintained by further surface seals by using bitumen emulsions. Both countries are evolving bituminous surfacing techniques to suit their needs, but in neither country have local skills evolved to the level that they are able to take full advantage of the variety of bituminous road surfacings. So there are two problems, one to decide which forms of bituminous surfacing are inherently suitable for use on roads in a particular country and the other to establish in the country a corps of people who have the necessary skills in the appropriate road-surfacing processes.

Physical environment has a considerable effect on this choice and the two predominant influences are those of climate and availability of road-making materials. In a dry climate pavements will tend to get stronger under the compacting action of traffic. In a wet climate they may get weaker (Figure 3). An equable climate (i.e., with only very small diurnal and seasonal temperature changes) favors the use of concrete pavements. A climate with large temperature changes is inimical to concrete because an important factor in the deterioration of concrete pavements is thermal expansion and contraction of the concrete in association with traffic loading.

Some countries must adapt their road-making methods to a limited choice of materials. At the extreme are places such as Malta, Bermuda, and some Caribbean islands where the only available material is the soft limestone from which the islands are made. The Deccan area of India is a vast plain of expansive clay without resources of rock for road-making. Similarly, coastal areas of Bangladesh are some 200 miles from the nearest supplies of rock for crushing and in both these areas bricks are used extensively in road-making. In Africa the quality of the indigenous lateritic and other road-making gravels varies considerably between different areas as does the access to rock suitable to be crushed for road works. All these factors have an influence on the choice of techniques for using bituminous materials in road-making, so much so that there are grave risks in attempting to generalize.

Some generalization will be useful, and the first generalization to make concerns the function of a bituminous surfacing on a low-volume road. The intrinsic strength and load-spreading properties required on lightly trafficked roads will normally be provided in the road base and subbase. The functions of the bituminous surfacing are to resist the abrasive action of traffic and to prevent rain from entering the road structure. The primary properties required are stickiness so that it adheres well to road-making aggregates and extensibility so that it can accommodate strains without rupturing as the pavement moves under traffic loads.

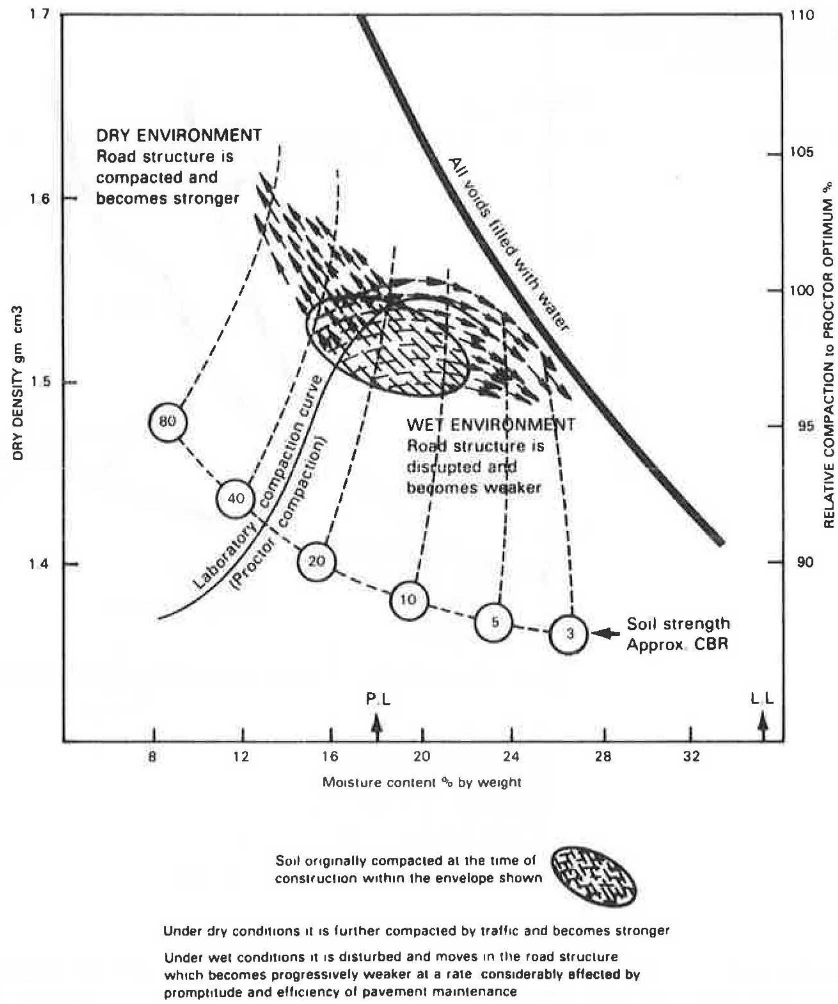


Figure 3. Density, moisture content, and strength illustrated by typical sandy clay; plastic limit is 18 percent, liquid limit is 35 percent.

Stickiness can be taken for granted for the time being as one of the recognized attributes of bituminous materials; extensibility needs some further explanation.

The term flexible pavement has long been synonymous with bituminous materials and the word flexible implies extensibility. But, in the search for stronger pavements to accommodate heavier and heavier traffic on roads and airfields, development has moved in another direction and emphasizes stiffness, rigidity, and load-spreading properties as desirable attributes rather than flexibility. In the structural methods of pavement design that are pursued so assiduously high stiffness is sought, with the limiting criteria being defined in terms of critical stress. In the United States the generic name for dense premixed bituminous materials, asphaltic concrete, implies the move from flexibility toward rigidity as a desirable attribute. There is no doubt that this is the right direction in the evolution of heavy duty pavements. But, is it right for the lightly constructed pavements that we have to use? I think not.

In lightly constructed pavements strains develop in the surface layer for many reasons--elastic deformation of the road pavement under traffic loads, permanent deformation because of the compacting action of traffic and, often, more deep-seated movements associated with changes in the moisture regime under roads. Assiduous control of compaction during construction can go some way to reduce these strains but will not eliminate them. In any case, such assiduous control is not likely to be the normal rule in improving secondary roads in the Third World. In providing the initial bituminous surfacing and in subsequent strengthening and surface maintenance, a primary requirement is that the surfacing should be able to accommodate strain without cracking or raveling. Where does this take us in selecting appropriate forms of bituminous surfacing for such roads?

We can get little guidance from the fund of knowledge now available on pavement design. Indeed, concentrating as it has on producing strong pavements for heavily trafficked roads, it may be misleading or inadequate. The aim for high stabilities has produced a trend toward bituminous mixtures in which the bitumen is present in the form of very thin films between tightly packed crushed stone, thus high stability is obtained at the expense of an ability to accommodate strain. The literature is growing on the behavior of dense asphaltic concretes under fatigue loading; it provides some guidance on how to design these mixtures to accommodate transient strains. But, these studies have not included asphaltic surfacings in which the bitumen is present in fairly thick films as these are regarded correctly as intrinsically unsuitable for use on heavily trafficked roads and airfields. And it is these surfacings in which the bitumen is present in fairly thick films that retain the flexibility necessary for use on low-volume lightly constructed roads.

What types of asphaltic surfacing are these? There are broadly two types of surfacing in which relatively thick films of bituminous binder are used:

1. Surface treatments, in which a film of asphalt is applied to the road surface followed by an application of chippings and
2. Mixtures of asphalt and coarsely graded aggregate.

The mixtures can take many forms, from grouting through mix-in-place, to premixes of the open-textured macadam type or denser gap-graded mixtures. All have the attribute that they are able to accept high transient and permanent deformations without cracking or disintegrating.

The two forms of treatment are complementary rather than alternatives. The normal sequence will be to use surface dressing as the first bituminous surfacing on a newly constructed bituminized low-volume road and then, when the road comes to be strengthened or the riding quality improved, to employ a bituminous mixture, either grouting or a premix.

Surface Dressing

Essentially, surface dressing involves application of a uniform film of asphalt to the prepared road base followed by a layer of single-sized stone. The asphalt seals and binds the road surface and the stone provides the running surface. Little quantitative evidence has been gathered on the rate of pavement deterioration of surface-dressed low-volume roads in comparison with such roads surfaced with other bituminous materials. Road Note 31 (5) tentatively suggests that a surface-dressed road will tolerate three times the transient deflection under load and still give the same design life as a similar pavement surfaced with 2 in of asphaltic concrete and there are many examples in practice of roads that consist of surface-dressed granular bases that give good service for many years, with traffic up to and sometimes in excess of 1000 vehicles/day.

A large body of literature gives practical recommendations on how to make good bituminous surface dressings and this paper will not replicate these or even attempt to review them.

Considerable skill is needed in choosing the appropriate specification for given circumstances. The stone chippings should be single-sized and the appropriate size must be chosen in relation to the type of road surface being treated and the traffic--large chippings for soft surfaces and heavy traffic, smaller chippings for harder surfaces and lighter traffic. In double-surface treatments it is appropriate to use two different sizes of chipping for the two treatments so that one can be bedded firmly in the interstices of the other. Opinions vary as to order in which the chippings are to be applied, and this is a point of some subtlety. If for instance the two treatments are to be applied one shortly after the other, it may be best to use the larger chipping (say 3/4-in nominal size) first followed by a further seal and application of a smaller chipping (say 3/8-in nominal size). But, if for any reason the second treatment is to be delayed, a chipping of medium nominal size (say 1/2 in) would probably be best for the first dressing.

Penetration-grade asphalts are frequently used for surface dressing in hot countries. In many such countries road temperatures can be quite low, especially in the early morning, and in these circumstances it is increasingly common practice to make the asphalt more fluid by incorporating small proportions of an oil of medium volatility such as kerosene. If this is done, it is vital that instructions be simple and effective to avoid the risk of fire.

Probably the most important factor in influencing the performance of surface dressings is that the rate of spread of asphalt be even and appropriate for the circumstances. Again, this is a point of some subtlety; the rate of spread of asphalt must be chosen in relation to the absorptive characteristics of the surface being treated, the size of the chippings, and the expected traffic intensity. One of the earliest attempts to rationalize this choice was in Hansen's concept of the average least dimension of the chippings to indicate the thickness of asphalt film that is appropriate for the size and shape of the chippings (6). Most current specifications embody this principle (7-10).

Even so, knowledge on how to specify and lay surface dressings has been derived entirely from carefully observed practical experience. It is none the worse for that. But one result is that it attracts little academic attention either in teaching or research, and many highway engineers never have the opportunity to learn the intricacies involved in securing good surface dressing.

The manufacturing process for surface dressing is undertaken on the road. This militates against the careful control that is necessary to produce a good product, in contrast with premixed bituminous materials in which a large part of the manufacturing process is carried out in a stationary plant on which control of the process is somewhat easier. This is not a disabling disadvantage; witness the consistently high quality of surface dressing done in Australia and New Zealand and the good service from them obtained as a result. But, it is the reason why surface dressing falls into disrepute in some countries where site control has been indifferent. One reason for using double surface dressings in new construction is that the second dressing corrects imperfections that arise from indifferent workmanship in the first. And variants exist that have the same objective, such as the Cape Seal used extensively in southern Africa. In this process the surface voids in the finished surface dressing are filled with an application of coated grit. Special machinery and skilled staff are needed. In industrialized countries these are often provided by specialist firms, a trend that should perhaps be encouraged in Third World countries.

Grouting

Grouting was one of the earliest forms of bituminous surfacing to appear. In it the upper layers of a crushed stone base are grouted with applications of liquid asphalt and the surface voids are then filled with fine aggregate. This process was done by hand, aided by simple machinery often little more than a roller and a simple hand sprayer. Though it did produce a robust surfacing capable of accommodating quite a large strain, construction was tedious and it used a lot of asphalt. In its semi-grout form, in which the aim is for the asphalt to penetrate no more than 2 in, it remains a possible surfacing in areas where skilled hand labor is readily available. It is still in regular use for instance in India, Bangladesh, and Indonesia. But it is subject to vagaries in skill of the workers. Both the spreading of the stone and the application of the bitumen can be mechanized and thus improve output and uniformity. The surface normally has it be sealed with a surface dressing to render it waterproof.

Mix-in-Place

Many thousands of miles of rural road in North America were first surfaced with mix-in-place bitu-

Table 1. Typical bitumen macadams.

Item	Open-Textured Wearing Course, Crushed Rock[a]		Single Course[a]		Open-Graded Base Course, Crushed or Natural[b]	
	Sieve Size (mm)	Percent Passing	Crushed Rock Percent Passing	Gravel	Sieve Size (mm)	Percent Passing
Aggregate	50		100	100		
	37.5		90-100	95-100		
	28		55-90	60-80	25	100
	20	100			19	90-100
	14	90-100	35-55	40-60		
	10	55-75			9.5	20-55
	6.3	25-45	20-30	30-45		
					4.75	0-10
	3.35	15-25	10-20	20-35		
					2.36	0-5
	300	2-10	2-10	5-15		
	75	2-6		2-6	75	0-2
Bitumen content (% total mix by weight)		4.8 ± 0.5, 4.6 for limestone	3.9 ± 0.6, 3.6 for limestone	5.0 ± 0.6	Determined from trial mixes	

Note: Binder for the open-textured wearing course and the single course was medium curing cutbacks and 300 penetration for hand laying; medium curing cutbacks and 300 and 200 penetration for machine laying. Binder for open-graded base course was medium setting, high float medium setting, and cationic medium setting.

[a]From British Standard 4987, coated macadam for roads and other paved areas.
[b]From the Asphalt Institute (7).

minous surfacings, and it is surprising that the process has found little use in the Third World. Perhaps one reason is that roads in developing countries have usually been designed as major new investments rather than being built by stage construction methods. (How would a mix-in-place surfacing be treated in a pavement design analysis?) The process employs natural gravels or sandy soils and cut-back asphalts or slow-breaking emulsions, the materials being mixed in place either with blade graders or with traveling mixers. When slow curing cutbacks are used, the mixed materials remain workable for a considerable time and a bumpy damaged surface can be restored by scarifying and remixing. Such was done, for instance, in Scandinavia in the 1950s by using heavy road oils and glacial gravels to provide thin pavements that could be restored after winter frost heave. It seems likely that this process has application on more lightly trafficked roads in regions of the developing world where there are readily available sources of sandy and gravelly soils of low plasticity.

Bitumen Macadams

Bitumen macadams materials evolved from grouted macadam following the realization that it is more convenient to coat the stone in a mixer than on the road. For some years such mixtures were marketed under proprietary names, but as experience became codified standard specifications were evolved for a wide variety of mixtures that go under this generic name. Essentially they are mixtures of coarse aggregate, fine aggregate, filler (mineral dust), and bitumen. The fine aggregate is not present in sufficient quantity to fill the voids in the coarse aggregate. As an approximate rule, mixtures that contain less than 15 percent passing a No. 8 American Society for Testing of Materials (ASTM) sieve are designated as open-textured bitumen macadams and those with 15-30 percent passing a No. 8 ASTM sieve are designated as a medium-textured.

The original concept of these materials has been modified by the introduction of dense bitumen macadams that have continuous gradings and are nearly but not quite asphaltic concrete. Here we are concerned with the open- and medium-textured macadams. The surface area of aggregate per unit volume is low in comparison with a dense mixture. Hence, with approximately the same amount of bitumen per unit volume the film of bitumen over the aggregate is considerably thicker. The filler has a special function: intimately mixed with the bitumen it produces a binding matrix that is more viscous and greater in volume than the bitumen itself. These mixtures are normally made with cut-back bitumen or with relatively soft penetration-grade bitumen. They can be made with unheated aggregate by using bitumen emulsions. They have two attributes that make them attractive for use in strengthening or correcting the profile of bituminous-surfaced low-volume roads: They are capable of accommodating large strains without fracture and, at least on lightly trafficked roads, they are more tolerant of deviations from specification in grading of aggregate and bitumen content than are dense mixtures. They are also cheaper.

As with surface dressing, specifications have been derived from closely observed field experience and there is no numerate method based on physical tests for designing them. Specifications are based on the grading of the aggregate and the viscosity and proportion of bitumen. Typical illustrative specifications are given in Table 1.

Again, these mixtures have attracted little academic attention in either teaching or research. The absence of a regime of physical tests to design and evaluate them has given such mixtures a psychological disadvantage. A generation of road engineers had been trained on the physical testing regime associated with asphaltic concrete. When confronted with these macadams, the first question they ask concerns the Marshall stability and flow values and the voids contents of such mixtures. When told that they cannot be evaluated in this way, the frequent reaction is to dismiss such mixtures as outlandish and absurd.

Bitumen macadams have a disadvantage in that they are not impervious. This can, under certain circumstances, be turned to advantage as in the use of open-textured macadam as an antisplash, antiskid surfacing. With the American aptitude for turning a happy phrase, these are known as popcorn surfaces. This permeability is not a serious disadvantage when they are used to cover an intact and well-sealed surface. If there is danger that water will penetrate through them to damage the old pavement below, they should be sealed soon after laying with a surface dressing. Indeed, the single-course bitumen macadam (Table 1) is a mixture specifically intended for use on low-volume roads and normally intended to be surface-dressed within a year of laying. Initiates will recognize from the designated composition that this material is cheap and relatively easy to mix and lay.

GAP-GRADED DENSE MIXTURES

Early asphaltic surfacings were frequently made with natural sand. These sand asphalts proved to be extremely durable. They were the basis for the cookery book recipes for premixed surfacings produced by Richardson in the early years of this century (11) and some can still be seen on city streets in the United States and still give good service. But sand asphalts passed out of general use for two reasons: one was the very practical reason that premix producers wanted to use the fines produced in their stone crushing plants and the other was that the use of crushed rock fines proved an advantage in gaining the high stabilities sought in the Marshall testing regime.

In Great Britain another evolutionary line was followed. With sand readily available in most parts of the country, producers continued to use sand asphalts but modified them by incorporating coarse aggregate like plums in a pudding. The resultant mixtures, known generically as rolled asphalt, were dense and impervious--an essential virtue in a wet climate. The coarse aggregate enhanced their resistance to deformation under traffic, though typical mixtures do not have the stability associated with asphaltic concrete. And the sand-asphalt matrix conferred flexibility on the mixture so that it would accommodate strains in pavement structure without cracking.

The next advance with this type of dense asphalt occurred in South Africa in the early 1960s with the development of mechanical testing regimes for their design (12). Stimulus to this development came from the opportunity it gave to employ the slurries from the gold mines, finely ground quartzitic rock, in the manufacture of this dense asphalt. At the same time, the move began in Great Britain to explore the use of mechanical tests for designing these mixtures and the Marshall testing regime is now tentatively in use alongside the proved recipe specifications (13).

These mixtures are mentioned for two reasons. One is the practical one that in many parts of the Third World there are available deposits of natural sand that can be used to make dense and potentially very durable premixed asphalt surfacings. Alluvial and aeolian quartzitic sands, coral sands, and fine volcanic scoria are examples. Where coarse aggregate is available this can be incorporated both to enhance stability and to reduce cost.

The second reason is technical, that where high stability is not a prime requirement such gap-graded mixtures may have advantages in being easier to mix and lay and in producing durable dense asphalts that are not prone to crack so readily when subject to strains as does continuously graded asphaltic concrete. It would have been good to be able to present this thesis fully supported by quantified data; unfortunately, I cannot do so. When I discuss this thesis with asphalt technologists it finds general acceptance. But they have been so busy solving the design problems of heavily trafficked roads and airfields that they have not had time to devote to the development of dense premixes for low-volume roads. I conclude this section by expressing the hope that this paper will prompt more attention to the development of robust and cheap dense asphalts for surfacing low- and medium-volume roads.

CONCRETE ROADS IN THIRD WORLD

In most developing countries the building construction industry absorbs nearly all available supplies of portland cement concrete. Small quantities are used for making soil-cement road bases and bridges but concrete roads as such are as yet little used. In some countries supplies of cement are increasing and price trends are moving in favor of concrete roads. This trend is accentuated if life-cycle costing methods are used because the maintenance needed on a well-made concrete road is normally less than on a bituminous road. This factor is of particular significance in those developing countries that are finding difficulties in building effective road maintenance organizations.

Another potential advantage for roads in the secondary network is that concrete roads are well adapted for construction by skilled and semi-skilled labor and a minimum of machinery. In fact, many examples exist in Europe and America of secondary roads and estate roads built of concrete by hand methods in the 1930s that are still giving excellent service. The advent of large and complex machinery has produced enormous increases in speed of construction and output per person. But, there has been little comparable increase in quality. The problems of joint construction in concrete laid by machine have not been solved satisfactorily. In concrete construction by hand, joint installation is a simple component well within the capacity of the carpenter or other worker who lays the formwork.

A further influence lies in climate. In some regions of the Third World diurnal and seasonal temperature changes are small, for example coastal areas in East and West Africa and the deltaic areas of many large rivers elsewhere, and large peninsulas or islands such as Malaysia, Indonesia, and the Philippines influenced by oceanic climates. In these regions concrete has a technical advantage because the deterioration of concrete pavements is very much influenced by thermal expansion and contraction, manifested by cracking and trouble at the joints. Concrete roads also have an advantage in construction over poorly consolidated soils in that the loads of pavement traffic are equitably distributed over the soils. An example that demonstrates both of these advantages lie in the heavily trafficked road that connects Bangkok with the international airport at Don Muang and the north of Thailand. Here a 20-cm reinforced concrete slab supported by a stabilized subbase lies on some 15 m of unconsolidated silty clay. Some settlement has occurred but the settlement has been even, and apart from work to correct the profile approaches to piled bridges and culverts, the pavement has needed practically no maintenance since it was constructed in the early 1960s.

CONCLUSION

I did not intend to produce a panegyric for concrete roads; the intention was more to illustrate the general thesis of this paper, which by now should be evident. This can be expressed in three propositions.

1. The trend in every country is to evolve toward road-building methods that are optimum for the local environment. These methods vary considerably to reflect both the nature of the available road-making materials and the climate. They may change to reflect changes in the economic and social life of the country.
2. Although countries of the Third World have benefited greatly from the importation of road-

making technologies from industrialized countries, this has sometimes distorted the evolution toward road-building methods that are appropriate to the local environment.

3. The effects of climate and of the nature of available road-making materials on road-building methods are now generally understood; however, this knowledge still needs to be refined and there is the opportunity for countries of the Third World to define the way in which their road-building technologies should be evolving and to make a conscious effort to promote this evolution.

REFERENCES

1. R. Robinson, H. Hide, J.W. Hodges, J. Rolt, and S.W. Abaynayaka. A Road Transport Investment Model for Developing Countries. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Lab. Rept. 674, 1975.
2. C.G. Harral, P. Fossberg, and T. Watanatada; World Bank. Evaluating the Economic Priority of Highway Maintenance. Pan African Conference on Highway Maintenance and Rehabilitation, Ghana, 1977.
3. J. de Weille. Quantification of Road User Savings. World Bank, Washington, DC, Occasional Paper 2, 1966.
4. H. Hide, S.W. Abaynayaka, I. Sayer, and R.J. Wyall. The Kenya Road Transport Study; Research on Vehicle Operating Costs. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Lab. Rept. 672, 1975.
5. A Guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and Sub-tropical Countries. 3rd ed. Transport and Road Research Laboratory; Her Majesty's Stationery Office, London, 1977.
6. F.A. Hansen. Bituminous Surface Treatments on Rural Highways. Proc., New Zealand Society of Civil Engineers, Vol. 21, 1934-1935.
7. A Basic Asphalt Emulsion Manual. Asphalt Institute, College Park, MD, Manual Series No. 1, MS 19, March 1979.
8. A Guide to Surface Dressing in Tropical and Sub-tropical Countries. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Overseas Road Note 3, (in press).
9. G.P. Jackson. Surface Dressing. Shell International Petroleum Company Ltd., London, 1963.
10. Principles and Practice of Bituminous Surfacing: Vol. 1., Sprayed Work. National Association of Australian State Road Authorities, Sydney, 1965.
11. C. Richardson. The Modern Asphalt Pavement. 2nd ed. Wiley, London and New York, 1908.
12. C.P. Marais. Gapgraded Asphalt Surfacings--The South African Scene. Second Conference on Asphalt Pavements for Southern Africa, Durban, South Africa, 1974.
13. Rolled Asphalt (Hot Process) for Roads and Other Paved Areas. British Standards Institution, British Standard 594, 1973.

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Improved Pavement Management System for Low-Volume Roads

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The economic consequences of pavement design and maintenance for low-volume roads need to be evaluated. Because many low-volume road networks have large mileages compared with high-volume road networks, the capital investment in a low-volume network can be high. Low-volume roads are more economically sensitive, on a percentage basis, to pavement design changes; therefore, the use of a pavement management system in the planning, design, construction, maintenance, and management of low-volume road pavement structures is important. An improved version of the computer program, Pavement Design and Management System (PDMS), was developed that greatly increases the capabilities of the system and also improves the rational basis for predicting pavement performance. A structural analysis of American Association of State Highway Officials road test pavement sections was conducted by using a nonlinear elastic layer procedure to characterize the pavement materials for four seasonal periods. A regression analysis was performed to develop a performance-prediction equation. The dependent variable used was the change in present serviceability index (PSI) divided by the change in vehicle applications for each seasonal period. The performance variable is used to predict the PSI-traffic curve for the pavement structure, thereby allowing the evaluation of the performance area under this curve. Because each vehicle type is considered separately, there is no need to consider axle equivalency factors. This is an important advantage because American Association of State Highway and Transportation Officials equivalency factors are found to have serious limitations.

The term pavement management system was first used in the late 1960s and early 1970s to describe a systems engineering approach to the problem of economical design, construction, and maintenance of roads. Since that time many developments have been made in the area of pavement management systems for both rigid and flexible pavements (1).

Interest in pavement management has increased substantially in recent years as transportation agencies look for new methods and tools to use in the efficient management of transportation networks. Pavement management can be a tremendous asset to the engineer faced with budget restrictions, material shortages, and important energy considerations, and at the same time it can meet increasing demands from heavier axle loads and traffic volumes.

NEED FOR LOW-VOLUME-ROAD PAVEMENT MANAGEMENT

The implementation of pavement management is associated with high-cost, high-volume roadways. The use of a pavement management system for low-cost, low-volume roads may have the appearance of applying too much sophistication to a low-cost situation. However, the term low cost may sometimes be a misnomer when applied to low-volume roads. This is because, in many transportation networks, low-volume roads constitute the majority of the network mileage.

In Texas, the Interstate highway system is com-