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USE OF RUBBER ASPHALT BINDER WITH GRADED AGGREGATE FOR SEAL COATS

AL REVIEW
EPS 4-NW-79-1
EST REGION
BER, 1979

Use of rubber asphalt binder with graded aggregate for seal coats.

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USE OF RUBBER ASPHALT BINDER
WITH
GRADED AGGREGATE FOR SEAL COATS

by

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Environmental Protection Service
ENVIRONMENT CANADA

Report EPS 4-NW-79-1
September, 1979

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ABSTRACT

During the summer of 1978, eight test sections were constructed to evaluate seal coats using rubber-asphalt as a binder membrane and a graded aggregate as protective cover.

A description of the test sections, construction problems, initial evaluation, and economic analysis is given.

Each test section represented a typical surface type and condition which included primed subgrade, cold-mix on subgrade, primed granular base course, asphaltic concrete on granular base and full depth asphaltic concrete.

The evaluation was considered necessary to determine whether low cost cold-mix and current seal coat surfaces could be replaced successfully and economically by this method of construction.

RÉSUMÉ

Au cours de l'été de 1978, on a construit 8 tronçons pour expérimenter les enduits de scellement où le caoutchouc-bitume joue le rôle de membrane de liaison et un agrégat calibré celui de couche protectrice.

Les tronçons et les difficultés de construction sont décrits, et l'évaluation initiale et l'analyse économique sont communiquées.

Chaque tronçon représentait une surface type et des caractéristiques comprenant une infrastructure préparée, un mélange préparé à froid sur l'infrastructure, une couche de base granulaire préparée, du béton bitumineux sur une fondation granulaire et un béton bitumineux sur toute l'épaisseur.

L'évaluation a été considérée comme nécessaire pour déterminer si les surfaces économiques constituées de mélange préparé à froid et des enduits actuels de scellement pouvaient être remplacées avantageusement et économiquement par cette méthode de construction.

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GLOSSARY OF TERMS

Term	Explanation
Chuckhole (Pothole)	Holes in the surface, usually no more than 150 mm diameter and 50 mm deep. Caused by traffic loosening surface aggregate particles and then 'chucking' them out by pick up on tires or shear action.
Grizzly	A metal grid used to remove oversize stones from gravel which is being fed into a hopper.
High-Float Emulsion	Asphaltic emulsions named after a characteristic asphalt test property.
High Viscosity Asphalt	An asphalt cement having a low temperature susceptibility.
Low Volume Dust Treatments	Thin asphaltic road surfacings applied to earth subgrades in order to stop dust in dry weather and mud in wet weather. These surfacings are applied to highways with low traffic volumes.
Prime	The application of asphaltic binder to seal the existing surface and create a good bond.
Pugmill	The mixing unit for asphalt and aggregate in the manufacture of asphaltic concrete.
Reflection Cracking	Propagation of crack from lower surface through the asphaltic seal or mix upper layer.
Rich Spots or Potholes	Areas with excess asphalt. Usually caused by successive applications of asphaltic seals to repair localized and recurring failures.
Rubber-Asphalt	A mixture of 25 percent vulcanized rubber crumb and 75 percent asphalt cement, heated to a temperature of approximately 160°C to achieve a reaction which will modify the properties of the asphalt.

Term	Explanation
Spot Seal	A seal coat applied over a localized fatigue failure. Usually limited to 3 m x 1 m in size.
Streaking (Roping)	Non uniform application of asphalt from distributor leading to a streaked appearance.
Tacking	The light application of an asphaltic binder to a pavement surface to aid in bonding the new surface to the old surface.
Temperature-Susceptibility	Change of viscosity with temperature.

CONCLUSIONS

1. Use of reclaimed rubber for rubberized asphalt seal coats on Saskatchewan Highways has been shown to be a practical construction application.
2. The economic justification for rubber asphalt seals will be determined after assessment of performance.
3. Initial indications are that Saskatchewan graded aggregates are a suitable cover material for the rubberized asphalt membranes in the trials.

1 INTRODUCTION

1.1 General

Saskatchewan Highways and Transportation materials engineers have long been interested in asphalts of low temperature-susceptibility. Considerable work has been done in correlating asphalt temperature susceptibility and low-temperature cracking in asphaltic concrete surfacings. In this regard, Culley (1969, 1972) reported on performance of so-called low and high viscosity asphalts and Clark (1974) reported on air-blown asphalts.

Since 1970, there has been a considerable increase in seal coating practice to waterproof low traffic volume dust treatment surfaces and to repair fatigue blocking in highway pavements. This practice delays need for more costly rehabilitation of highway surfaces such as the application of asphaltic concrete overlays.

Also, low temperature-susceptible asphalts resist bleeding in summer but are soft enough at freezing temperatures not to become brittle and break out under traffic. Use of high-float emulsified asphalts in seal coats has facilitated these requirements as their viscosity at 60°C, and penetration at 25°C, is high. Other advantages of use of high-float emulsified asphalts are:

a) solvent content allows use of cheap, graded aggregates rather than chips;
b) moisture in the aggregate is not a handicap;
c) emulsions can be used at cooler air temperatures more successfully than can cutback asphalts;
d) these latter two considerations lead to more production time from the sealing crew thereby leading to lower unit costs.

However, fatigue cracks sealed with high-float emulsion seals reflect through fairly rapidly depending on traffic volume, deflections, and severity of cracking. Also, the residual asphalt is still not sufficiently soft at freezing temperatures to resist cracking and breaking out under high deflections if seals are applied to thin dust treatments or directly on subgrades.

It has been known for considerable time that rubber in asphalt will considerably modify the properties of asphalt. However, most work incorporating rubber has been confined to small quantities (4 percent or less) of latex rubber added either to the liquid asphalt or directly into the pugmill when mixing for asphaltic concrete.

1.2 Background

In the early 1960's, C.H. McDonald, City Engineer of Phoenix, Arizona, began experimenting with rubber crumb ground up from old car tires using much larger quantities of rubber in asphalt than used heretofore. Field trials were initiated in the winter of 1964-65 and results reported to the Highway Research Board in January, 1966 (Morris and McDonald, 1978).

Since then, numerous other trials have been constructed in Arizona as shown below:

YEAR	AGENCY	PROJECT	LENGTH
1967	City of Phoenix	Main taxiway, Sky Harbour Airport	-
1968	City of Phoenix	Various city streets	24 lane - kilometres
1968	Arizona Department of Transportation	Black Canyon Freeway	4 kilometres
1969	Town of Tolleson	Main Street	-
1971	Arizona Department of Transportation	Minnetooka Project	1 kilometre
1972	Arizona Department of Transportation	Aguila Project	19 kilometres
1973	Arizona Department of Transportation	Flagstaff Project	16 kilometres

To the date of the report, all the experimental trials have functioned successfully.

Subsequent to these trials, the State of Arizona has begun using rubber-asphalt seals to control reflective cracking in hot-mix overlays on a regular basis (Lansdon, 1976).

Saskatchewan Highways and Transportation became interested in McDonald's product in 1971. A few lab experiments were conducted using tire buffings from a local tire retread plant. Some effort was made to determine the effects of temperature, asphalt type, and rubber crumb gradation on reaction time. A small experiment conducted on a wooden bridge deck consisted of heating asphalt cement in a portable asphalt kettle and then adding rubber crumb and kerosene. This experiment was somewhat inconclusive because the rubber-asphalt had to be broomed on and aggregate was not properly rolled. The following spring, severe abrasion occurred from traffic trailing mud across. However, the rubber-asphalt stayed soft at temperatures below minus 15°C.

In 1972, laboratory experiments were conducted to determine the effects on viscosity and penetration values of asphalt by adding rubber crumb at different temperatures and using different times of reaction. To reduce the variables to a minimum, the experiment was limited to eight variables which included low and high levels of rubber content, reaction temperature and reaction time.

A Saskatchewan Highways and Transportation AC 5 asphalt was used and a Uniroyal 808 rubber crumb having 100 percent smaller than 560 µm.

Table 1 shows the variables tested and the viscosity and penetrations obtained at different testing temperatures.

Figure 1 shows the interaction effects of the rubber-asphalt preparation variables on the viscosity tested at a temperature of 93.3°C. Because of the large increase in viscosities with rubber content at the 60°C temperature, it was not possible to do a complete series at this temperature. However, the relative viscosity change at 93.3°C should be similar to that at 60°C.

Figure 1 is interesting in that it shows that the high rubber content, low reaction temperature and high mixing time gives the most reaction for the rubber used.

Figures 2 and 3 show the effect of the same variables on change in penetration at 25°C and 4°C respectively. These two figures show that the high rubber content, high reaction temperature and high reaction time gives the highest penetration in both cases.

TABLE I

PROPERTIES OF RUBBER ASPHALT COMBINATIONS

RUBBER ASPHALT COMBINATIONS			BROOKFIELD VISCOSITIES*(Pa.S)			PENETRATIONS	
PERCENT RUBBER	REACTION TEMPERATURE °C	REACTION TIME (MIN')	60°C	93.3°C	135°C	4°C	25°C
0	0	0	66	3	--	15	203
10	177	10	210	8.5	--	10	127
10	177	30	178	16	--	15	120
10	232	10	178	8	--	11	167
10	232	30	144	9	--	16	172
30	177	10	14500	80	23	11	78
30	177	30	--	125	27	11	75
30	232	10	--	34	11	23	187
30	232	30	--	24	6	20	141

*Viscosities corresponding to a shear rate of 0.12 sec $^{-1}$ using a LV-4 spindle.

FIGURE 1

EFFECTS OF RUBBER, HEATING TIME AND HEATING TEMPERATURE ON SASKATCHEWAN AC5 ASPHALT VISCOSITY AT 93.3°C.

VISCOSITY DETERMINED BY BROOKFIELD VISCOMETER AT A SHEAR RATE OF 0.12 sec^{-1}

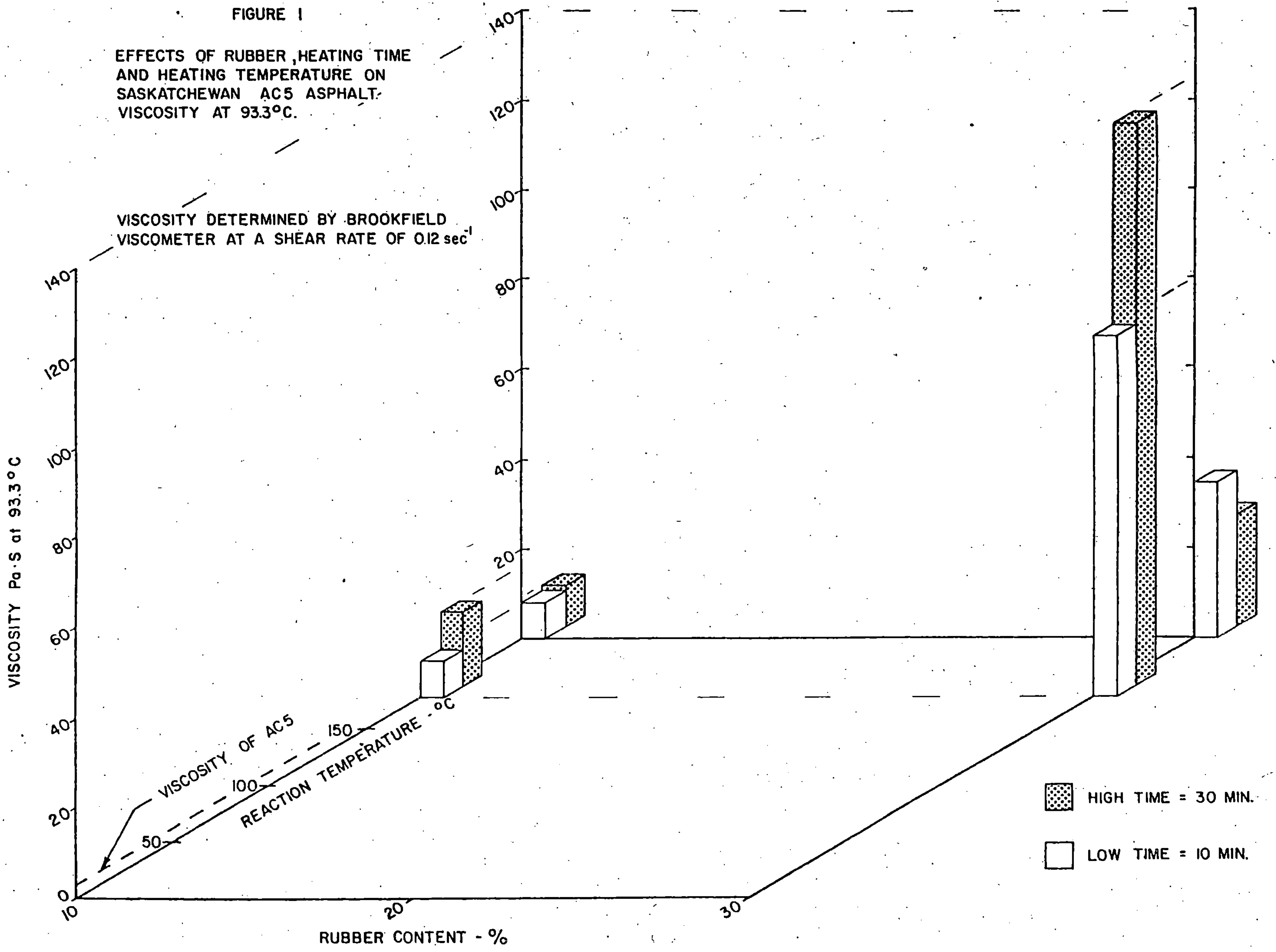


FIGURE 2

EFFECTS OF RUBBER, HEATING TIME AND HEATING TEMPERATURE ON SASKATCHEWAN AC5 ASPHALT PENETRATION AT 25°C.

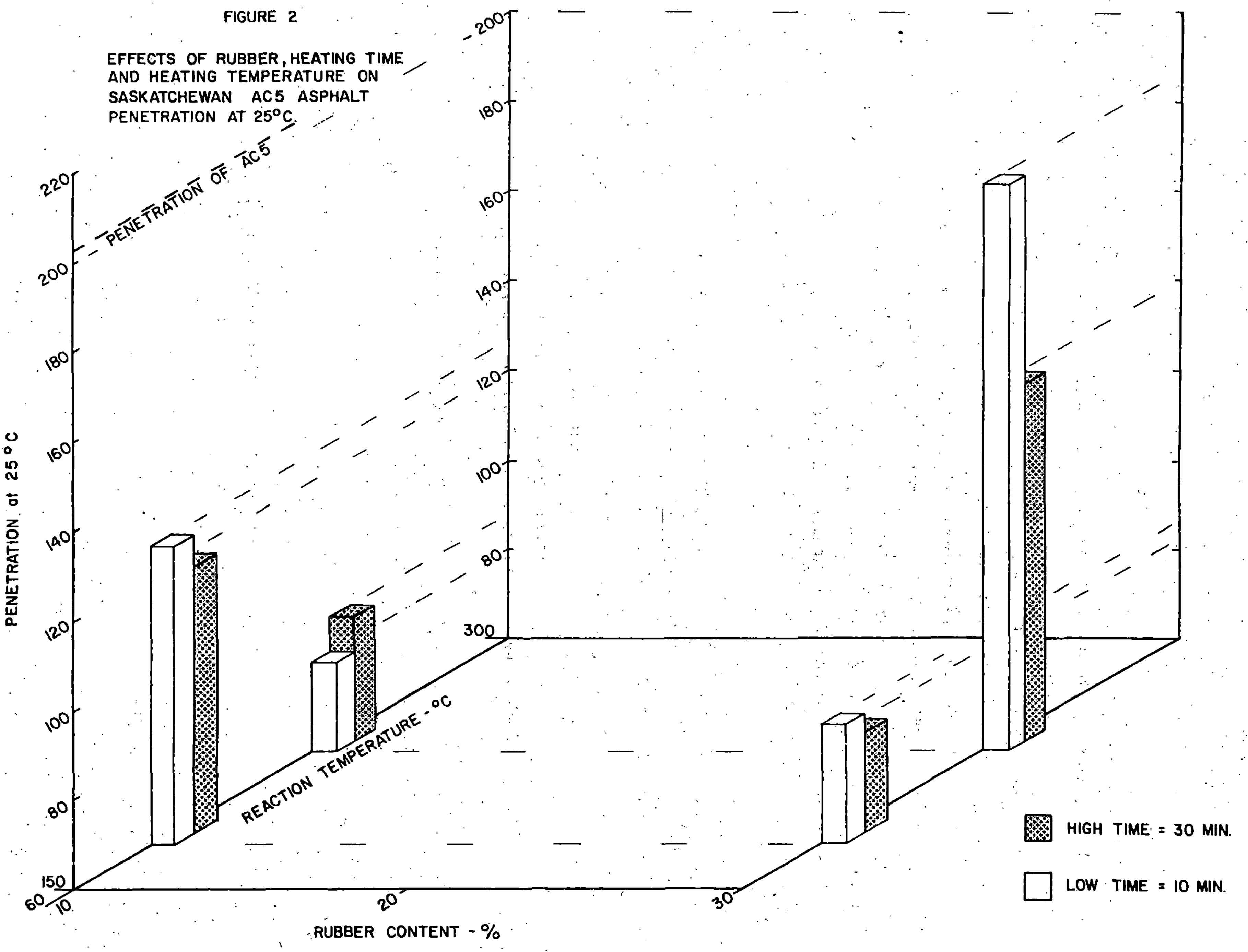


FIGURE 3

EFFECTS OF RUBBER, HEATING TIME AND HEATING TEMPERATURE ON SASKATCHEWAN AC5 ASPHALT PENETRATION AT 4°C.

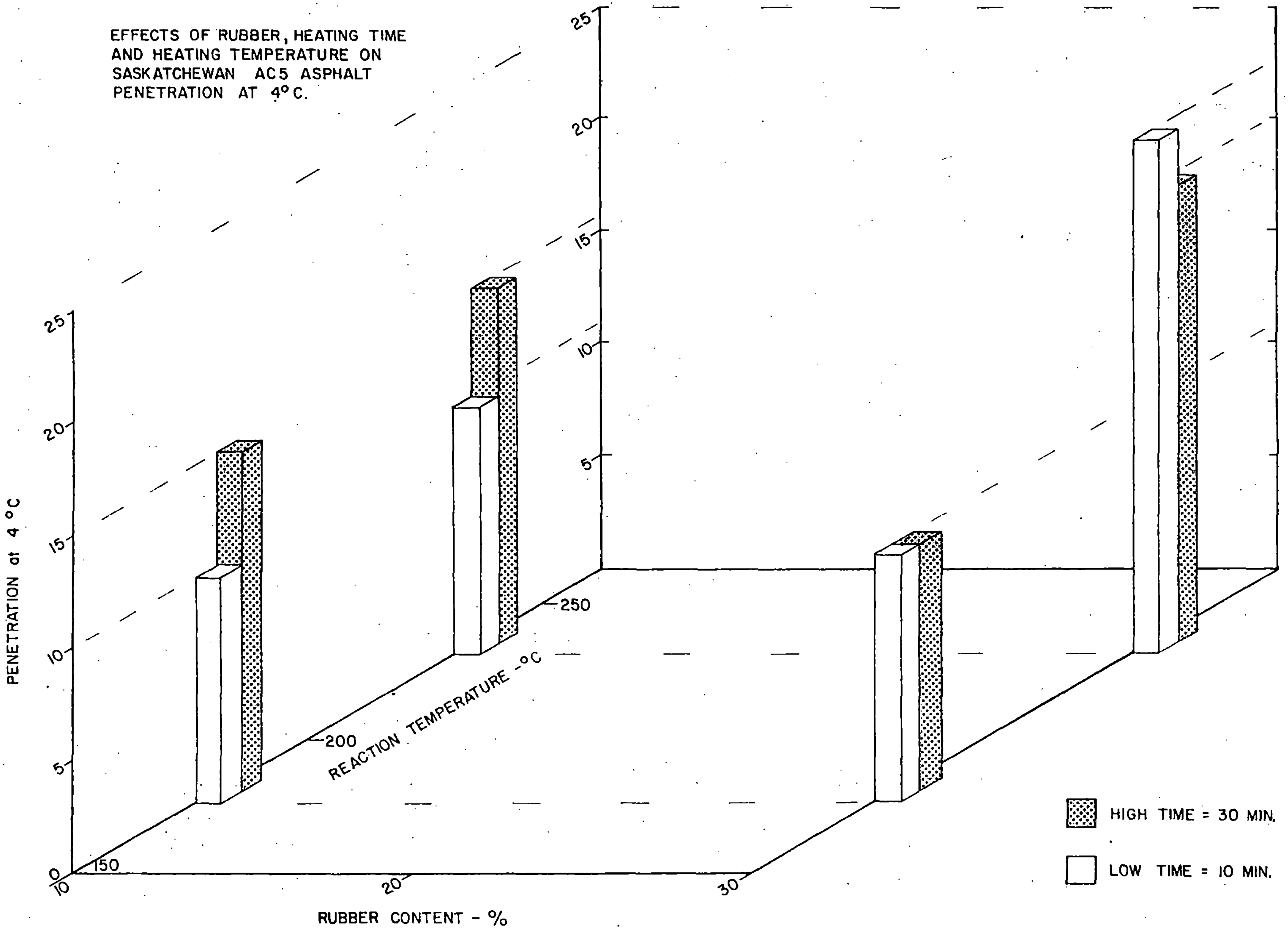


Figure 4 shows a plot of the two sets of penetrations in comparison with the original asphalt. If it is assumed that the same relationship holds for rubber-asphalt as for untreated asphalt, then it appears that for low temperature flexibility it may be better to heat at the higher temperature.

Subsequent to this experiment, Saskatchewan Highways and Transportation Research Branch designed and constructed two test sections to evaluate whether rubber-asphalt could be used with graded aggregates on a highway, and with lightweight one-sized aggregate in a city. Despite inadequate mixing and application equipment, the graded aggregate seal coat was considered a success. The lightweight aggregate seal coat was a partial success as the asphalt remained rubbery. However, an insufficient application rate led to loss of much of the cover aggregate. This problem was increased by a 150 mm rainfall three hours just following completion of the seal coat construction.

1.3 Scope

These initial trials were encouraging in that they showed rubber asphalt could provide effective seals that might last longer than standard seals. It was decided that larger trials should be made using proper equipment. The intent of these trials was to evaluate:

a) construction techniques;
b) suitability of graded aggregate;
c) performance of such seal coats on various highway surfaces;
d) economics of the procedure.

This report describes the full-scale trials conducted in 1978.

2 DETAILS OF TEST SECTIONS

2.1 Locations

Figure 5 shows locations of the test sections in the highway system. The test sections are numbered according to the order in which they were constructed.

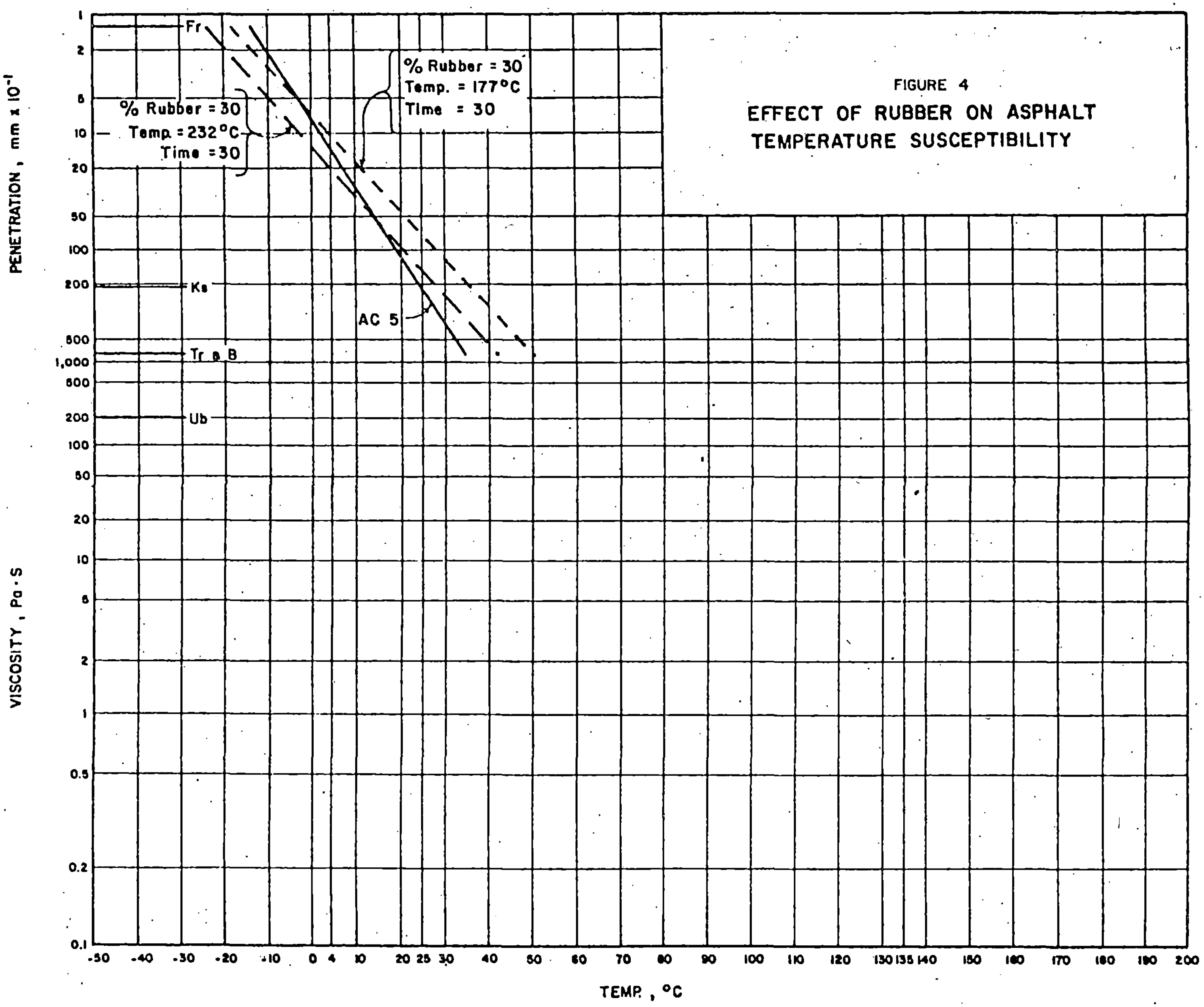


FIGURE 4

EFFECT OF RUBBER ON ASPHALT TEMPERATURE SUSCEPTIBILITY

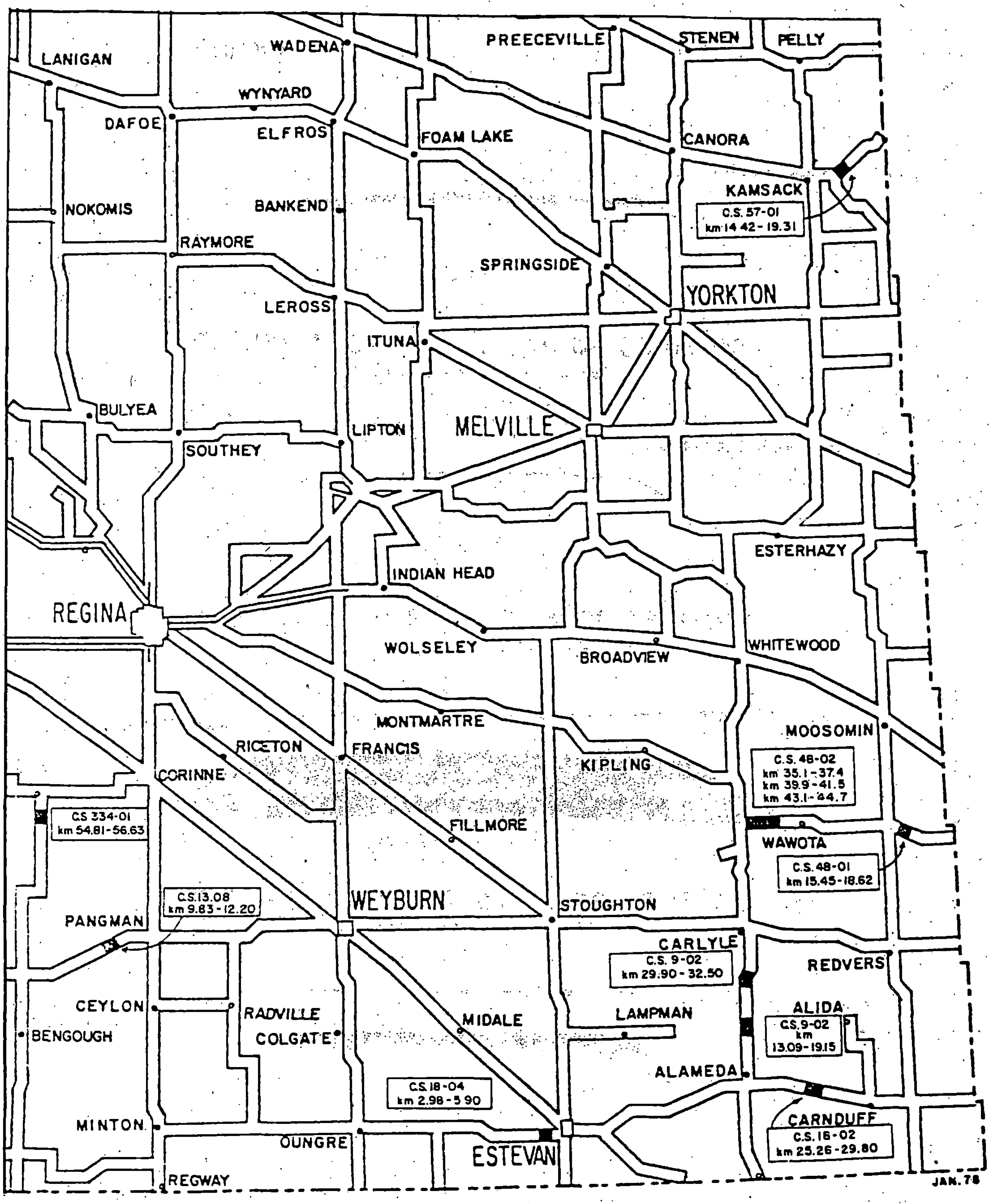


FIGURE 5
LOCATION OF TEST SECTIONS

2.2 Descriptions

Figures 6 to 13 show appropriate cross-sections and seal construction lanes while Table 2 briefly describes the highway structure for each test section.

3 SPECIFICATIONS

3.1 Materials

3.1.1 Rubber Crumb. The specification used for rubber crumb is shown in Appendix I. Gradation limits were chosen on recommendations by Sahuaro Petroleum and Asphalt Company of Phoenix, Arizona, who provided the specialized rubber-asphalt spraying and mixing equipment for construction of the test sections.

Gradation of rubber crumb was chosen to limit the rate of viscosity increase to that needed for uniform distribution of the rubber-asphalt. Limits on the percent of fines or dust-sized particles, are based on their tendency to rapidly increase viscosity while maximum size is limited to prevent clogging of the #5 size nozzles used on the distributor. This results in a fairly narrow range of crumb sizes, ranging from 2.50 mm size down to 400 µm size.

Fully vulcanized rubber is required for maximum reaction between rubber and asphalt. Rubber crumb was supplied by Canasphere of Moose Jaw, Saskatchewan.

3.1.2 Asphalt Cement. Appendix II contains Saskatchewan Highways and Transportation asphalt cement specifications. Samples of AC 6 and AC 1.5 were sent to the Sahuaro Petroleum laboratory, together with available rubber crumb, to ascertain suitability of reaction. Based on length of reaction time of approximately 80 minutes, Sahuaro recommended use of AC 6 asphalt cement.

3.1.3 Solvent. Solvents for thinning rubber-asphalts are generally chosen on the basis of boiling points and aromatic contents. A high initial boiling point is required to reduce the chance of flashing when added to the rubber-asphalt. However, a low final boiling point, or end point, is required to allow fairly rapid curing of the cutback mixture. Low aromatic content is required to reduce chances of depolymerization.

FIGURE 6 CROSS SECTION OF C.S. 48-01

2 Seal Construction Lanes

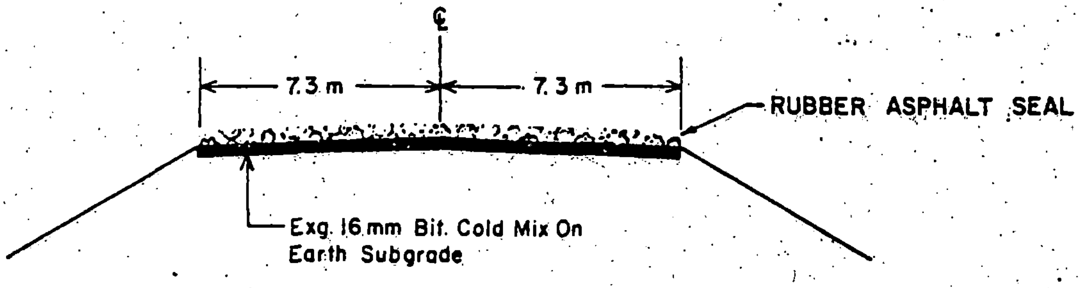


FIGURE 7 CROSS SECTION OF C.S. 48-02

3 Seal Construction Lanes

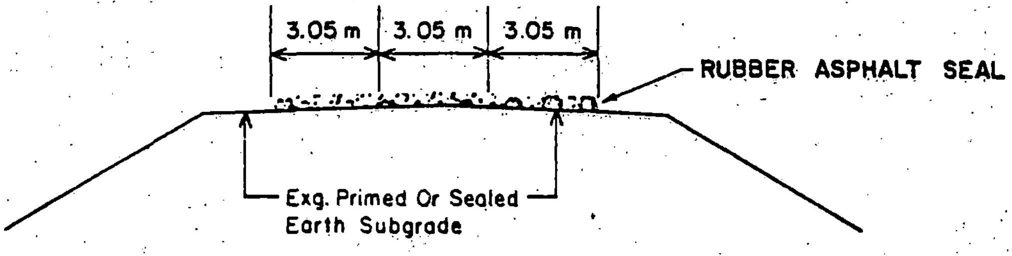


FIGURE 8 CROSS SECTION OF C.S. 9-02

2 Seal Construction Lanes

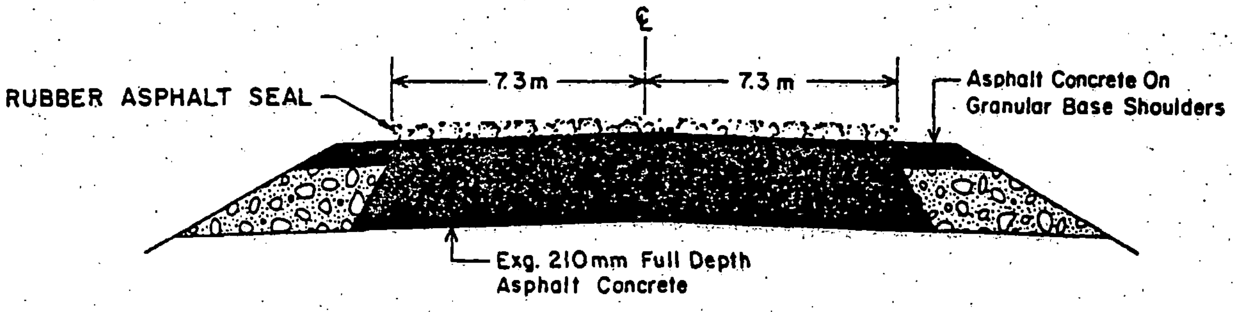


FIGURE 9 CROSS SECTION OF C.S. 18-04

2 Seal Construction Lanes

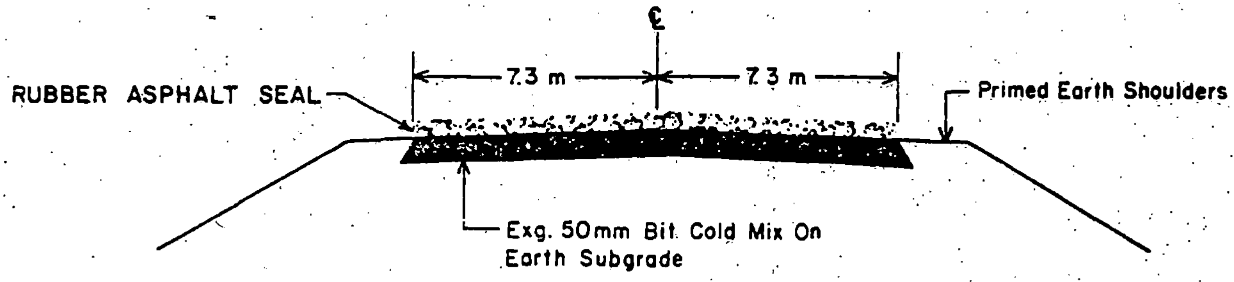


FIGURE 10 CROSS SECTION OF C.S. 18-02
2 Seal Construction Lanes

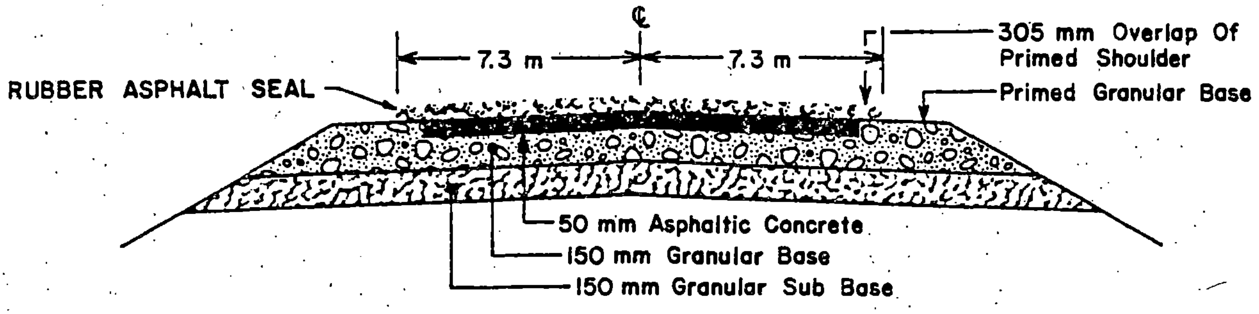


FIGURE 11 CROSS SECTION OF C.S. 13-08
3 Seal Construction Lanes

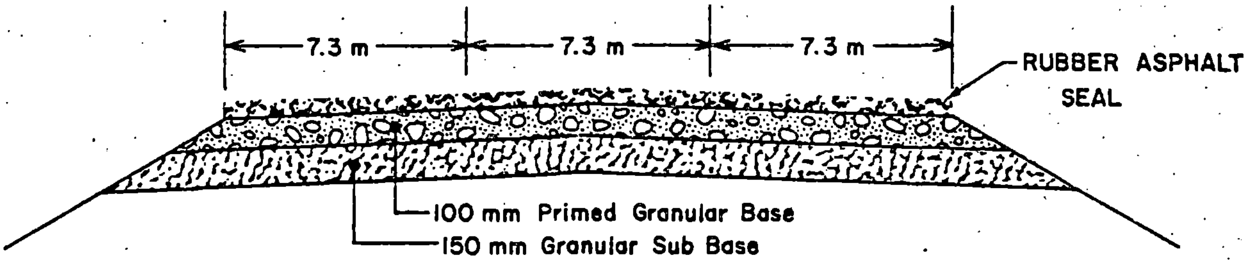


FIGURE 12 CROSS SECTION OF C.S. 334-01
2 Seal Construction Lanes

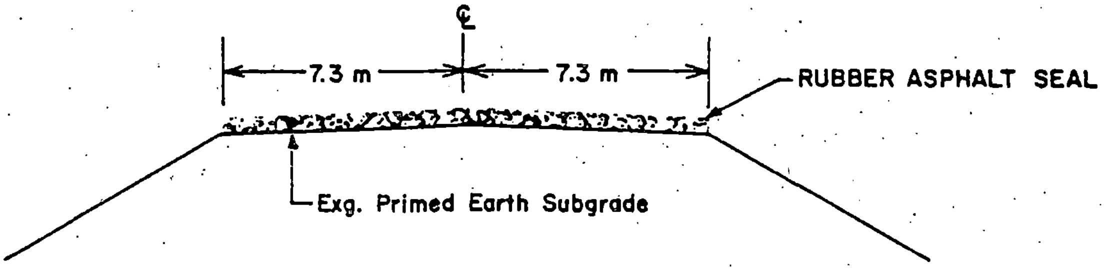


FIGURE 13 CROSS SECTION OF C.S. 57-01
2 Seal Construction Lanes

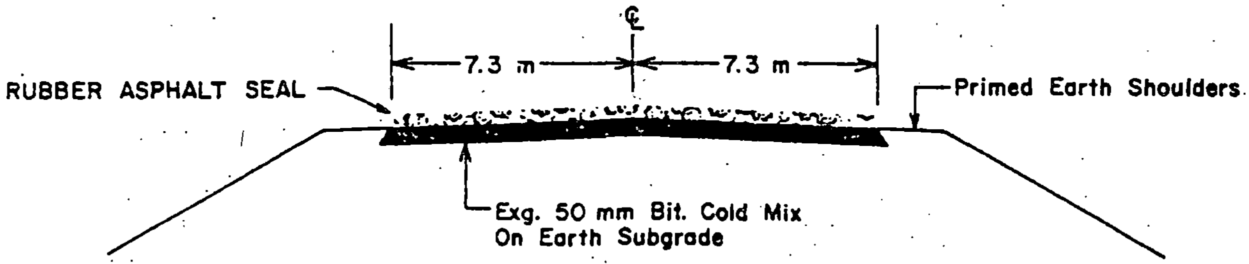


TABLE 2

LIST OF TEST SECTIONS

Test Section	Control Section	km to km	Surface To Be Sealed
1	48-01	15.45 - 18.62	A 7-year old sealed oil treatment (16 mm thick cold mix on earth subgrade).
2	48-02	35.1 - 37.4 39.9 - 41.5 and 43.1 - 44.7	Three seal coat lengths constructed on a primed or sealed earth subgrade. Gaps were left between seals to compare with 50 mm cold mix placed on similar subgrades. One subgrade length was only completed just prior to the seal. The remaining subgrade was completed in 1977, but one portion had been sealed with high float emulsion and the other had only been primed.
3	9-02	13.09 - 19.15 and 29.90 - 32.50	Seals were placed in two locations on a 210 mm full depth asphaltic concrete structure to cover fatigue blocking. One lane is subjected to heavy traffic loading from regular hauling by potash trucks.
4	18-04	2.98 - 5.90	A one-year old 50 mm cold mix on earth subgrade.
5	18-02	25.26 - 29.80	A 14-year old 50 mm asphaltic concrete mat showing considerable fatigue. The mat is constructed on top of 150 mm of base and 150 mm of sub-base.
6	13-08	9.83 - 12.2	A 250 mm granular structure with a primed surface constructed in 1978.
7	334-01	54.81 - 56.63	A primed earth subgrade constructed in 1969.
8	57-01	14.42 - 19.31	A 4-year old 50 mm cold mix on earth subgrade.

A typical solvent specification is shown in Appendix III. However, such solvents are not readily accessible in Saskatchewan and are quite costly to purchase. Consequently, a kerosene from Gulf Oil with a high enough initial boiling point of 170°C, but also a high final boiling point of 285°C, was used.

3.1.4 Aggregate. Conventional seal coating practice requires use of relatively uniformly sized aggregate particles (chips). Because of the success of graded aggregates used in high-float emulsion seal coats and in the initial rubber asphalt test sections, it was decided to evaluate use of graded aggregates in the 1978 rubber-asphalt test sections.

Gradations with 16 mm and 12.5 mm maximum size particles were chosen with 65 percent maximum passing the 5.00 mm and 6 percent maximum passing the 71 µm screens. Appendix IV contains gradation limits of each material.

3.2 Contract Specifications

Appendix IV contains the seal coat specifications.

Because of difficulty of knowing in advance what the specific gravity of the final product might be, measurement of the quantity of rubber-asphalt used was based on the total litres of asphalt cement corrected to 15°C, plus the total litres of kerosene plus the litre equivalent of the rubber crumb computed using a specific gravity of 1.15.

4 EQUIPMENT AND MANPOWER

4.1 Supplied by Contractor

Sahuaro Petroleum and Asphalt of Arizona is a company which has been specializing in the development and construction of chip seals utilizing rubber-asphalt. They are equipped with sophisticated distributors capable of mixing and maintaining rubber crumb in suspension at the required elevated temperature.

To ensure a successful application of the rubber-asphalt and to develop expertise in this technology, the department entered into an agreement with Sahuaro to provide the equipment and manpower necessary to mix and spray rubber-asphalt on the test sections.

4.2 Supplied by Department

The department provided the remainder of the seal coating and traffic accommodation crews and equipment. Because of the much higher viscosity of the rubber-asphalt in comparison to high-float asphalt emulsion, it was judged that heavier rollers would be required than were normally used by department crews. Consequently, two additional heavy rollers, one at 18 tonnes and the other at 32 tonnes, were rented for the test sections to support the three standard 12 tonne rollers. Low-boy flat beds were also rented to haul the heavy rollers from job to job.

To handle kerosene, two distributors were provided, one a 13 600 litre unit and the other a 4 550 litre unit. The smaller distributor provided kerosene at the mixing site whilst the larger one was absent loading fresh supplies.

Because of aggregate spreading problems as discussed in 6.2.2, additional labourers and tandem gravel trucks were required to add additional gravel, spread surplus quantities, or remove oversize material.

4.3 Summary

Table 3 lists the total equipment and manpower used for the sealing operation.

5 CONSTRUCTION PROCEDURES

5.1 General

Except for preparation of the rubber-asphalt mixture, the sealing operation was no different from standard practice. Appendix V contains photographs related to construction methods used.

Rubber-asphalt mixing sites were selected as close as practicable to each sealing project. The longest haul was 26.5 km and the shortest was 1.6 km.

5.2 Mixing Rubber and Asphalt

Asphalt at 135°C was delivered to the mixing site from the refinery by five-axle truck tanker and then pumped into the rubber-asphalt distributors. The distributors were equipped with on-board scale units enabling precise measuring of asphalt, rubber, and kerosene quantities. Weights were displayed on a digital read-out mounted in the cab.

TABLE 3

EQUIPMENT AND MANPOWER REQUIRED FOR SEALING OPERATION

Equipment	Manpower
(a) Sahuaro rubber asphalt mixing and spraying crew	
2 18 000 litre capacity distributors	2 distributor drivers
1 Rubber crumb loading conveyor	1 bootman
1 Crew cab truck	2 labourers for loading crumb
	1 supervisor
(b) Department Sealing Crew	1 Foreman
1 Flaherty Aggregate Spreader	1 Spreader operator 3 Labourers
1 Low-boy trailer	
3 Bros, 9 wheel rubber tired 12 000 kg rollers with 200 mm wide tires	5 Roller operators
1 Rented Tampo, 9 wheel 18 000 kg roller with 280 mm wide tires	
1 Rented Browning, 7 wheel 32 000 kg roller with 355 mm wide tires	
7 Regular tandem gravel trucks, 12 700 kg/load. Up to 5 extra tandem gravel trucks rented when haul distance required	7-12 truck drivers
1 Distributor, 13 600 litre capacity for kerosene	
1 Distributor, 4 550 litre capacity for kerosene	
2 Crew cabs	
1 Office car	1 Office clerk
1 Front end loader	1 Front end loader operator
1 Power broom	1 Broom operator
2 Rented low-bed trailers for moving larger rollers	
	2 Flag persons
(c) Department Maintenance Forces	1 Foreman
1 Traffic pilot car	1 Pilot car operator
1 Tandem gravel truck	1 Truck driver
2 Power brooms	2 Broom operators
	2 Labourers/flag persons

The temperature of the asphalt had to be raised by burner units in the distributor from the 135°C at delivery to the 190°C mixing temperature. At this point, rubber crumb was added by a loading conveyor.

The rubber crumb was delivered to each mixing site by maintenance forces from storage areas in maintenance yards. For the most part, it was in 22.6 kg polyethylene bags and had to be loaded and off-loaded by hand.

Bags were broken open and rubber crumb dumped into the hopper of the elevating conveyor. The rubber crumb was mixed and kept in suspension by means of an auger mounted in the lower part of, and running the entire length of, the distributor.

During the mixing period, the temperature was allowed to drop to about 155°C. The average heating time was 77 minutes and the average cooking and mixing time was 95 minutes. Addition of kerosene, haul to the road, application of rubber-asphalt, and return to mixing site took an average of 110 minutes, for a total time of 282 minutes per distributor load. The fastest distributor load completion was 220 minutes.

5.3 Application of Rubber-Asphalt and Aggregate

The average distance covered per distributor load for an average 3.5 m width lane was 1 362 m.

At the road, the distributor started from a tar paper strip. The tar paper not only allowed for a clean straight line, but also allowed the bootman to unclog any blocked nozzles. Short spray trial bursts on to the tar paper were used to reveal blocked nozzles. Nozzles were unclogged with a piece of wire.

Once spraying started, the distance between the distributor and aggregate spreader was kept to a minimum and generally was less than 15 m. When the spreader hopper was nearly empty, the spreader operator would signal the distributor operator to stop spraying. Aggregate would then be spread to within 300 mm of the end of the asphalt membrane, thus minimizing cooling of the asphalt while aggregate trucks were changed. Before recharging the hopper, the spreader would back up 3 m to allow for a slight overlap in aggregate application.

When there was a delay in delivery of rubber-asphalt, the spreader would overrun the asphalt membrane to allow rolling to be completed right at the end of the seal. The transverse edge would be hand-swept and a new join started on tar paper. Tar paper was not used when truck change-over was rapid.

Direction of travel was usually towards the aggregate source to avoid loaded trucks having to turn around on the highway. The first lane sprayed was against traffic so that the distributor driver could use the edge of the pavement mat or shoulder as a guide. The inside edge of the newly sprayed lane was then used as a guide for the second lane.

5.4 Rolling

The two heavy rollers were kept close behind the aggregate spreader and worked in tandem, overlapping on the centre of the lane. The remaining three light rollers operated over a longer section to give a variable number of coverages. The objective was to obtain a minimum of four complete coverages with all rollers. Tire pressures of the large rollers were kept at 690 kPa and those of the lighter rollers at 500 kPa. The ballasting of the heavy rollers was adjusted to obtain about 18 tonnes of weight on each. The lighter rollers were ballasted to about 11 tonnes.

5.5 Brooming Operations

Surfaces were broomed and tacked, where necessary, between one day and a week ahead of the sealing. Tacking was done with SS1 emulsion diluted with an equal quantity of water and sprayed at a rate of about 0.27 L/m^2. Parts of some test sections were left untacked to evaluate the need for tacking. Power brooming of the surface was repeated just ahead of the sealing operation in order to clean off any accumulated dirt and debris after tacking or to remove any moisture accumulations after rain.

The centreline of the first lane was lightly broomed prior to laying the second lane in order to achieve a good edge and to remove loose aggregate from the surface of the second lane. The end nozzle of the spray bar was allowed to lap the edge to ensure a tight join of seal and aggregate. Most stone on this lap wears off due to the lower application rate on the lap.

On most jobs, traffic was controlled by a pilot car to reduce speed and improve safety in the construction zone. Although it is desirable to traffic a new seal for as long as possible to improve embedment, flying stone hazards necessitate brooming of the seal coat as soon as possible. A minimum of four hours was required before light brooming was allowed but, in most cases, brooming was delayed until the following day.

6 CONSTRUCTION PROBLEMS

6.1 Materials Problems

6.1.1 Rubber Crumb. Production capacity of rubber crumb was not very high at this time, so the rubber had to be purchased over a period of time and stored at local maintenance yards. Because of lack of covered storage, bags in many instances were stored outside. A combination of wind storms and poor covering techniques caused considerable exposure to the bags. Most bags were unsealed polyethylene, and, as a result, the rubber crumb took on moisture while stored. For the most part, moisture content was about two percent but occasionally ranged up to 11 percent. Excessive moisture at one mixing site led to the rubber asphalt boiling out of the top manhole of the distributor. Moisture was also a factor in slowing the mixing process as more care had to be taken to allow it to flash off.

Packaging of rubber crumb also contributed to problems of handling by maintenance forces. The rubber crumb was delivered from the shipper on pallets with 40 bags on each. The pallets were loaded from front to rear of trucks backed up to a loading platform. Maintenance yards had no loading platforms, necessitating off-loading from truck sides. As a result, pallets had to be turned 90 degrees for fork lifts to be inserted under them. In the process of turning, bags became loosened and tended to fall from the pallet. This required considerable manpower to move bags after delivery due to the unsuitability of fork lifts for the operation.

Gradation of the rubber was not always within specification and was at times too fine. This led to a more rapid increase in viscosity of the mixture and necessitated an increase in kerosene content to aid in spraying. Even so, this did not eliminate the problem of streaking or roping in asphalt application.

Table 4 lists gradations of rubber crumb stored at the different maintenance yards.

TABLE 4 RUBBER CRUMB GRADATIONS

Location	Number of Samples	Percent Passing 2.00 mm	Percent Passing 900 μm	Percent Passing 400 μm	Standard Deviation 900 μm	Standard Deviation 400 μm
Milestone	4	100	68.7	7.8	10.9	12.1
Ogema	6	100	73.6	3.0	6.5	1.0
Estevan	6	100	80.1	10.4	8.5	5.4
Carlyle	10	100	76.1	2.8	9.5	1.5
Kamsack	6	100	74.5	7.0	10.4	6.6

6.1.2 Asphalt. There were considerable delays in deliveries by the shipping company because of a lack of truckers. The first load of rubber-asphalt on any day rarely got to the job site before 9:30 a.m. Thus, sealing crews were idle for considerable time each morning and had to work overtime to make up for this lost time. Asphalt delivery temperatures were another source of delay. Although the refinery had promised to deliver asphalt at 200°C, vacuum problems in their towers prevented them from doing this. For a larger rubber-asphalt sealing program, this problem can probably be solved at the refinery. The alternative is to have on-site heated storage.

6.1.3 Aggregate. Because of the nature of Saskatchewan gravel deposits, it was quite difficult to keep the less than 71 μm content down to six percent and the larger than 5.00 mm stones above 35 percent. As a result, aggregate gradations tended to push the upper limit of the specifications. There were also some difficulties with oversize, root and turf contamination, and moisture contents.

It was judged that five percent or more moisture in a stockpile would create too much of an adhesion problem. Consequently, two stockpiles were plant dried to a lower moisture content. One stockpile was rescreened to increase the percentage stone content while the use of other stockpiles was discontinued when contamination or less than 71 μm content was too high.

6.2 Equipment Problems

6.2.1 Rollers. The standard 12 tonne roller used by the department on high-float emulsion seals fits easily into the box of a gravel truck. The rented larger rollers were too wide to do this and therefore extra flat-bed hauling equipment had to be rented to transport these rollers. Because of lack of loading ramps at the job sites, pits had to be dug for these trailers to be backed into, thereby allowing rollers to drive out from ground level.

If heavier rollers are purchased for rubber-asphalt sealing, special transporting equipment will also be required, thus increasing the equipment train required by the crew.

If heavy rollers are purchased for future sealing programs, consideration will have to be given to the type of ballasting arrangement. Water ballast is best as it is easy to load and unload. However, it is not always desirable to fully ballast rollers. This can result in water ballast lurching within the roller leading to instability. Thus, a baffle or compartment arrangement needs to be provided to minimize this effect.

6.2.2 Aggregate Spreaders. Aggregate spreaders have generally been designed to spread one-sized chips. With graded aggregate, these spreaders are very prone to creating segregation, especially if the aggregate has less than two percent moisture.

Course aggregate from the aggregate splitters tends to accumulate along the edges of the three piles above the spreader auger. At each join in the piles, coarse aggregate drops onto the road at a much lower density of spread than the rest of the aggregate. Because asphalt may pump up through this thin layer, the overall spread rate was increased to minimize this action. This results in a waste of material and a tendency to leave a streaked appearance in the seal.

Where moistures are less than two percent, a grid which fits below the spreader gate would appear useful to ensure that the stone drops into the asphalt ahead of the finer material.

As neither a grid nor a "grizzly" was available for the spreader used on these test sections, problems with oversize material were encountered. Oversize material jammed the spreader gates and interfered with the flow of aggregate creating numerous bare spots. Also, the large stones interfere with the rolling process.

Four labourers were required to cover bare spots caused by spreader acceleration and oversize segregation, and to distribute excess piles built up from aggregate overflow from the hopper or from loss through the gate while stationary.

6.2.3 Distributors. The Sahuaro distributors were designed to cope with specific problems associated with rubber-asphalt mixing and spraying. On-board scales make the proportioning of asphalt, rubber, and kerosene fairly precise. The same scales are an excellent method of checking application rates by checking weight loss over a length of spread.

Large capacity burners ensured fairly rapid heating of asphalt to the desired mixing temperature. The built-in auger agitator prevented settlement of the rubber crumb. Previous experiments by the department had shown that usual circulation systems of distributors were unable to do this satisfactorily.

Hydraulically controlled valves enabled each nozzle to be operated individually, which proved to be an asset in unclogging nozzles without having to operate the whole spray bar. Spray bar versatility was enhanced by the ability to hydraulically move the bar laterally up to 0.6m. This allowed spraying to road edge without having to run the distributor at the edge of the roadway.

Despite all these features, a certain amount of "roping" occurred in the final spray, especially towards the end of the bars where pressure was not sufficient to pump out an even application. Part of this problem was attributed to the higher viscosities obtained with fine rubber crumb. However, greater attention to nozzle alignment and correct spray-bar height would have minimized this problem.

The problem of proportioning kerosene was solved by means of a metering device and checked by the on-board scales.

7 JOB DESCRIPTIONS

7.1 Control Section 48-01

This is an old oil treatment (thin cold-mix dust prevention treatment) which is badly rutted and fatigue cracked. The surface is fairly rich in asphalt due to numerous seal and re-seal patches. With addition of a tack coat, there is a distinct possibility that asphalt will bleed through the rubber-asphalt seal (RAS). Subgrade support is low and deflections were high enough to cause reflective cracking to appear in the new seal while being rolled. These cracks have since disappeared under traffic kneading.

This surface is considered to be a severe test of the RAS ability to hold a surface together. The 1977 average daily traffic (ADT) volume of 230, however, is sufficiently low to ensure some chance of success.

Asphalt application rates were varied along this section in an effort to establish the rate most suitable for a graded aggregate seal. Because of rain during construction, some of the aggregate stockpile was dried and applied at less than two percent moisture. To complete the test section prior to an imminent rainfall, the last 100 m of the second lane was constructed using a local maintenance aggregate stockpile. A heavy thunder shower fell on this portion as rolling was completed.

7.2 Control Section 48-02

This test section was chosen to evaluate the ability of an RAS to waterproof a newly constructed subgrade in comparison with a 50 mm cold-mix on subgrade. Part of the subgrade was built in 1978 but the remainder, built in 1977, had more time to settle under traffic loading. The 1977 subgrade was partly primed only and partly primed and sealed. Therefore, three sections of RAS were constructed to allow for any differences to show between a freshly primed subgrade, a one year old primed subgrade, and a one year old primed and sealed subgrade.

Some weakness in the subgrade and the method of construction was leading to fatigue blocking and some potholing in the primed surface. Again, this will severely test the RAS ability to last. In addition, surface breaks in the primed surface had reflected through the sealed surface to detract from the smoothness of ride. Again, low ADT of 310 could ensure success.

One section contained a seal applied across the full half width of subgrade and down the sideslope a distance of 6 m. This should ensure that all surface water is shed into the ditch and prevent softening of the subgrade shoulder. In theory, this should improve lateral support and reduce rutting in the surface. In practice, it remains to be seen whether spring freeze-thaw action will offset this potential benefit.

Asphalt application rates were raised, kerosene content increased, and moisture contents varied on these sections in an attempt to combat gradation problems of increasing 71 µm and decreasing stone content. Eventually, the stockpile source was changed to obtain better gradation.

7.3 Control Section 09-02

This is a full-depth asphaltic concrete structure showing some signs of fatigue. The ADT of 800 includes an average 33 trips of nine-axle potash trucks loaded to 50 000 kg. The RAS was put on this section to evaluate its ability to withstand heavy truck loading and to permanently seal fatigue cracking.

Initially, moisture contents in the aggregate stockpile caused concern and drying was started. However, the dry aggregate led to considerable dust. This not only made it difficult to judge rates of spread but also caused considerable discomfort to people working downwind of the operation. Visibility in the construction zone was reduced considerably creating a potential hazard to the safety of crews and passing traffic. With stockpile moisture dropping as the pile was worked, drying was stopped.

The aggregate top size on this section was 12.5 mm, except for a short section of 16.0 mm where stockpiles were switched while the drying process was being arranged.

Because of a change in test section arrangement, the seal on this section was lengthened by approximately 3.0 km at the south end. It was decided to leave the extension non-tacked to evaluate the need for tacking a clean pavement. The remainder was tacked with SS-1 emulsion at a rate of 2 650 L/km for a width of 7.3 m.

7.4 Control Section 18-02

The same aggregate stockpile was used on this section as for C.S. 09-02. No attempt was made to vary rates of asphalt or aggregate. Rain fell overnight between the first and second day of seal coat construction. This made brooming of the first day's application difficult while care had to be taken to ensure that brooming did not damage the seal.

The surface asphaltic concrete mat on a granular stabilized base and sub-base had considerable fatigue but very minor rutting. The ADT for this section is 800 vehicles. The mat width was 6.7 m and adjacent primed base shoulders contained considerable chuckholing at their join with the mat. The seal was applied over a width of 7.3 m to try to reduce this problem.

Problems with oversize aggregate required additional labour behind the spreader to cover bare patches and remove the oversize.

Approximately 1.5 km of the east end of this section was left untacked. The remainder was tacked at a rate of 2 650 L/km for 7.3 m width.

7.5 Control Section 18-04

The seal coat aggregate had not been prepared for this section, so a 16.5 mm cold-mix aggregate of similar gradation was used instead. The aggregate stockpile had excess of six percent moisture and was dried down to two percent and covered for two or three weeks ahead of the sealing operation. The dried aggregate gave similar dust problems as experienced on C.S. 09-02. In addition, piles of aggregate built up below the spreader gates at each truck changeover due to the gates not closing completely. The gate opening adjustment device was tightened to its limit and the problem was largely removed.

At mid-day, a heavy thunderstorm occurred and the surface of the road had to be dried by power brooming ahead of the sealing operation.

The 50 mm cold-mix surface on earth subgrade was considered sufficiently clean and rich enough in asphalt not to be tacked. The ADT for this section is 350 vehicles.

7.6 Control Section 13-08

This was a newly constructed 250 mm primed granular structure carrying an ADT of 400 vehicles. No tacking was done as the prime was considered fresh enough. Because the rubber asphalt available for this section exceeded that required to cover the primed portion, sealing was extended over 0.4 km of previously sealed granular structure.

Stockpiles were changed part way through this job due to deleterious material contamination. A mid-afternoon rain shower delayed sealing but, after the surface was power broomed dry, the operation proceeded.

The heavy rollers were withheld from a small section to observe the effects of using light rollers only.

7.7 Control Section 334-01

This is a former municipal road with an ADT of 330 vehicles where the seal was applied. However, the commercial vehicle volume is very low.

The subgrade was primed several weeks ahead of the sealing operation and had deteriorated considerably. Consequently, the surface had become very irregular and this reflected through the seal to create a rough ride.

The stockpile aggregate gradation was very good for this section, being low in 71 µm and high in plus 5.00 mm sizes. This ensured a fairly good stone retention.

A light re-prime was applied two days prior to the seal.

7.8 Control Section 57-01

This is a 50 mm cold-mix which had not received a maintenance seal coat since it was constructed. The ADT of 650 is mainly light traffic, as this is a Provincial Park access. Considerable fatigue block cracking was showing on the surface and numerous maintenance spot seals had been applied, creating rich spots. Some rutting was tending to occur towards the east end. A tack coat was not applied because the surface tended to be sufficiently rich in asphalt.

The stockpile was rescreened to reduce the 71 µm fraction and increase the 5.00 mm sizes. The most easterly 100 m of the eastbound lanes had non-screened aggregate applied when the screened aggregate was depleted.

The most westerly 0.8 km of the eastbound lanes had light rolling only while the remaining 4.1 km test section only had one heavy roller operating. The second heavy roller was returned to the owner prior to this section being laid.

A few light showers occurred during the sealing operation but were insufficient to seriously wet the surface.

8 ASSESSMENT OF PERFORMANCE

8.1 General

All RAS test sections will be assessed for two conditions, durability of the seal materials and ability of the seals to maintain or enhance structural capacity of road surfaces.

8.2 Durability

8.2.1 Stone Retention. Stone retention is important in order to protect the rubber-asphalt from traffic wear and to ensure adequate skid resistance. All the seals have retained sufficient stones to meet these requirements. However, some seals have stone spacing up to 80-100 mm which is barely adequate, besides being costly in lost aggregate. Stone loss occurred mainly at the brooming stage where the stones were never held initially by the rubber-asphalt. Since that time, stones which were held have improved embedment and adherence except on C.S. 13-08 where stone loss has occurred due to lack of traffic in the early stages.

In an attempt to relate stone retention to some of the variables experienced on these several test sections, photographs of the surface were taken randomly and all stones larger than 5.00 mm and contained in a given area, were counted. A metal frame enclosing an area of 300 mm x 300 mm was placed on the surface before photographing to give a constant unit area at each location.

Sufficient locations were chosen to represent each section where it was judged a change had taken place in asphalt application rate or aggregate gradation. Locations were chosen in the office to avoid bias at the road. The metal frame was placed in the outer wheelpath of each construction lane except where three construction lanes were applied when inner and outer wheel paths were photographed.

Thirty-six locations were photographed and are listed in Table 5 together with five variables, a visual rating of the general section and the number of stones counted.

The stone count was plotted against each variable and a linear regression analysis made using a Call 360 Statpack computer program. Table 6 shows the correlation coefficients so obtained. Such low correlations show that there is no relationship between the stone retention rate and the given variables of asphalt rate, stone particles in excess of 5.00 mm, percent 71 µm, aggregate rate and aggregate moisture content. However, this was not a scientific experiment as it was not possible to design the variables to obtain exact measurements at the point photographed. Moreover, one sample of 0.09 m^2 inasmuch as 6 000 m is not very representative of the total area. Also, interactions of variables will have an effect.

Figure 14 shows the typical shot-gun scatter of points obtained by plotting stone retention against the asphalt spray rate. Based on visual observations all the 12.5 mm stone retentions looked good. Therefore, a stone count of 265 per unit area has been chosen as satisfactory for this material. Taking the ratio of cross sectional areas of the 16 mm and 12.5 mm top size and applying it to the 12.5 mm stone count, a value of 170 stones per unit area is obtained for the 16 mm top size. Two vertical lines have been placed on Figure 14 at these values. Figures 15 and 16 show stone retentions corresponding to these values for the 16.0 mm and 12.5 mm aggregates respectively.

Figures 17 and 18 show the best stone retention for the 16.0 mm and 12.5 mm aggregates respectively.

The horizontal lines in Figure 14 represent the asphalt rates at which generally good stone retention was achieved. For the 12.5 mm aggregate, rates of between 2.28 and 2.47 L/m^2 achieved good stone retention. Although some good stone retention occurred in the 16.0 mm aggregate for asphalt rates below 2.62, most of the poor retention occurred below this value. Of those that show good retention,

TABLE 5
STONE RETENTION COUNTS AND THE FACTORS AFFECTING THEM

CONTROL SECTION	NO. STONES COUNT	ASPHALT RATE	% 5 mm	% 71 μm	AGGREGATE RATE kg/m²	AGGREGATE PERCENT MOISTURE	VISUAL RATING
334-01	216	2.39	63	3.1	25	2.8	G
334-01	210	2.39	63	3.1	25	2.5	G
13-08	203	2.28	59	1.0	25	3.6	F
13-08	123	2.61	52	5.1	25	4.7	F
13-08	95	2.34	59	1.0	25	5.0	F
13-08	98	2.28	59	1.0	25	3.6	F
13-08	94	2.56	59	1.0	25	3.6	F
18-04	277	2.34	58	5.9	30	1.8	G
18-04	167	2.45	58	5.9	30	1.5	G
18-02	267	2.50	58	5.8	23	3.5	VG
18-02	300	2.28	58	5.8	23	2.8	VG
09-02	342	2.28	64	5.7	20	6.0	G
09-02	338	2.39	64	5.7	22	2.0	VG
09-02	373	2.45	53	5.8	22	3.7	VG
09-02	291	2.45	53	5.8	22	3.5	VG
09-02	200	2.34	73	6.3	20	3.8	F
57-01	232	2.45	49	6.2	24	4.0	F
57-01	114	2.45	71	7.4	24	4.0	P
57-01	272	2.50	49	6.2	24	4.0	F
57-01	301	2.56	49	6.2	24	4.0	F
48-02	187	2.61	67	10.0	35	4.2	P
48-02	186	2.60	67	10.0	35	4.2	VP
48-02	177	2.94	67	10.0	30	4.0	P
48-02	213	3.59	67	10.0	30	4.0	P
48-02	280	2.72	52	5.9	28	4.5	G
48-02	89	2.83	67	10.0	33	2.0	VP
48-02	150	2.61	67	10.0	35	2.0	VP
48-02	170	2.88	51	8.2	28	4.5	G
48-02	213	2.83	52	5.9	28	4.5	G
48-01	150	2.56	69	7.4	33	6.2	G
48-01	287	2.66	41	6.6	27	3.0	G
48-01	247	2.56	51	5.4	22	4.7	VG
48-01	302	2.45	41	6.6	27	3.0	VG
48-01	238	2.66	69	7.6	33	2.0	G
48-01	195	2.72	69	7.4	30	6.0	G
48-01	265	2.88	41	6.6	27	3.9	VG

VISUAL RATING
VG = VERY GOOD
G = GOOD
F = FAIR
P = POOR
VP = VERY POOR

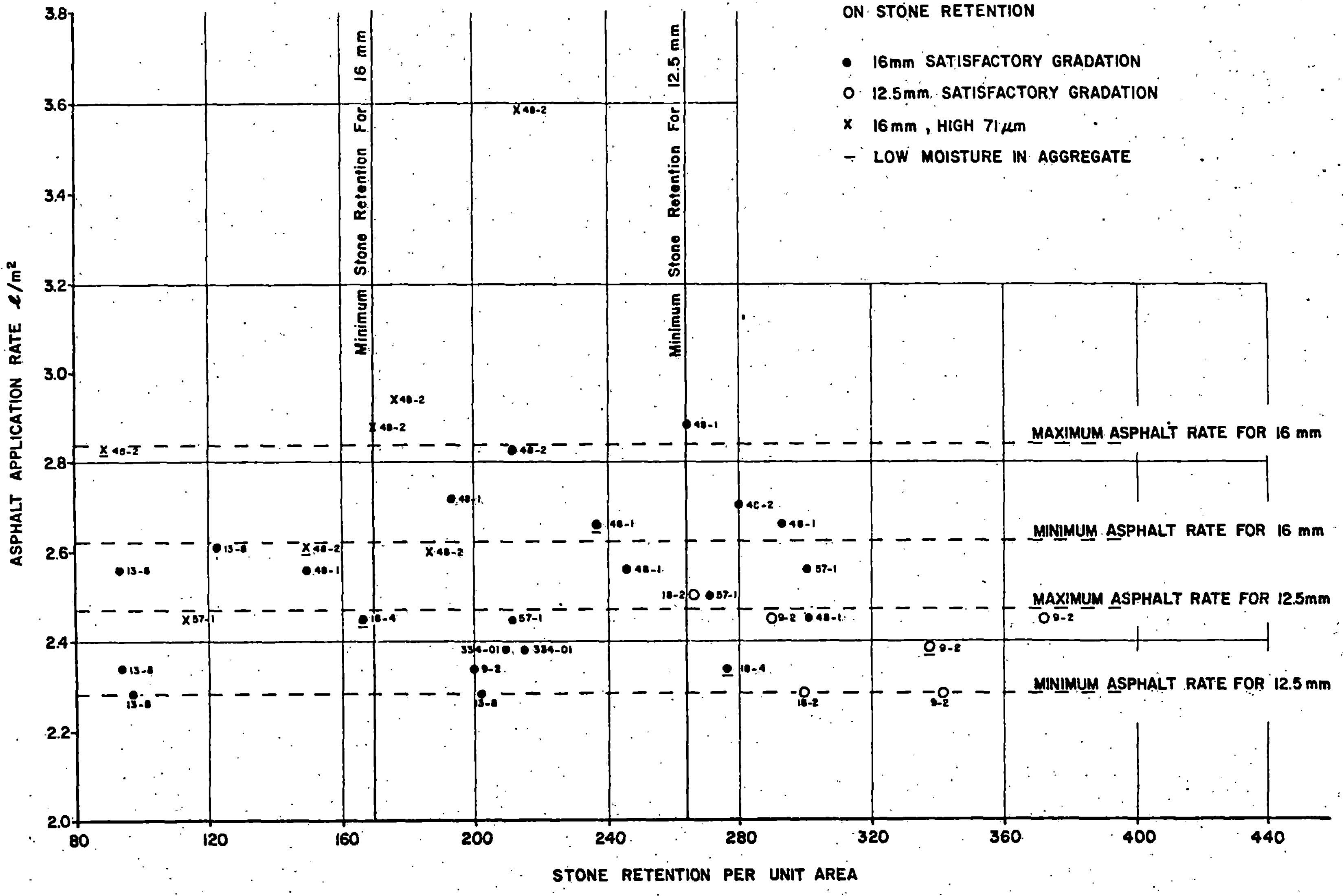
TABLE 6

LINEAR REGRESSION CORRELATION COEFFICIENTS FOR STONE COUNTS VERSUS THE VARIABLES AFFECTING THEM

VARIABLE	CORRELATION COEFFICIENT
Asphalt Application Rate	0.146
Percent Passing 5.0 mm	0.261
Percent Passing 71 μm	0.185
Aggregate Application Rate	0.405
Moisture Content in Aggregate	0.081

FIGURE 14

EFFECT OF ASPHALT APPLICATION RATE ON STONE RETENTION



C.S. 48-2 km 35.1 - km 37.4
N.L. km 36.0 ; ASP.=2.88 L/m^2
16mm AGG.=28 kg/m^2
1 HVY. ROLLER ; 77 SEALED S-G

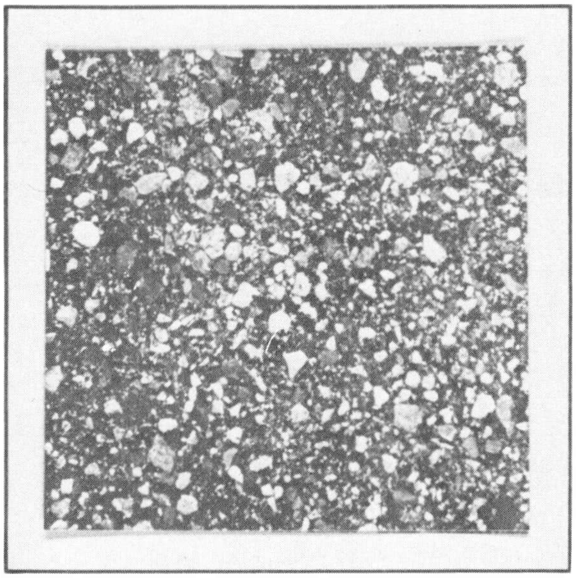


FIGURE 15

Minimum stone retention of 170 per .09 m^2 for 16 mm aggregate.

C.S. 18-2 km 25.26 - km 29.8
W.B.L. km 27 ; ASP.= 2.5 L/m^2
12.5 mm AGG.= 20-26 kg/m^2

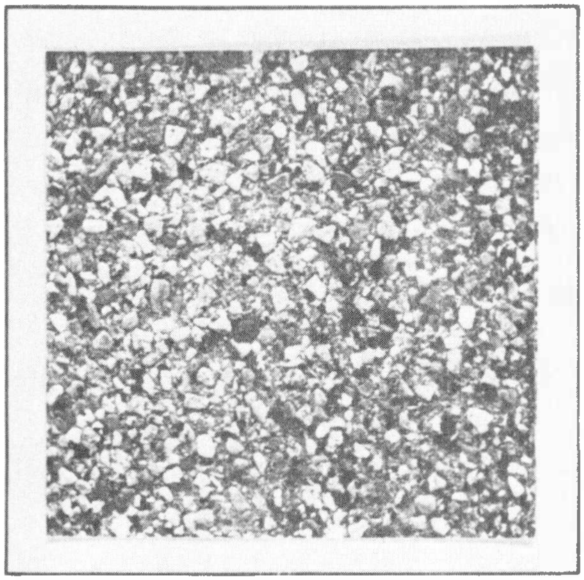


FIGURE 16

Minimum stone retention of 265 per .09m^2 for 12.5 mm aggregate.

C.S. 48-1 km 15.4 - km 18.6
W.B.L. km 17 ; ASP. =2.66 L/m^2
16mm AGG.= 27 kg/m^2 (COARSE)

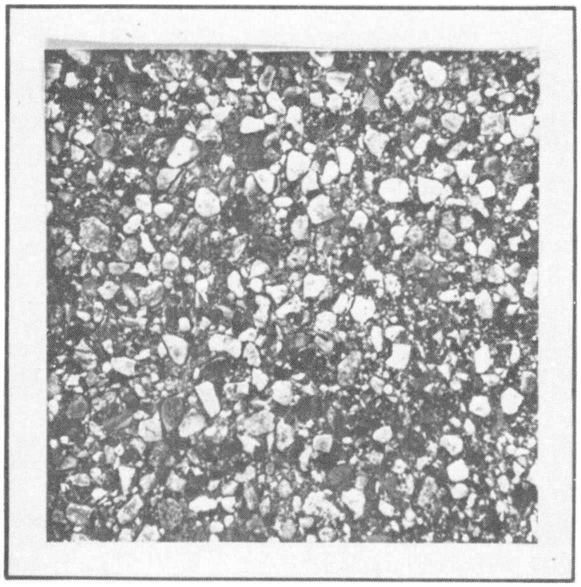


FIGURE 17

Best stone retention for 16mm aggregate.

C.S. 9-2 km 13.1 - km 19.15
S.B.L. km 15.5 ; ASP.=2.45 L/m^2
12.5 mm AGG.=20-24 kg/m^2
LOADED

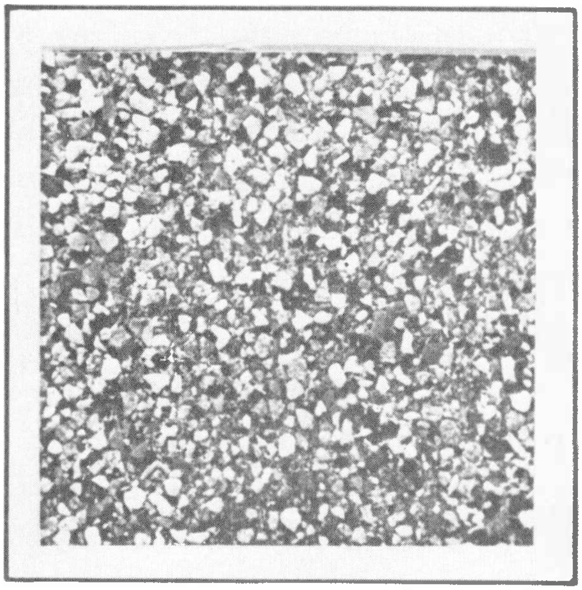


FIGURE 18

Best stone retention for 12.5 mm aggregate.

C.S. 334-01 had relatively few stones larger than 12.5 mm and almost qualifies for the 12.5 mm aggregate. C.S. 57-1 shows good retention, but has lost considerable stone since initial application due to insufficient embedment and lightness of traffic. The only anomaly appears to be C.S. 18-04, where a fairly good stone retention was obtained but embedment was not as good as elsewhere and stone loss could occur over winter. Thus minimum and maximum asphalt rates of 2.61 to 2.84 L/m^2 are suggested for 16.0 mm aggregates depending on hardness of surface on which the seal is being placed.

Figure 19 shows the percent passing the 5.00 mm sieve versus the asphalt application rate according to the stone criteria for pass or fail. Most of the failures lie above the 65 percent passing line. The three failures which lie below the line are all on C.S. 13-08 which had insufficient asphalt applied. Of those with satisfactory stone retention above the line, C.S. 9-2 is subject to continuous heavy truck passes, C.S. 48-1 used dried aggregate and 48-2 had very heavy asphalt application.

Figure 20 shows the percent passing the 71 µm sieve versus the asphalt application rate according to the pass and failure stone criteria. Most of the failures lie above the line. Of the two which occur below the line, C.S. 13-08 is under-asphalted and 18-4 is a borderline failure. Thus there appears to be some benefit in increasing the asphalt content when the percent passing the 71 µm is increased.

8.2.2 Resistance to Hot Weather Bleeding. Hot weather bleeding will show only with time and will have to be assessed subjectively. Bleeding is migration of excess asphalt to the surface and results in a slick surface. Causes of this condition in a seal may be an excess of asphalt applied during sealing or pumped from rich patches below the seal. Also, hardness of the surface on which the seal is placed will affect total depth of embedment of the stone into the asphalt.

8.2.3 Resistance to Cold Weather Cracking. Cold weather cracking is a function of the brittleness of the asphalt at low temperatures. Previous observations and experiments have shown that rubber-asphalt continues to remain flexible down to -15°C. Cracking in a road surface is usually divided into load and non-load associated cracking. Non-load

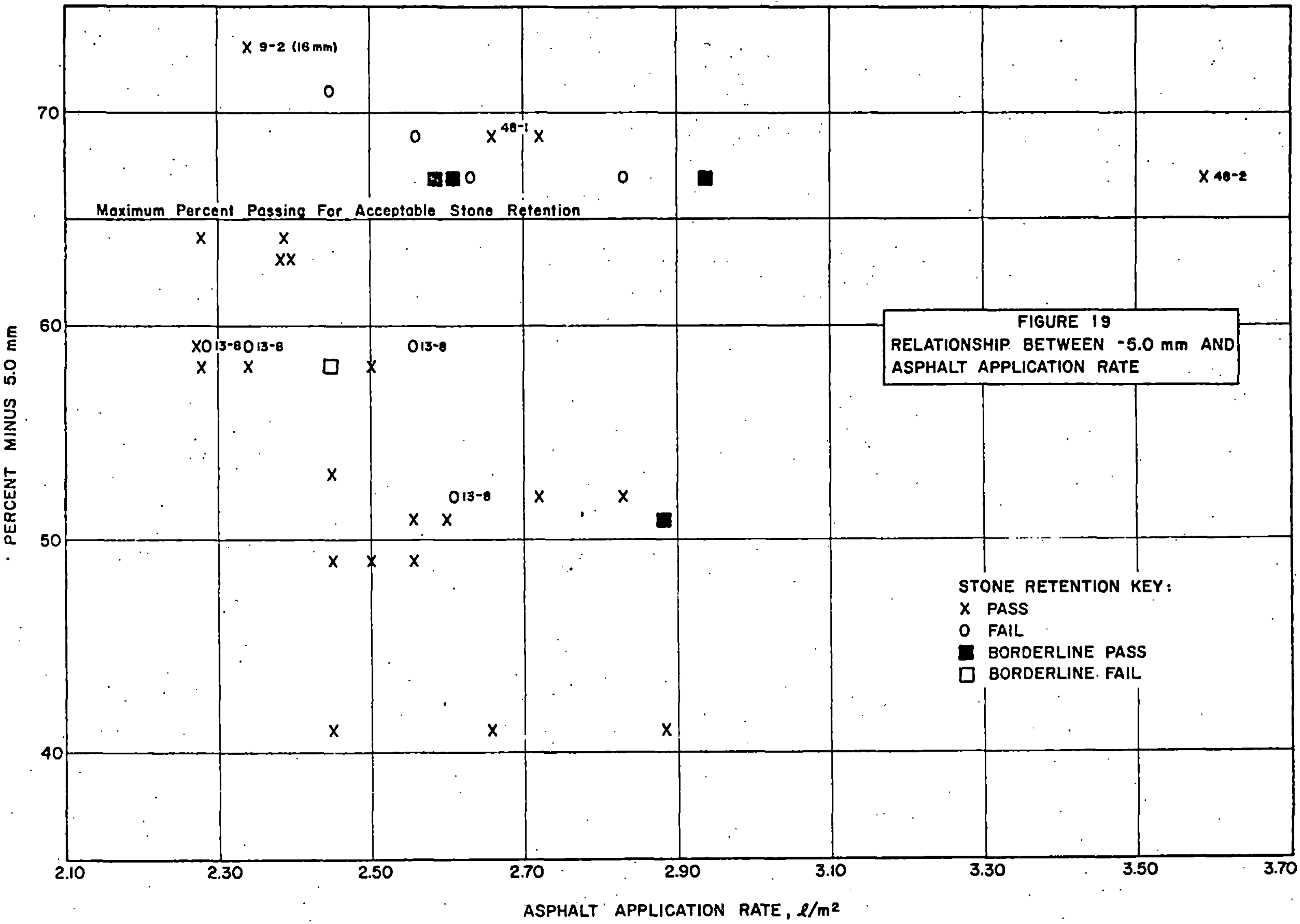


FIGURE 19
RELATIONSHIP BETWEEN -5.0 mm AND ASPHALT APPLICATION RATE

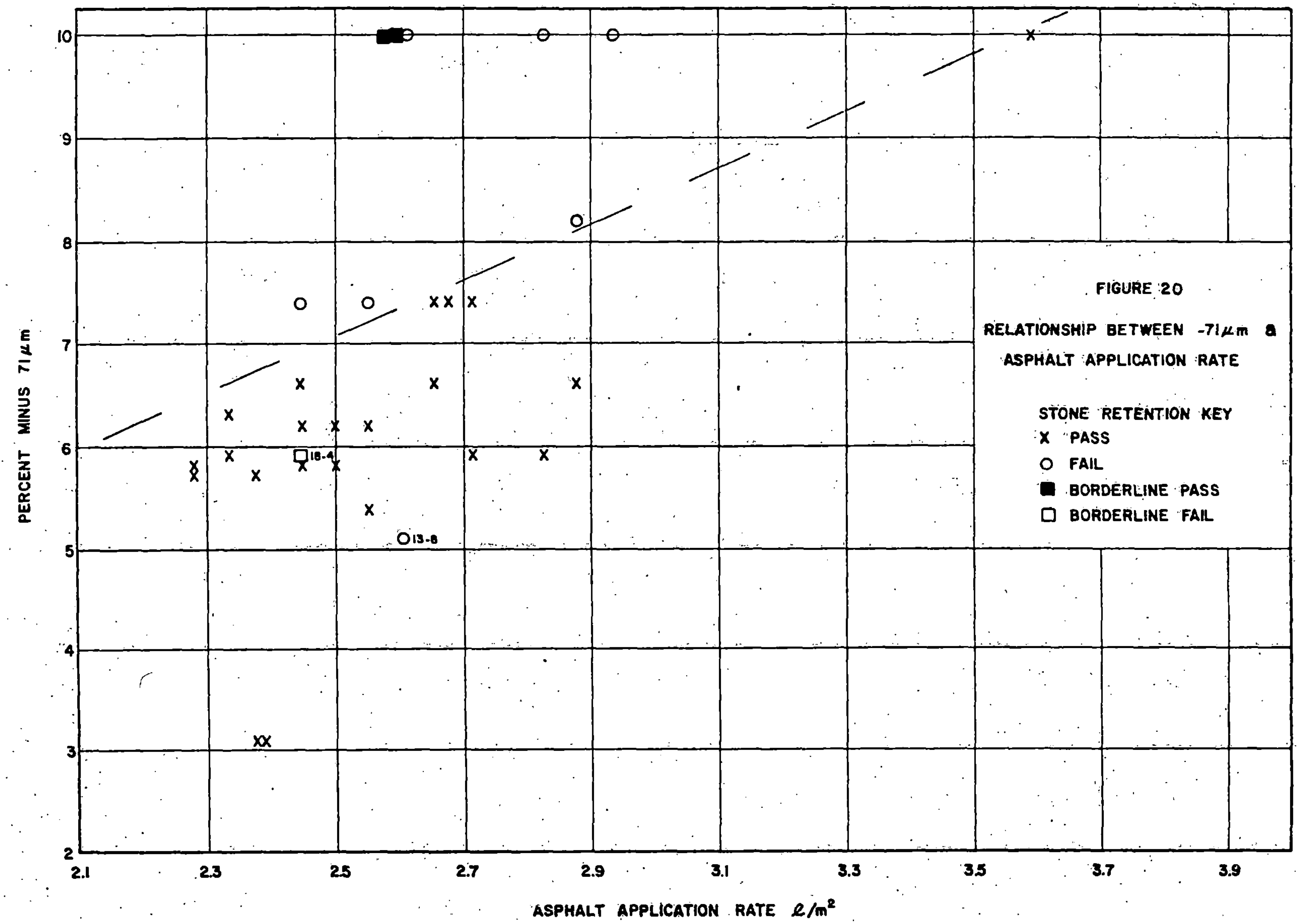


FIGURE 20

RELATIONSHIP BETWEEN -71μm & ASPHALT APPLICATION RATE associated cracking such as transverse and longitudinal cracking result from large strain movements over a very short length. It is not expected that RAS will resist this type of cracking. Load associated cracking results from fatigue in the surface after a large number of bending repetitions. The flexibility of RAS at low temperatures is expected to resist reflection of this type of cracking through to the surface.

8.3 Structural Enhancement

Test sections were chosen to reflect the numerous surface types used in Saskatchewan and the different states of repair for the same surface type. The following surfaces were used:

a) Two primed earth subgrades, one newly constructed and one which had operated as a gravel surface for several years. The soil type of the new subgrade was basically till and that of the old subgrade was heavy lacustrine clay.

   The objective of the test sections on primed earth subgrades is to compare the capability of an RAS dust treatment against other dust treatment surfaces. For C.S. 48-02, the RAS will be compared with a 50 mm cold-mix surface and a double high-float emulsion seal constructed at the same time. On C.S. 334-01, the ability of the RAS to waterproof the surface and thereby prevent rutting in the heavy clay subgrade will be an important factor.

b) A 16.5 mm cold-mix surface near the end of its service life. Resistance of RAS to spring breakup of cold-mix surfaces will be assessed together with associated maintenance costs and increased life.

c) Two 50 mm cold-mix surfaces, one newly constructed and one with four years of operation. The seals will be compared with high-float seals for resistance to reflection cracking, maintenance costs, and increased life of the surface.

d) A newly constructed 250 mm light granular structure. Such structures are usually surfaced wtih a double graded-aggregate high-float seal. The single RAS replaced the double seal. It is believed that a single RAS applied full-width will perform as well and at slightly lower cost than the double seal.

e) An old 50 mm mat on granular base and sub-base which required a seal coat to combat fatigue in the mat.

f) A 210 mm full-depth asphaltic concrete structure showing fatigue under heavy truck hauling since 1970. On this structure and (e) above, the RAS will be assessed on its ability to waterproof the surfaces to prevent rutting and further fatigue in the mats, thus delaying need for structural upgrading.

Assessment of seals for each of these surface types will be on the basis of economics, cost effectiveness, and general performance.

9 LABORATORY TESTS ON RUBBER ASPHALT SAMPLES

Samples of asphalt cement and rubber-asphalt at the end of the mixing process were collected daily and returned to the central laboratory. The samples were stored in a freezer until testing could be made.

Table 7 shows the results of viscosity tests run on the rubber-asphalt at two temperatures, with and without kerosene. In order to compare Brookfield and vacuum viscosities more realistically, the Brookfield viscosity was calculated for 0.12 sec^{-1} shear rate which was the average calculated rate for the Koppers vacuum viscometer.

The results show that viscosities at 60°C of the rubber-asphalt far exceed that of the original asphalt cement. Even after the addition of 8 percent kerosene, the viscosities only reduce to the same order as Saskatchewan AC6. Therefore, for Saskatchewan conditions, a considerably softer asphalt could be used without any risk of bleeding. Current high-float residual asphalts used for sealing give viscosities of 200 Pa·S at 60°C.

At the higher temperatures, viscosities even with the kerosene added are also far in excess of spraying viscosities of the high-float emulsions. This makes it very important to minimize the time between

TABLE 7

VISCOSITY TESTS ON SAMPLES OF RUBBER ASPHALT

CONTROL SECTION	DATE SAMPLED	VISCOSITY AT 60°C WITH KOPPERS TUBE, 10 cm Hg		SHEAR RATE $= \frac{40 \text{ sec}^{-1}}{\text{t ave.}}$ 0% KEROSENE	VISCOSITY AT 160°C WITH BROOKFIELD AT 0.12 sec^{-1} SHEAR RATE	
		0% KEROSENE Pa·S	8% KEROSENE Pa·S		0% KEROSENE mPa·S	8% KEROSENE mPa·S
48-01	30/6/78	1 445	350	0.12	3 900	2 200
48-01	5/7/78	1 840	-	0.108	-	-
48-02	10/7/78	2 280	-	0.09	6 600	-
18-04	12/7/78	1 850	30	0.106	-	2 350
9-02	13/7/78	1 465	57	0.12	7 700	2 200
9-02	14/7/78	1 700	-	0.12	5 450	-
18-02	17/7/78	2 510	-	0.078	5 300	-
13-08	19/7/78	950	-	0.168	-	-
334-01	20/7/78	1 500	110	0.135	5 400	1 800

spraying, applying aggregate and rolling. This also underlines the need for maximizing the tire pressures and number of rolling passes.

Such high viscosities also restrict the temperature conditions under which such a product can be successfully constructed. For Saskatchewan, such temperature conditions only occur for about three months of the year.

It is interesting to note that the Brookfield viscosities with zero percent kerosene at 160°C are about double those obtained at 135°C in the 1972 laboratory tests. This probably reflects the longer reaction time given the rubber in 1978 (80 minutes) versus the 1972 (30 minutes). Green (1977) shows that viscosity will continue to increase with time of reaction to a maximum.

Because Saskatchewan conditions do not need such high viscosities at 60°C but do need more flexibility at cold temperatures, it appears that a softer asphalt might be a better choice. Also, provided such an asphalt will give considerably more flexibility at low temperatures, it may not be necessary to wait for full reaction time. Savings in time for reaction to take place would lead to a considerable reduction in the cost of sealing on a per kilometre basis.

10 ASSESSMENT OF ECONOMICS

10.1 Total Costs

The total cost for the test sections was approximately $449 000. The total length of equivalent 7.3 m roadway which was sealed, was 36.64 km. Thus, cost per kilometre for a standard 7.3 m roadway was $12 255. This compares with current graded aggregate high-float seal coat costs of between $2 175 and 2 480 per km.

The following table shows the costs of materials and activities involved in the seal coat operation.

Item	Cost	Percent of Cost	Cost Per Kilometre
Department Forces	$115 240	25.7	$ 3 145
Asphalt, Rubber, Kerosene	114 530	25.5	3 126
Contract Items	199 820	44.5	5 454
Aggregate	17 140	3.8	468
Engineering	2 270	0.5	62
TOTAL	$449 000		$12 255

Examining these figures for possible savings, it can be seen that Department Forces, Asphalt, Rubber, Kerosene and Contract Items offer the largest potential.

10.2 Department Forces Costs

Because this contract consisted of a large number of short test sections, there were extra moving, organizational, and miscellaneous costs which would not normally be incurred on a longer contract.

If extra moving, aggregate drying and reprocessing and miscellaneous extra activities by maintenance forces are excluded from Department Forces total costs, a probable more appropriate cost can be obtained for a routine sealing operation.

The following table shows where costs were incurred and gives a comparison of probable routine seal coat costs:

Operation	Costs For Test Sections	Costs For Routine Seals
Seal Crew - Construction	$ 53 440	$53 440
- Moves	18 000	N/A
Drying and Rescreening Aggregate	8 000	N/A
Extra Trucks	7 800	7 800
Maintenance - Routine	20 000	20 000
- Miscellaneous	8 000	
	$115 240	$81 240

For 137 hours of production, an hourly cost of \$593 is obtained. On the basis of 3.74 hours per kilometre, a routine Department Forces cost would become \$2 218 per kilometre for a similar operation involving two rubber-asphalt distributors and heating asphalt in the distributors at the job site.

To reduce these costs, two areas can be improved. The first is to increase the number of distributor loads put out in a day. Based on the average cycle time observed on the test sections, Figure 21 shows how three distributors could achieve seven spray loads in an 11-hour day. With the use of this arrangement, there would still be two periods of two hours and 45 minutes of waiting by seal crews between delivery periods. A fourth distributor would reduce the waiting time to a total of four hours and 10 minutes and achieve another two spray loads.

On this basis, seal crew costs per kilometre would reduce from \$2 218/km to 1 352/km for three distributors and \$1 058/km for four distributors. These costs are on a basis of 1.37 km per distributor load.

Equipment costs per kilometre for use of three or four distributors would also drop by a small amount.

A more substantial saving would be achieved if time for heating asphalt could be reduced. Figure 22 shows how three distributors could achieve nine spray loads in a 10-hour day. Total waiting time would be reduced to three hours and 10 minutes. A fourth distributor could be used to put on two more spray loads in that time to obtain eleven spray loads in a 10-hour day. Total waiting time would be reduced to a tolerable one hour and 50 minutes. On this basis, seal crew costs per kilometre would reduce to \$962 for three distributors and \$787 for four distributors.

10.3 Materials Costs

Savings on asphalt, rubber, and kerosene are difficult to achieve except on the basis of competitive bidding. The overall average asphalt spray rate was 2.46 L/m^2 corrected to 15°C. (See Appendix VI) This rate appears generally adequate and probably could be reduced for the 12.5 mm aggregate. However, it is doubtful whether significant savings can be made.

Chart showing Mixing and Spraying Cycle for Rubber Asphalt when heating Asphalt on Site for up to Four Distributors

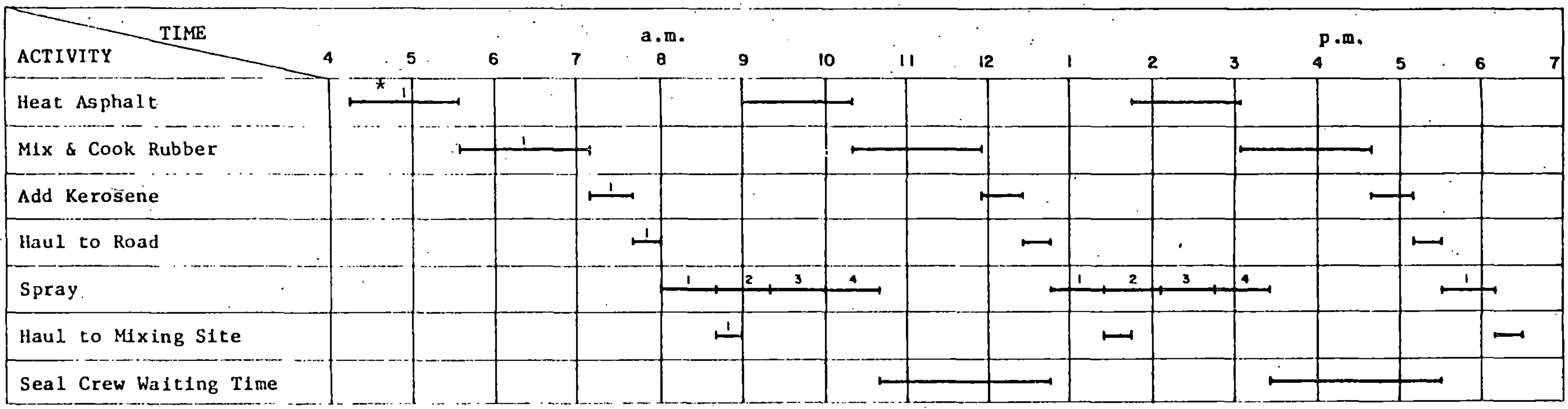


FIGURE 21

Chart showing Mixing and Spraying Cycle for Rubber Asphalt when Asphalt is heated at Refinery for up to Four Distributors

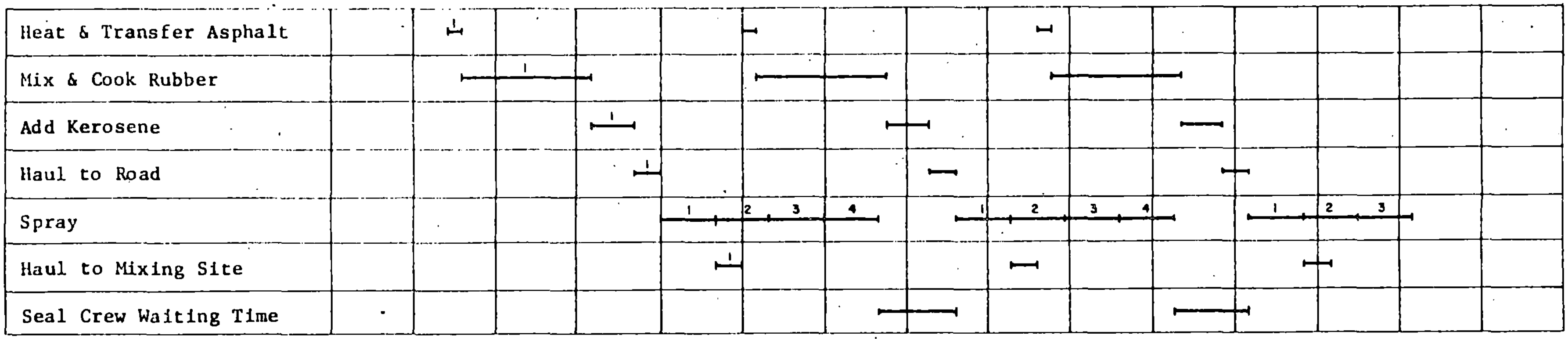


FIGURE 22

* Numerals refer to Distributor Number

A rubber crumb with less 900 µm and 400 µm fractions would reduce kerosene requirements from eight to six percent to effect another small saving as the cost of kerosene is approximately 50 percent higher than asphalt cement.

10.4 Contract Items Costs

The other major cost is that of Contract Items. It is difficult to do an analysis on Sahuaro's costs as normally competitive bidding should ensure reasonable contract bids. In this case, sealing conditions in Saskatchewan were unknown to the contractor. Also, the nature of a contract involving several short test sections created major uncertainties. Thus, the bid price was very conservative to ensure no losses would occur. Until more companies are available to do this kind of work, competitive bidding will not take place.

The only other route the Department can follow is that of purchasing the special distributors and doing the complete sealing operation by their own forces. Because the Department sealing program is extensive, there is very little downtime by Department crews other than for weather and for moves. Thus, equipment is utilized to a maximum and costs for equipment are minimized.

In the case of rubber-asphalt seals, work would be restricted to some three months of the year and would involve 600 hours. Assuming a cost of $200 000 per distributor and a 5-year life, each unit could be operated at an hourly cost of $67. Operator costs would not exceed $15 per hour to give a total cost of $82 per hour. This is a relatively conservative figure as the tractor unit would have a much longer life than 5 years and also the distributor would be used on standard sealing projects at other times of the year.

On this basis, and for heating on site, the cost per kilometre for three distributors used would be $82 x (3 distributors) x 2.28 (hours/kilometre) = $561. For four distributors the cost would be $82 x 4 x 1.78 = $433. Approximately another $110 per kilometre would be required for rubber handling, loading and mixing.

Thus, on a continuous sealing program run by Department Forces, the costs per kilometre for the two conditions would become:

	Alternative A Heat Asphalt on Site		Alternative B Heat Asphalt at Refinery	
	3 Dist.	4 Dist.	3 Dist.	4 Dist.
Department Forces	1 352	1 058	962	787
Asphalt, rubber, kerosene	3 126	3 126	3 126	3 126
Cooking, mixing and spraying	671	694	506	543
Aggregate	468	468	468	468
Engineering	62	62	62	62
TOTAL COST/km	5 679	5 408	5 124	4 986

11 FUTURE PLANS

Experience and observations to date have shown that acceptable rubber-asphalt seals can be constructed using graded aggregate. It is now necessary to bring the costs down to the point where they are competitive with other surfacing types. A second agreement will be made with Sahuaro Petroleum for approximately another 190 kilometres of sealing in 1979. These projects will be let on a routine basis and should allow for maximum efficiency to be achieved in production. Approximately 850 tonnes of rubber crumb will be purchased which will give potential suppliers a better idea of costs and distribution problems. At that point, a decision will have to be made whether to use Department forces to reduce costs to a more acceptable level. Besides reducing costs, it is necessary to improve construction techniques to achieve a better prepared primed subgrade and base surface. This will reduce surface failures and achieve a smoother road surface.

The combination of these factors should lead to substantial replacement of cold-mix and seals as currently constructed. In anticipation of these developments, the Department has invited proposals to construct a plant to produce rubber crumb. Tentative production requirements have been estimated as follows:

Year	Tonnes
1981	2 000
1982	3 000
1983	3 400
1984	3 700
1985	4 000

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NON-CITED REFERENCES

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ACKNOWLEDGEMENTS

This report is the product of a co-operative effort by numerous people. Saskatchewan Highways and Transportation Regina and Yorkton Districts, Head Office staff in Operations and Highway Engineering Division, and Works Branch personnel warrant special mention. In particular, Brian Gray, Resident Supervisor and Al Scott Maintenance Area Foreman at Carlyle, need special thanks for ensuring a smooth running logistical and administrative operation despite a fairly complex set of variables posed by the contract.

Gratitude is also due the contractor, Sahuaro Petroleum and Asphalt Company of Phoenix, Arizona, who provided the expertise in asphalt rubber mixing and application.

APPENDIX I

SPECIFICATION FOR GROUND TIRE RUBBER

APPENDIX I

SPECIFICATION FOR GROUND TIRE RUBBER

1. Description

These specifications apply to ground tire rubber for use in hot asphalt-rubber seal surface treatment.

2. Materials

The ground tire rubber shall consist of one hundred percent vulcanized rubber, free of fabric, wire, or other contaminants and having a specific gravity of 1.15 ± 0.02.

The ground tire rubber shall comply with the following gradation except that no particle shall have a length in excess of 7 mm.

Canadian Metric Sieve	Percent by Weight Passing Canadian Metric Sieve
2.38 mm	100
2.00 mm	98 - 100
400 μm	0 - 10

Up to four percent of calcium carbonate shall be added to prevent particles from sticking together.

The ground tire rubber shall be subject to rejection because of failure to conform to any of the specification requirements.

3. Delivery

Ground tire rubber is to be supplied in sturdy bags weighing not more than thirty kilograms and not less than twenty kilograms.

The supplier shall select the method of delivery. The Department will be responsible for unloading trucks or railway cars. The supplier shall ensure that the product is not contaminated or damaged because of improper handling or storage.

The Department will accept deliveries upon notification from the supplier.

4. Payment

Invoices must show the price of Ground Tire Rubber per tonne F.O.B. Regina. Payment for GROUND TIRE RUBBER will be made at the unit price per tonne (one thousand kilograms) F.O.B. Regina, as specified by the Saskatchewan Government Purchasing Agency order.

APPENDIX II

SASKATCHEWAN DEPARTMENT OF HIGHWAYS AND TRANSPORTATION SPECIFICATION FOR BITUMINOUS BINDER

APPENDIX II

SASKATCHEWAN DEPARTMENT OF HIGHWAYS AND TRANSPORTATION

7100 - SPECIFICATION FOR BITUMINOUS BINDER

7100 - 1 DESCRIPTION

These specifications apply to the manufacture of asphalt binders to be used for the construction of asphalt pavements and ancilliary work. The types and grades of asphalt to which this specification will apply shall be those indicated under Construction.

7100 - 2 MATERIALS

All asphalt binders shall be prepared from petroleum oils. They shall be free from water and other impurities. Solvents used in the manufacture of cut-back asphalts shall be derived from petroleum oils. Emulsifiers used to stabilize asphalt emulsions shall not be harmful to the performance of the asphalt in service.

7100 - 3 CONSTRUCTION

The refining process shall be selected by the supplier provided that the resulting product conforms to all applicable requirements of this specification when tested in accordance with methods shown.

A. Asphalt Cements

The grade of asphalt shall conform to the following requirements and shall not foam when heated to a temperature of 175 °C and shall be uniform in character throughout.

GRADE		AC 1.5		AC 4		AC 5		AC 6	
REQUIREMENTS	ASTM TEST METHOD	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Visc. @ 60°C, Pa·s @ 135°C, mPa·s	D2171 D2170	15 100	- -	(1) -	- -	(1) -	- -	(1) -	- -
Penetration @ 25°C, 100 g, 5 s	D5	350	-	(1)	-	(1)	-	(1)	-
Ductility @ 15°C, 5 cm/min, cm	D113	60	-	-	-	-	-	-	-
Ductility @ 25°C (3)	D113	-	-	100	-	100	-	100	-
Flashpoint (COC), °C	D92	205	-	205	-	235	-	235	-
Solubility in Trichloroethylene,%	D2042	99.5	-	99.5	-	99.5	-	99.5	-
Thin Film Oven Test Weight Loss, %	D1754	-	2.2	-	1.0	-	0.6	-	0.6
Penetration @ 25°C of residue, % of Original	D5	-	-	45	-	50	-	55	-
Viscosity @ 60°C of residue, % of Original	D2171	-	320	-	-	-	-	-	-
% Xylene in N-Heptane - Xylene for negative spot test	(2)	-	-	-	50	-	45	-	40

Note (1) Viscosity @ 60°C and Penetration @ 25°C shall fall within the area described in Figure 1.

Note (2) AASHTO Test Method T102.

Note (3) If ductility at 25°C is less than 100 cm, the material will be acceptable if its ductility at 15°C is more than 100 cm.

APPENDIX II - Cont'd

GOVERNMENT OF THE PROVINCE OF SASKATCHEWAN

SASKATCHEWAN DEPARTMENT OF HIGHWAYS AND TRANSPORTATION

SPECIFICATION FOR ASPHALT CEMENT

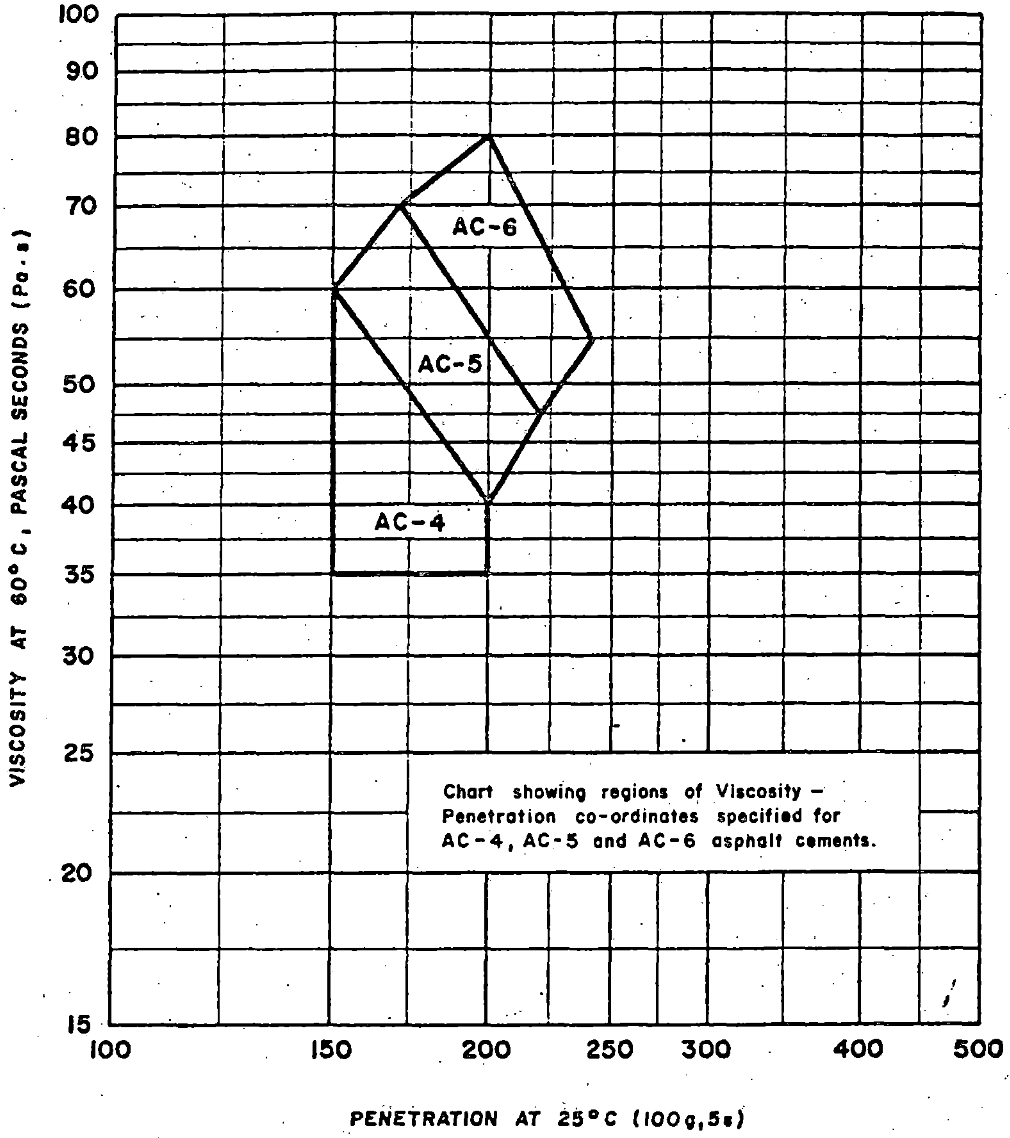

Chart showing regions of Viscosity – Penetration co-ordinates specified for AC-4, AC-5 and AC-6 asphalt cements.

GRADE OF ASPHALT CEMENT		AC-4		AC-5		AC-6	
	CO-ORD	VISC.	PEN.	VISC.	PEN.	VISC.	PEN.
VISCOSITY AND PENETRATION SHALL BE WITHIN GRAPHIC REGIONS DESCRIBED BY THE LETTERED CO-ORDINATES	A	60	150	70	170	80	200
	B	35	150	60	150	70	170
	C	35	200	40	200	47	220
	D	40	200	47	220	55	240

FIGURE I

APPENDIX III

SPECIFICATION FOR SHELL SOL 140 SOLVENT

APPENDIX III

SPECIFICATION FOR SHELL SOL 140 SOLVENT

Property	Test Method	Shell Sol 140
Specific Gravity @ 60°F	ASTM D-1250	0.786
Gravity, °API	ASTM D-287	48.5
Pounds per Gallon @ 60°F	ASTM D-1250	6.55
Color, Saybolt	ASTM D-156	+28
Kauri-Butanol Number	ASTM D-1133	31
Aniline Point, °F	ASTM D-611/D-1012	155
Mixed Aniline Point, °F	ASTM D-611/D-1012	-
Flash Point, T.C.C., °F	ASTM D-56	142
Distillation, °F	ASTM D-86	-
IBP	-	368
10% Recovered	-	371
30%	-	372
50%	-	373
70%	-	375
90%	-	378
Dry Point	-	-
End Point	-	398

Evaporation Rate, Seconds, Shell Evapo-Rater®

10%		1050
30%		3200
50%		5400
70%		7780
90%		10280
100%		12700

Composition, % Volume

Paraffins		48.4
Naphthenes		47.7
Aromatics (total)		3.9
Toluene plus Ethyl Benzene		0.0
C_8 plus Aromatics excluding EB		3.9

APPENDIX IV

SASKATCHEWAN DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
RUBBER ASPHALT SEAL COAT SPECIFICATION

APPENDIX IV

SASKATCHEWAN DEPARTMENT OF HIGHWAYS AND TRANSPORTATION RUBBER ASPHALT SEAL COAT SPECIFICATION

DESCRIPTION OF WORK

The work shall consist of mixing and applying a rubber asphalt bituminous binder on a prepared surface at the locations and in conformity with the dimensions shown on the attached plans or as designated by the Engineer.

In this agreement, the following definitions will apply:

AGGREGATE - The crushed graded seal coat aggregate before applying to the road surface.

SEAL COAT - Graded aggregate seal coat.

RUBBER CRUMB - Ground tire rubber as per Department specifications attached.

RUBBER ASPHALT BINDER - The bituminous asphalt binder after, rubber crumb and kerosene added.

A. MATERIALS

The Department will select and pay for the bituminous binder.

The bituminous binder will be AC-6 as per attached Department Standard Specification 7100.

The Department will supply the kerosene. The Department will supply the rubber crumb to the site.

APPENDIX IV - Cont'd

The aggregate to be supplied and applied by the Department will comply with one of the following gradations.

SIEVE DESIGNATION	PERCENT BY WEIGHT PASSING CANADIAN STANDARD SIEVES	
16 mm		100%
12.5 mm	100%	
5 mm	35 - 65	35 - 65
2 mm	30 - 45	30 - 45
71 μm	0 - 6	0 - 6

B. EQUIPMENT

The following equipment shall be used:

1. A self-powered pressure bituminous material distributor with a capacity not less than ten thousand (10 000) litres. The distributor shall be equipped with the following appliances and devices in proper operating condition.

   (a) Tachometer
   (b) Pressure Gauge
   (c) Adjustable length spray bar
   (d) Positive displacement asphalt pump with separate power unit
   (e) Heating coils and burner capable of applying even heat to bituminous material
   (f) Thermometer well and accurate thermometer
   (g) A mechanical agitating device capable of keeping the rubber particles in suspension at all times.

2. Equipment capable of adding the rubber crumb to the distributor which will readily allow computation of the percentages by weight of the rubber crumb and bituminous binder

in the distributor.

Before the application of rubber asphalt binder, the Contractor shall ensure that the distributor meets the following adjustments and requirements.

(a) The rear chassis springs have been blocked or chained, if necessary, to prevent the height of spray bar from changing as the tank is unloaded.

(b) All spray bar nozzles are of the same manufacture, type and size.

(c) Clogged nozzles have been removed and cleaned individually with solvent.

(d) All nozzles have been set in the spray bar so that the nozzle slots make the same angle (15° to 30°) with the longitudinal axis of the spray bar.

(e) The spray bar has been adjusted to the correct height to ensure uniform application without streaking.

(f) The spray bar has been provided with a positive shut-off to prevent dribbling.

(g) The distributor is capable of maintaining a uniform speed.

(h) The distributor may be checked for calibration by the Engineer before being used on the work.

3. The Department will supply the following equipment:
   - (a) A mechanically operated, rotary type power sweeper.
   - (b) A self-propelled aggregate spreader.
   - (c) Two or more pneumatic tire rollers.
   - (d) Distributor or storage for kerosene.

C. MIXING

1. The materials shall be combined as rapidly as possible for such a time and at such a temperature that the consistency of the mixture approaches that of a semi fluid material. The temperature of the bituminous binder shall be between 175° and 230°C. At the lower temperature, it will require approximately 30 minutes for the reaction to take place after the start of the addition of rubber crumb. At the higher temperature, the reaction will take place within five minutes; therefore, the temperature used will depend on the type of application and the methods used by the contractor. The engineer shall be the sole judge of when the mixture has reached application consistency. After reaching the proper consistency, application shall proceed immediately and in no case shall the mixture be held at temperatures over 160°C for more than one hour after reaching that point.

2. The proportions of the two materials, by weight, shall be 75%±2% bituminous binder and 25%±2% rubber crumb. After the full reaction described in C(1) above has occurred,

the bituminous binder and rubber crumb mixture shall be diluted with kerosene. The amount of kerosene used shall be 5½% to 7½%, by volume, of the hot bituminous binder rubber crumb mixture as required for adjusting viscosity of spraying or better "wetting" of the cover aggregate. The kerosene shall have a boiling point of not less than 175°C, and the temperature of the hot bituminous binder rubber crumb mixture shall not exceed this temperature at the time of adding the kerosene.

D. APPLICATION OF RUBBER ASPHALT BINDER

The rubber asphalt binder shall be applied with a pressure distributor in a single uniform continuous spread over the section to be treated. The rubber asphalt binder shall be applied in accordance with the following temperature limits.

TYPE OF BITUMINOUS BINDER	TEMPERATURE
AC-6	160°C to 180°C

The quantity of rubber asphalt binder to be used per square metre shall be 2.3 to 2.8 litres or as directed by the Engineer.

The rubber asphalt binder application shall be started on a strip of building paper at the beginning of each spread. The paper shall be removed and burnt. Skipped areas or deficiencies shall be corrected by hand spray. No more than ten metres (10 m) of road surface shall be sprayed in advance of the aggregate spreading operation.

Rubber asphalt binder shall not be spilled, sprayed or tracked on completed sections of seal coat except that binder for the adjacent lane shall be applied such that half the spray fan from the end nozzle overlaps the join.

E. WEATHER LIMITATIONS

Rubber asphalt binder shall not be applied to a prepared surface when:

1. The atmospheric temperature is 15°C and falling.
2. The weather is misty or rainy.
3. Later in the day than two hours before sunset local time.

F. MEASUREMENT

The rubber asphalt binder will be measured in litres. The volume will be computed on the following basis:

- Litres of bituminous binder to be calculated at 15°C.
- Litres of kerosene to be calculated at 15°C.
- Litre equivalent of rubber crumb to be calculated by using a specific gravity of 1.15.

G. PAYMENT

Payment for preparing and applying rubber asphalt binder will be at the contract unit price per litre. The unit price will be full compensation for heating the bituminous binder, adding and mixing the rubber crumb, adding and mixing the kerosene and applying the rubber asphalt binder on the road.

APPENDIX V

PHOTOGRAPHS OF CONSTRUCTION OPERATION

Loading Rubber Crumb by Motorized Belt

Preparing to Spray R.A.S.

Maintenance Truck Provided Gravel for Missed Patches

Brooming of C.S. 9-2 Showing Excess Aggregate

APPENDIX VI

SUMMARY OF TOTAL ASPHALT, RUBBER AND KEROSENE USED

APPENDIX VI

SUMMARY OF TOTAL ASPHALT, RUBBER AND KEROSENE USED

CONTROL SECTION	ASPHALT (litres)*	RUBBER (kg)	KEROSENE (litres)
48-1	40 840	13 880	5 090
48-2	108 140	36 670	14 050
9-2	103 100	33 200	13 250
18-4	35 000	11 250	4 515
18-2	54 340	17 370	6 960
13-8	43 850	14 130	5 610
334-1	20 410	6 530	2 620
57-1	60 370	19 370	7 720
TOTAL	466 050	152 400	59 815

* Corrected to 15°C

For Specific Gravity of Rubber = 1.15 kg/L
Total Equivalent litres = 658 390
For Total Area Sprayed = 36 640 x 7.3 m^2
Overall Average Spray Rate = 2.46 L/m^2