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Pavement Drainage in Seasonal Frost Area, Ontario

J.B. MACMASTER, G.A. WRONG, AND W.A. PHANG

During the last two decades, full-width granular construction filter courses; improved ditching, trenches, and drains; and axle-load controls have all been implemented on Ontario highways. In spite of this, pavement damage during late winter and spring continues to be a problem for the Ontario Ministry of Transportation and Communications. This paper illustrates how this problem is compounded in seasonal frost areas. During warm winter days, melt-water from deicing salts enters the partly thawed base. Trapped there by frozen subbases and shoulders, it creates differential heaving during subsequent freezing periods. Two experiments carried out to explore the problem of pavement edge cracking are described briefly. These tests include the use of plastic pavement edge skirts and partial-width paved shoulders. The success and practicality of the paved shoulders prompted the Ministry to use them on a continuing basis. The Ministry has been using plastic pipe pavement edge drains since 1978 to improve the drainage of rigid pavements. Details are given on how the drains are placed with trenchless plows; an innovative and very successful installation technique. The Ministry's limited use of open-graded drainage layers is touched on briefly. In the area of preventive maintenance, the discussion centers on preliminary studies on the use of primed and surface-treated shoulders as waterproofing measures. Routing and sealing of cracks has also become a significant feature of the Ministry's program in upgrading the performance of pavements and prolonging the life of overlays.

It is generally acknowledged by highway agencies that, of all the environmental factors that adversely affect the performance of pavements, water is the most significant. Excess moisture in granular base and subbase layers leads to high pore pressures under the dynamic loading of traffic. These high pore pressures tend to overcome the frictional forces between the granular particles and cause a reduction in the bearing capacity of the base. This in turn causes an increase in stress in the wearing course.

Cedergren and Godfrey (1) claim that inadequate drainage of excess moisture in the structural section leads to premature damage of the pavement. Ratios of damage caused by traffic impacts on pavements with free water versus those with little or none and the tests that determined them are as follows: Western Association of State Highway Officials (WASHO) Road Test (2), up to 70 000:1; American Association of State Highway Officials (AASHO) Road Test (3), up to 40:1 (Cedergren analysis of Liddle data); University of Illinois Circular Test Track (4), 100:1 to 200:1 (Cedergren analysis of test data).

In Ontario, as in other seasonal frost areas, weakening of the pavement occurs during the spring when the subgrade begins to thaw. The thaw period can spread over several weeks, particularly in northern Ontario where the frost has penetrated more than 3.0 m (10 ft) below the surface. However, this spring effect may, in the southern parts of Ontario, be repeated several times during the winter, since the base layer is subjected to periodic thaw cycles caused by deicing salts.

In the past 15-20 years, designers have developed various changes in the physical structure of pavements and in the materials used in highway construction. This reflects the attempt to improve the performance of roadways, in part by maintaining a low moisture content in pavement structures.

Subdrains have been installed at various locations within the right-of-way to intercept water that might otherwise enter the base and subbase. Pipes have been located below ditchlines to lower high water tables in the subgrade and cut slopes. Drains have also been placed in the outer edges of the shoulders to help drain the pavement structure when it was impossible to provide side ditches of adequate depth. Such treatments, although effective, were limited in scope and constructed to deal with specific problem locations.

In the early 1960s, the Ontario Ministry of Transportation and Communications (MTC) switched from a core, or earth shoulder, design to full-width granular construction in order to provide lateral drainage of the pavement structure. At the same time, the specifications of the base and subbase materials being used in Ontario were being altered (made more dense) to achieve greater stability to cope with the increasing volume and weight of traffic loads. However, while the densities and bearing capacities of these aggregates were increasing, the permeability values were decreasing, thus reducing the effectiveness of the full-width lateral drainage.

In more recent years, some highway drainage experts have vigorously promoted the use of an open-graded drainage layer within the pavement structure. These layers of materials that exhibit high permeability may be constructed full width and daylighted at the side slopes or designed to outlet into a collector drain installed beneath the shoulder. Cedergren (5) advocates that such a drainage layer have laboratory permeability rates of 6000 m/day (20 000 ft/day) in areas where frost penetrates below the depth of the drainage layer. He cautions, however, that actual field values are likely to be of the order of 2100-3000 m/day (7000-10 000 ft/day).

In this report, experiments are described that demonstrate the pavement structure drainage problem in a seasonal frost area of Ontario and the steps that are being taken to avoid or reduce the damaging effects. These include limited use of very permeable drainage layers but principally relate to provision of partly paved shoulders and pavement edge pipe drains.

SOURCES OF WATER

Although it is known that excess moisture adversely affects the performance of roadways in any climate, pavements in seasonal frost areas are subject to additional stresses at certain times of the year (6).

Figure 1. Snowmelt trapped by plowed snowbanks.

Figure 2. Spring breakup due to poor subsurface drainage.

During the winter, most precipitation remains frozen above ground in the form of ice and snow. Snowbanks created by winter plowing operations tend to restrict the movement of water produced from salting operations or direct sunlight (Figure 1). This melt water remains on the granular shoulders long enough to infiltrate the base and subbase layers and enter through cracks in the pavement. During warm winter days the granular shoulder adjacent to the pavement may thaw slightly, due to the heat-absorbing qualities of the asphalt. The standing water can then penetrate and further saturate the base. While the granular base beneath the pavement thaws, the remainder of the shoulder, insulated by the snowbanks, remains frozen. The result is a trough or bathtub effect in which water is trapped beneath the surface. During the night, this moisture freezes and causes the pavement to heave. Repeated freeze-thaw cycles in late winter and early spring overstress the asphalt and cause longitudinal cracking to develop at the pavement edge. In time, these cracks progress inward toward the wheel-track area and when pavement courses are thin [less than 40 mm (1.5 in)] eventually cause pavement breakup. Frozen drainage ditches can also aggrevate the bathtub effect and result in pavement breakup such as that in Figure 2.

Figure 3. Plastic edge skirts in gravel shoulder.

INVESTIGATION OF TREATMENTS AND PARTLY PAVED SHOULDERS

In southwestern Ontario, a study of thin asphalt surfacing failures resulting from edge cracking indicated that moisture was entering the base via the shoulder and causing excessive heaving of the asphalt (7). Experiments were conducted to see whether directing the water away from the pavement edge would improve the performance.

Pavement Edge Skirts

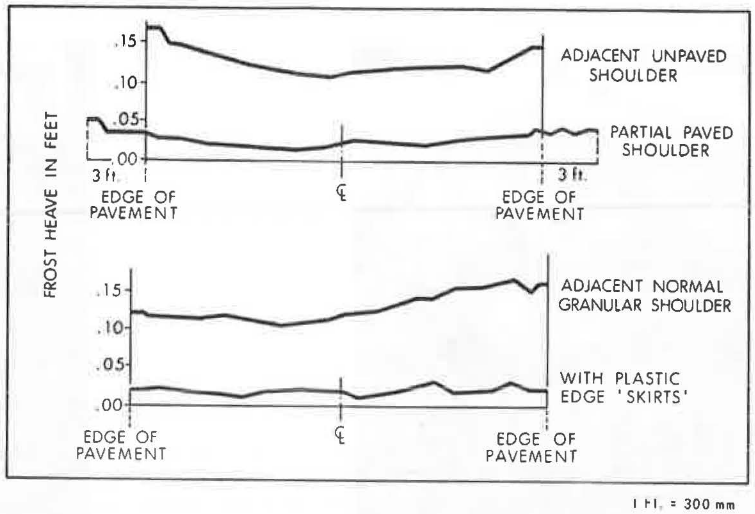
In this test, 0.2-mm (8-mil) polyethylene sheeting was draped into a shallow trench excavated in the shoulder (8). One edge of the sheeting was tacked to the old surface with asphalt cement and then covered with a strip of natural rubber membrane 0.3 m (1 ft) wide to provide protection against the hot overlay (Figure 3). The trench was backfilled and the roadway resurfaced. Monitoring consisted of crack surveys, deflection measurements, and measurements for frost heaving.

Partly Paved Shoulders

This experiment was carried out on a newly constructed county road. Through the test section, the 40-mm lift of asphalt was extended by 0.9 m (3 ft) on either side of the two-lane road. Monitoring was similar to that carried out in the skirted sections. The most significant results concerned the heaving pattern of the pavement within and adjacent to the test sections in both experiments. As shown in Figure 4, the skirts and partly paved shoulders produced similar results. Not only was the magnitude of heaving reduced in each case, but the differential heaving between the central portion of the roadways and the edges of the pavement was significantly reduced.

These results confirmed that (a) much of the excess moisture that enters the pavement structure

Figure 4. Cross-section heave measurements at partly paved shoulder and skirt sections.



does so from the surface and (b) changing the flow pattern of this surface water reduces the detrimental effects of frost on the pavement, especially at the point where wheel loads are greatest.

Paved Shoulders

While the preceding experiments produced similar results, economics dictated that, for province-wide applications, placing a single lift of asphalt concrete 0.6 m (2 ft) wide on the existing gravel shoulder adjacent to the driving lane was a more feasible treatment. The 0.6 m served nearly as well as 0.9 m in keeping surface water away from the pavement edge. MTC has constructed partly paved shoulders for the past four years in accordance with criteria listed below; fully paved sholders are used in urban freeway sections where traffic volumes exceed 20 000 annual average daily traffic (AADT):

1. Two-lane highways where AADT = 4000 within next five years,
2. All four-lane undivided highways,
3. Four-lane divided highways where AADT = 20 000 within next five years,
4. All of TCH-401,
5. Route continuity, and
6. Special locations determined by highway accident rate and high maintenance demand.

Partly paved shoulders are generally placed when resurfacing is scheduled and are constructed integrally with the traveled lanes. In 1980, problems occurred on some resurfacing projects in Eastern Ontario when the edges of partly paved shoulders, paved to the same crossfall as the driving lane (2 percent), heaved to such an extent that water was trapped on the driving lane. This prompted the construction of experimental sections on TCH-17-N near Petawawa. With the use of a new, adjustable screed extension, 0.6-m partly paved shoulders were placed at 2 and 6 percent crossfall. No construction problems were encountered in placing the shoulders at 6 percent crossfall, and measurements taken through the following winter and spring revealed that, although some heaving did occur, the shoulders always maintained a positive crossfall.

Assured that there would be an adequate supply of screeds available to accommodate paving contractors, MTC issued a directive in June 1980 stating that partly paved shoulders would be laid at 6 percent crossfall in the future.

PAVEMENT STRUCTURE DRAINAGE SYSTEMS

Pavement Edge Drains

Poor pavement performance is not restricted to conventional flexible pavement structures. Rigid structural sections, such as portland cement concrete and composite designs, develop distresses that can be attributed to excess moisture within the base and subbase layers. Common distresses include faulting at joints and cracks, settlement and corner cracking of slabs, and deterioration of the underside of the concrete.

In the early 1970s, the above problems were becoming prominent on concrete pavement in Ontario. Most of the concrete pavements under the jurisdiction of MTC are found on expressways and multilane facilities such as TCH-401. Surveys carried out in southwestern Ontario revealed multiple transverse cracking and serious deterioration of the underside of the slab. Breakdown of the concrete was quite prominent at joints. Free water was discovered beneath the pavement in many areas, which lent support to the opinion that the permeability rates of bases and shoulders are not high enough to permit proper lateral drainage of the structural section. It was evident that in order to prevent complete failure of the pavement and prolong the service life of rehabilitative treatments, some form of continuous drainage system was required.

A survey carried out by AASHTO in 1975 (9) revealed that a small number of states were installing edge drains to provide drainage for transportation facilities. Polyethylene pipe appeared to be the most common type of drain used. Some states employed equipment such as chain or wheeled trenchers with automatic backfilling apparatus capable of placing an envelope of free-draining filter material around the pipe.

In 1976, MTC investigated the possibility of installing subdrains along the edges of concrete pavements. The pipe chosen was 100-mm (4-in) perforated polyethylene tubing. In order to keep installation costs down, it was decided to place the tubing in the shoulder by using a trenchless plow (Figure 5). Both tubing and plow are quite familiar in the area of farm drainage.

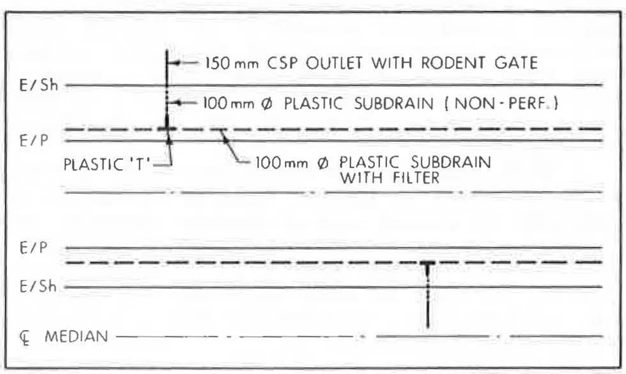
An 0.8-km (0.5-mile) test section was constructed on TCH-401 near Chatham, Ontario (10). Polyethylene tubing 100 mm in diameter wrapped in a knotted polyester filter sock was plowed into the shoulder at

both edges of the 7.2-m (24-ft) concrete pavement. The drains were offset about 0.3 m (12 in) from the edge of the slab and located at subgrade level so that the pipe had about 0.5 m (20 in) of cover. No attempt was made to place any special backfill around the pipe, and outlets were provided at 75-m (250-ft) intervals. Results were evident almost immediately. Discharge was noted by maintenance staff on a regular basis during the summer and fall (Figure 6).

Figure 5. Installing plastic pipe subdrains by using trenchless plow.

Figure 6. Discharge from pavement edge subdrain.

Figure 7. Layout of pavement edge subdrain system.



10 mm = 0.39 IN.

Encouraged by the performance of the drains and the potential of the plowing technique, the Ministry included subdrains on a 23-km (14-mile) resurfacing contract the next year. By using a tracked plow and four backhoes, the contractor installed 96 900 m (323 000 ft) of perforated tubing and 2370 m (7900 ft) of nonperforated outlet tubing in five working days. Changes were made to the plowing technique to increase production. Rather than plowing in individual lengths of tubing [75 m (250 ft)], the contractor joined the rolls to form one continuous run. This allowed the operator to plow without stopping until an interchange or bullnose was encountered. The main line was then tapped at the desired interval by a backhoe and outlet tubing connected with special T-couplers (Figure 7).

The installation of plastic subdrains by plowing has now become a standard feature of concrete pavement rehabilitation in rural areas. Several contracts have been awarded for pavement drainage in advance of resurfacing projects. The cost of installed pipe, including outlets, averages $1.90/m ($0.57/ft). Since the initial contract referred to above, a total of 981 000 m (3 270 000 ft) of perforated plastic tubing with filter wrap has been placed by MTC. This accomplishment is summarized by year below (1 km = 0.6 mile):

Year	No. of Contracts	Plowed Subdrains (km)	Outlet Pipe (km)
1978	4	270	5.3
1979	6	675	9.8
1980	4	187	3.0
1981	3	274	6.3

On recent projects, tracked plows have been replaced by rubber-tired units (Figure 8). This move has increased average daily production from 16 to 23 km (10-14 miles). In addition to providing operator comfort, the new method is advantageous because the pavement surface is no longer marred by the steel tracks. Tubing is now supplied in 1200-m (4000-ft) rolls, thus reducing the handling required.

To date, priority has been given to draining beneath concrete pavements. Investigations have shown, however, that excess moisture is also present within composite pavement structures (asphalt over concrete base over cement-treated granular subbase). Moisture infiltration in composite pavements is serious because water contaminated with salt attacks the cement-treated subbase. A total of 200 130 m (667 100 ft) of subdrain pipe was plowed in composite pavements in 1981.

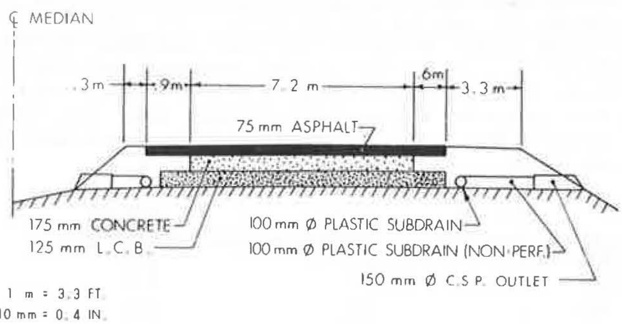
The use of plastic subdrains for pavement drainage has proved to be quite successful in Ontario due to the low cost of materials and the ease of construction. Such a system could be adapted to flexible pavements. Full-depth and deep-strength asphalt pavements are currently under review to determine whether edge drains are required.

Our pavement edge drains, prior to 1981, were all retrofits to existing facilities. On two contracts recently completed, edge drains were incorporated into the pavement structure at the design stage (Figure 9). This represented the Ministry's first effort at providing a built-in drainage system.

The long-term performance of underdrains is often questionable. Examination of this type of pipe after four years in service has shown no deterioration of the pipe or clogging of the filter sock. Over this same period, no change in discharge rates has been observed, either in the experimental sections or in the runs subsequently placed.

Figure 8. Trenchless plow mounted on rubber-tired tractor.

Figure 9. Plastic edge drains located in new composite pavement.



Open-Graded Drainage Layers

As noted earlier in this paper, much attention has been given to the construction of highly permeable drainage layers within the pavement structure. Johnson (11) suggests that in frost areas this open-graded layer should be located in the upper portion of the structural section, preferably beneath the wearing course.

Figure 10 illustrates gradation curves for typical aggregates necessary to achieve the permeability rates advocated by Cedergren (5). Superimposed on this chart are Ontario's specifications for the granular base course ("Gran. 'A'"). It is evident that with this material located below the asphalt wearing course, water will remain in the pavement structure for some time.

In 1975, the Ministry constructed a series of test sections that incorporate an open-graded drainage layer. The site of the experiment was a new section of two-lane highway near Stoney Creek in southern Ontario. The designed pavement structure consisted of 125 mm (5 in) of asphalt concrete over 525 mm (21 in) of granular A base. The drainage medium was the course aggregate used in HL 8 asphalt concrete (Figure 10). In the first test area, the upper 75 mm (3 in) of base was replaced with a similar depth of the above stone. The second test area was identical to the first except for the addition of 3 percent asphalt cement as a binder. The third trial section contained 150 mm (6 in) of untreated stone. Apart from movement of untreated stone under construction traffic, no problems were encountered during construction.

Monitoring data has indicated some settlement problems in test section 3. Investigations will be under way shortly to determine the reason for this problem. Cracking is more extensive over the 150-mm layer of stone than in the other two test areas. The small amounts of cracking in the first and second test sections are quite similar.

Data will have to be fully analyzed before definite conclusions can be made as to the effectiveness of the drainage layers.

Figure 10. Permeability of granular A base: Ontario specification.

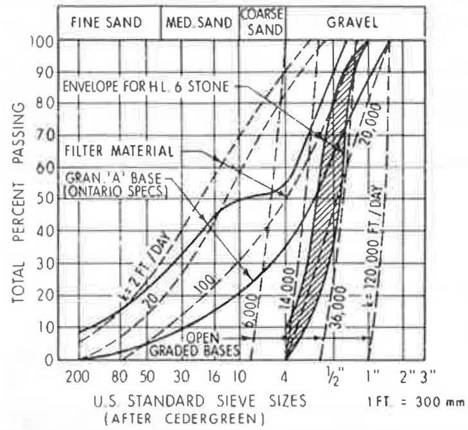


Figure 11. Primed gravel shoulder three years after application.

WATERPROOFING

Shoulder Treatments

Although a good deal of effort is being expended in developing means to remove excess moisture from pavement structures, attention also needs to be directed toward the prevention of surface water infiltration. The sealing of permeable surfaces would appear to be a logical step in this direction since it has been shown that a good deal of water enters the base through the shoulder at the edge of the pavement.

In 1977, the Ministry constructed test sections at several sites in southern Ontario as part of an experiment to control edge-of-pavement dropoff. One of the treatments applied was RC-30 prime over a 0.9-m width of shoulder next to the pavement. After three years, much of this treatment was still in place (Figure 11). Its potential for waterproofing purposes is now being studied.

During the winter of 1978-1979, heaving of partly paved shoulders on an expressway occurred near

Ottawa, indicating that moisture was entering the base. In an effort to seal the remaining 3.0 m of granular shoulder, the maintenance staff applied a surface treatment consisting of a high-float emulsion and 16-mm (0.625-in) crushed gravel. This treatment has been in place for two years and is still in very good condition. No further heaving of the partly paved shoulders has taken place.

Where infiltration of moisture on gravel shoulders is creating deterioration of the pavement, waterproofing of the shoulder by either priming or surface treatment is considered as a preventive-maintenance measure.

Routing and Sealing Cracks

Dense-graded asphaltic concrete pavements are relatively impermeable for a period of time following construction. In time, cracks develop in various forms in overlays and in pavements placed on new grade. These cracks represent a very significant source of entry for surface water. Studies have shown that up to 70 percent of surface runoff can enter a crack no wider than 0.8 mm (0.031 in) (1).

Treatment in past years usually consisted of spray patching and sand sealing when the severity of the cracks caused a decrease in riding comfort or threatened the integrity of the pavement. Such treatment was successful, although usually for only a short time. Fillers became displaced, and in many cases riding comfort was affected by a buildup of sand in the vicinity of the crack.

In the last four or five years, new sealing compounds have been developed that are designed to penetrate and adhere to the sides of the crack. They compress or stretch as the crack closes or opens with changes in temperature. The product is delivered in cake form and is then melted down in large kettles.

In order to provide a reservoir to ensure that there will be sufficient sealant to fill the crack properly, it is routed and cleaned with compressed air prior to filling. Experience has shown that, usually, a 16x16-mm opening is adequate. For wider cracks that develop over bases such as cement-treated granular, an opening of 19x19 mm (0.375x 0.375 in) may be required. The routed crack is overfilled rather than underfilled.

The success rate of the Ministry's sealing program has been encouraging. Contracts have been awarded specifically to explore the suitability of available sealants. Work is scheduled when the cracks have opened sufficiently to permit routing. The importance of preventing the infiltration of surface water in the pavement structure justifies the need to return to sections of highway more than once, as cracks develop. A large number of maintenance patrols are now equipped to carry out crack sealing. The Ministry is currently considering tendering contracts that would contain a lump sum of money designated for crack sealing a year or two after construction.

The Ministry is also engaged in evaluating new crack-sealing products as they become available. Test sections have been established and manufacturers invited to supply and supervise placing of their sealants. The trials are being monitored to compare the effectiveness of these treatments under similar field conditions.

CONCLUSIONS

Since the performance and ultimately the life of a pavement can be appreciably curtailed when excess moisture exists within the base and subbase, it is imperative that every effort be made to keep surface water out of the pavement structure. Although base courses have been upgraded to provide increased stability, the drainage characteristics have often been adversely affected.

Experiments carried out by MTC have shown that in frost areas, infiltration of surface water has had a detrimental effect on pavement performance. Where moisture has been diverted away from the pavement, heaving and distortion of the asphalt have been dramatically reduced. Plastic edge skirts, although showing promise in achieving this result, have given way to the more practical and cost-effective partly paved shoulder.

The use of plastic edge drains has become a major feature of the Ministry's pavement drainage scheme. Their low cost and ease of installation by plowing have made them an attractive system for all types of pavement structures.

Open-graded drainage layers have had a limited application to date in Ontario; nevertheless, MTC will continue to evaluate this method of drainage and modify current designs to achieve an efficient system.

From the point of view of preventive maintenance, crack sealing is being actively implemented in many districts. Priming and surface treating of gravel shoulders have been recent innovations, but they show excellent potential as interim measures to redirect surface water.

The cost of constructing and maintaining a highway system continues to escalate as supplies of good-quality aggregates diminish and petroleum products increase in cost. Providing adequate drainage of the pavement structure to prolong pavement life is a major step toward protecting the investment made in a highway network. MTC is actively addressing this problem and will continue its efforts to improve and develop drainage designs and systems to achieve this goal.

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Simulating Pavement Performance Under Various Moisture Conditions

MICHAEL J. MARKOW

A computer program to simulate highway pavement performance, maintenance, and rehabilitation has recently been completed for the Federal Highway Administration. As part of this effort, closed-form pavement performance equations have been incorporated to predict the onset and propagation of various damage mechanisms as a function of layer thicknesses and material properties, traffic loadings, cumulative damage already sustained, moisture, and temperature. Both flexible and rigid pavements are considered. The simulation is carried out on a seasonal basis (up to 12 seasons per year allowed) to permit users to specify variations in climatic conditions and pavement material properties. In addition, moisture-induced decreases in layer and subgrade strengths are rendered sensitive to the amount of unsealed cracking in the pavement surface, the seasonal rainfall, and the quality of subsurface drainage. In this way the preservation of road investment, as represented by rates of future damage accumulation, is explicitly tied to both pavement drainage characteristics and the quality of subsequent surface maintenance. This paper describes the technical assumptions and relationships employed in this approach and gives examples of its application to a selected pavement design, maintenance policy, and climatic region. The case study indicates that subsurface drainage above can have a significant effect on pavement life, influencing the date of required resurfacing by up to four years.

The structural design, construction, and performance of pavements have been the subject of much theoretical and empirical research. Most efforts in this area have concentrated on the relationship of component layer thicknesses and material properties to the formation and propagation of particular types of distress. Comparatively little attention, however, has been devoted to the changes in pavement condition over time as damage begins to accumulate and the interaction between this damage and the pavement environment to influence subsequent pavement performance. The specific mechanism of interest here is the infiltration of water into cracks and joints, with resulting potential weakening of the pavement structure. This mechanism is important because a good deal of structural maintenance and rehabilitation is devoted to preserving the integrity of the pavement surface. The benefits of such work are often justified in part by the reduction in water infiltration, but typically no quantitative evidence of impacts on future pavement damage is provided.

The lack of current information on the effects of water infiltration and drainage has been cited by Cedergren (1). By using data from several road tests and test tracks, he calculated relative damage factors, which ranged from 5 or 10 to 1 to 70 000 to 1 for wet versus dry conditions, respectively. Although the trend indicating shortened pavement life with increasing traffic loads under wet conditions is clear, the wide range of these estimates precludes their applications to predicting pavement performance.

Recently modifications have been completed of the Federal Highway Administration's EAROMAR system--a simulation model of freeway performance that enables one to conduct economic analyses of different strategies for roadway and pavement reconstruction and pavement reconstruction, rehabilitation, and maintenance (2). As part of the simulation of pavement performance, we have included models of water infiltration to the pavement substructure, its effect on material properties, and resulting changes in damage accumulation. The approach followed within EAROMAR bases the amount of water entering the pavement structure on the seasonal rainfall and the extent of cracking in the pavement surface. Reduction in pavement strength is dependent on the length of time the sublayers remain saturated, which is a function of the amount of water that has entered the pavement and the drainage characteristics of the sublayers input by the user. The model considers only water entering the pavement structure through discontinuities in the surface (typically the most significant source); groundwater sources and side infiltration are not included. The technical relationships employed are based on work by Moulton (3) supplemented by data presented by Cedergren (1) and by assumptions on pavement material behavior.

GENERAL MODEL CONSIDERATIONS

In pavements subjected to rainfall, one may distinguish three periods associated with wet weather in addition to the period corresponding to dry conditions:

1. The time during which rain is falling, in which the pavement sublayers may or may not be building up to saturation;
2. If rainfall is sufficiently heavy or the sublayers are of sufficiently low permeability, the time during which the sublayers are saturated or sufficiently wet to affect material properties and structural behavior; and
3. The time during which any residual water not sufficient to affect pavement behavior is drained off.

Data for several cities throughout the United States were reviewed in their months of maximum rainfall. Seldom do the total days of precipitation greater than 0.1 in (2.5 mm) exceed 10, and the number of days in which the precipitation exceeds 0.5 in (12.7 mm) is typically 7 or fewer. However, the period of saturation following a rain can last from 5 to 20 days, except in those pavements that have exceptionally good drainage qualities (1). Therefore, in our model we considered only the second period above--the period (after it stops raining) during which the pavement is significantly