ROADWAY MANAGEMENT: AN INVESTIGATION OF SCANDINAVIAN PRACTICE

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Roadway management in the Scandinavian countries has much in common with that in Alaska. Of particular interest are winter maintenance practices, pavement markings and asphalt pavement design and construction. This report on those topics is based on a series of interviews and literature reviews conducted by the author while based at Sweden's Tekniska Hogskolan i Lulea (Lulea University of Technology) during a sabbatical leave from the University of Alaska Fairbanks in fall 1992.
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ABSTRACT

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1.0 Introduction

The writer spent the fall semester of 1992 in Scandinavia while on sabbatical leave from the School of Engineering at the University of Alaska Fairbanks. Based at Sweden's Tekniska Högskolan i Luleå (Luleå University of Technology), he was able to travel to several locations in Scandinavia to inquire about local practices with respect to roadway management.

Funding was provided from the Alaska Cooperative Transportation and Public Facilities Research Program (ACRP) to cover a portion of the travel expenses and the preparation of this report.

At the request of the Department of Transportation and Public Facilities, the following three topics were of primary concern: 1) Winter Maintenance Practices, 2) Pavement Markings, and 3) Asphalt Pavement Design and Construction. The report is organized around these three topics, with some brief commentary regarding other topics of interest at the end.

This report is based on an extensive set of interviews with road agency personnel, contractors, engineers and engineering faculty throughout Finland, Norway and Sweden, plus a large amount of printed material. Both a list of meetings and a bibliography of reference material are included as final sections of the report. Appendix D, previously submitted as a separate volume in one copy, contains much of the written material that was reviewed in the preparation of this report.
2.0 Winter Maintenance Practices

Several topics related to winter maintenance practices are currently of interest in Scandinavia. They include the use of salt and other melting agents and environmental effects thereof, mechanical deicing methods and materials, icing conditions as a function of type of pavement structure, guidelines for maintenance and operations, computer-based road weather information systems, selection of snow moving equipment, and safety and trafficability as correlated to winter maintenance actions.

2.1 Melting Agents

Salt, primarily sodium chloride (NaCl), has been used for deicing roads in Scandinavia for many years. In both Finland and Sweden, the practice began in the 1960's. (Finnish National Road Administration, 1991; Öberg, Gustafson and Axelson, 1991) It is still common practice in most regions, especially those with high traffic volumes.

Several disadvantages of the use of sodium chloride on roadways are recognized. The primary disadvantages noted by Swedish officials are (1) increased corrosion of vehicles, (2) damage to concrete and to bridge structures, and (3) negative impacts on the environment, including trees, other vegetation and ground water. An estimated annual cost of corrosion in vehicles in Sweden is five to six billion SEK, or roughly $US1 billion, of which one third is due to the use of salt on pavements in the winter. This vehicle corrosion cost has been approximated as five to ten times the cost to public agencies of providing the chemical deicing (Simonsson and Gustafson, 1990).

A study of the environmental impact of highway deicing in Sweden (Bäckman, 1980) found that the determining factors were prevailing geological and hydrological conditions. Damage to conifer trees is very common near the roadway. Ground water and surface water were impacted only slightly in the samples studied. Another measure of the impact of deicing salts is the "dirtiness" of the road. A Swedish study in the early 1980's compared the transmission of light through glass plates subjected to splash from salted and
sanded roads. The study "clearly shows that salting causes increased dirt spray compared to sanding" (Helmers and Ytterbom, 1986).

Because of the disadvantages of the use of standard granular salt, as noted above, the Nordic countries have investigated several alternatives. The MINSALT program of the Swedish Road and Traffic Institute, conducted between 1985 and 1991, is an outstanding example of the work done in Scandinavia on this topic (Öberg, Gustafson and Axelson, 1991). Summaries of research results and current practice for several alternatives are given below.

2.1.1 Prewetted Salt

To decrease the total amount of salt used, both Sweden and Finland pre-wet the salt before it is placed on the roadway. The reaction time is increased, and there is less waste outside the roadway because the particles tend to stick to the roadway surface. Testing in Sweden throughout the 1980's began with calcium chloride; however, due to its aggressiveness on concrete, sodium chloride soon became the standard material (Gustafson, 1985).

Either water or a salt solution can be used to pre-wet the salt. A typical spreader configuration is shown in Figure 1, which consists of a hopper bin for the dry salt, a tank for the pre-wetting agent (generally sodium chloride) and a spreader plate where the two elements are combined. In Sweden, a typical operation adds a saturated sodium chloride solution at 30% by weight to the dry salt; the amount of dry salt is reduced by 30%. Since some of the solution is water and not salt, the net effect is a reduction in the total salt used.

More recently, a simpler pre-wetting technique has been used with some success for relatively small applications. With this method, water is sprayed with a hose directly onto the loaded salt hopper; conventional equipment may be used, but, for effective wetting, the quantity of salt in the hopper is restricted to between two and three cubic meters (Öberg, Gustafson and Axelson, 1991).

Pre-wetted salt can be spread effectively at temperatures down to -6°C. It is spread at a rate of about one cubic meter per 30 kilometers of roadway.
The approach used in Finland is similar to the simpler of the two methods described above, wherein water is sprayed on the salt in the hopper. Spreading equipment used in Finland is manufactured there and in Denmark and Germany.

2.1.2 Salt Solution

A recent addition to the winter maintenance manager's arsenal is the use of saline solutions. Studies were begun in 1987, and each country started practical applications of the results in about 1989. The method requires a tank truck equipped with either nozzles or a spinner. The preferred salt is sodium chloride, which is mixed with water at a rate of between 8% (Norway) and 26% (maximum for Finland) by weight.

Experience to date indicates that (1) the solution remains on the roadway better than granular salt, (2) there is less ground water pollution, (3) much less salt is required and (4) it is extremely effective as a preventive measure and to counteract hoarfrost. In Sweden, a solution of 20 grams per square meter of pavement surface (corresponding to 5 g/m² of dry salt) was found to be
sufficient. Roadways with ADT's between 1500 and 12,000 utilized the method successfully. Spreading could be accomplished at speeds up to 60 kph (Oberg, Gustafson and Axelson, 1991).

Disadvantages include (1) its lack of effectiveness during a snowfall or where ice has already formed, (2) the expense of the equipment and of preparing the mixture, and (3) the corrosive effect on the spreading equipment.

2.1.3 Calcium Chloride and Other Compounds

Calcium chloride as an alternate to sodium chloride has been tested to a limited degree. Its major disadvantage seems to be its negative effect on concrete. In Finland it is not used as a deicing agent but is used for dust control on gravel roadways in the summer. Urea and sodium formate have also been tested in Sweden, but the conclusion is that "none of these substances can be regarded as a serious alternative to NaCl for winter road maintenance purposes" (Oberg, Gustafson and Axelson, 1991).

2.1.4 Calcium Magnesium Acetate (CMA)

CMA has also been studied extensively in Sweden, even before the MINSALT program. In short, its expense, even if the product is produced in large quantities, is prohibitive. Its advantages include (1) considerably less corrosive effect than sodium or calcium chloride or urea, (2) less environmental damage, (3) less harm to concrete (at least in the concentrations associated with normal use), and (4) a longer lasting effect than the chloride products. However, its deicing effect is somewhat less (that is, "More CMA is needed for the same melting effect" (Simonsson and Gustafson, 1990)), and it costs between 15 and 20 times as much as sodium chloride.

2.1.5 Potassium Acetate (Clearway I)

This chemical is a non-corrosive liquid-acetate solution, which has been tested for two winters at a Swedish airfield. Again, its extremely high cost has resulted in its being classified as infeasible (Simonsson and Gustafson, 1990).
2.1.6 Mixtures of Salt and Abrasion Agents

When sand is used to reduce skidding, it is often mixed with salt. The recommended proportion in Finland is a maximum of 20 kg per cubic meter of sand, whereas Sweden recommends between 20 and 50 kg/m³ (Öberg, Gustafson and Axelson, 1991). Salt is added primarily to facilitate the storage of sand in cold weather and to improve its adhesion and durability.

In Finland, the general practice is to use wetted salt on roadways whose ADT is greater than 2000 vpd. For those roads, a mixture of salt and sand is used if the road surface temperature is lower than -6°C. For roads whose ADT is between about 1000 and 2000 vpd, the use of salt is confined to fall and spring, whereas roads with ADTs less than 1000 utilize mechanical sanding only.

Some areas of Norway use mixtures of sand and salt. In general the experience has been that this approach is less expensive than using salt alone but it is also less effective.

With increasing interest in minimizing the use of salts on roadway pavements, the possibility of eliminating them completely has attracted much attention. The following section describes some of these efforts. Note that the small proportion of salt added to sand, as described in the previous paragraphs, may even be replaced by a non-salt additive without compromising the mixture's effectiveness.

2.2 Mechanical Deicing Methods and Materials

First, this report briefly covers some research conducted in both Finland and Sweden with respect to properties of several anti-slip abrasives. Then a discussion follows on experience with programs that use essentially no salt in their winter road maintenance programs.

Studies in Finland investigated the following materials: sands; crushed gravel; crushed rock; a monocalciumsilicate with crystal water (chiefly sand and lime) called Absol; granulated blast furnace slag; crushed limestone; crushed expanded clay and coal ash; mixtures of some of these materials with Absol, dry
salt or saline solution; and heated sands. The best friction values and adhesion properties were obtained with hot stone material at spreading temperatures above +110°C. The other tested materials did not display "decisively better" skid resistance and adhesion than the currently-used sand/sodium chloride mixture (30 kg NaCl per m³ of sand), thus leading to the conclusion that this mixture will continue to be the material of choice. Friction values obtained with Absol were sufficient to warrant further study, based on environmental considerations. Gravel with calcium chloride at 50 kg per cubic meter was slightly more effective than gravel with sodium chloride but presumably cannot be justified economically (Functional Properties of Mechanical Anti-Slip Materials, 1990; Hiekoitumateriaalien Kitka-Ominaisuudet Tieolosuhteissa, 1990).

Sweden's MINSAL project tested crushed limestone, crushed stone aggregate, slag products and Absol. Advantages of limestone included a slightly better deicing effect than sand/salt mixture, its spreadability with conventional equipment, and its counteraction against acidity by raising the pH in the surrounding area. A disadvantage is that it must be stored under cover. Crushed stone aggregate, usually the 2 to 5 mm fraction, costs roughly the same as sand/salt mixtures. Its advantages are (1) better long-term effect, (2) better skid resistance, (3) reuse, and (4) availability. Disadvantages include (1) its ineffectiveness on hoar frost and black ice, (2) flying stones striking vehicles (just like Alaska!), and (3) inconvenience for bicyclists.

Slag products have been judged unsuitable because of their corrosive and environmental effects. In spite of positive results with Absol, it is not used to any great extent because it freezes into lumps in storage and it generates dust (Öberg, Gustafson and Axelson, 1991).

Sweden experimented with no-salt policies in three regions between 1986 and 1989 -- Gotland, Dalarna and Västerbotten -- to determine impacts on accidents, road conditions, the environment, road maintenance costs and other factors. Vehicle speeds decreased under this policy. The impact on accidents was varied, but generally there were statistically significant increases with the no-salt policy. There was a marked decrease in corrosion of vehicles; in Gotland, for
example, the reduction on unpainted steel was between 80 and 90% compared to seasons when salting was used.

The impact of less salt was measurable in ground water and soil; coarse-grained soils showed a more rapid reduction after salting was discontinued, as might be expected. Road maintenance costs were clearly higher with the no-salt policy. For rural roads in Gotland, the average cost increase was 55%, while for municipal streets the increase was about 75%. In Dalarna, costs for snow clearance remained unchanged, those for chemical de-icing decreased by 50%, and those for mechanical ice control increased threefold; the overall effect was a 30% increase in winter maintenance costs (Öberg, Gustafson and Axelsson, 1991).

In the Kuipio District of Finland, an experiment with a sand-only--no-salt--winter roadway maintenance policy was begun in fall 1992, but no results have been reported to date.

2.3 Icing Conditions, Pavement Structure Type, and Drainage Design

Two considerations are of interest in controlling icing on road pavements. The first is the design of the roadbed and pavement, which has received considerable attention in Sweden since 1976. In that year, Test Field Linköping was constructed to study the icing risk potential of different road structures, including conventional uninsulated pavements and those insulated with plastic foam, sulfur foam, expanded clay and pelletized slag. Although the results were reported more than ten years ago and are probably well-known to DOTPF, we include a summary of Gustafson's report (1983) as follows:

Of the uninsulated road pavements, those incorporating ungraded crushed rock obviously had the greatest icing risk potential owing to the relatively low thermal conductivity and heat capacity of the crushed rock material. The differences among the other uninsulated pavements are relatively small. However, thicker courses of bitumen stabilized gravel produce a somewhat elevated icing risk in relation to a pavement incorporating a gravel base course.
The depth at which the insulation is laid has a critical influence on icing risk potential. Roads with the insulation placed near the surface have a very high icing risk potential. If the insulation is laid at a depth of about 35 cm, the icing risk potential is high in relation to most uninsulated road structures but it is about the same as that of a pavement incorporating ungraded crushed rock below the asphalt concrete wearing course. For roads insulated in conformity with Swedish specifications, i.e., with the insulation laid at a depth of 50 cm or more, the risk of icing is relatively small but is still somewhat higher than that of most uninsulated roads.

When insulation is laid high up in the road structure, the thickness of the insulation layer has a certain, but comparatively small, effect on icing risk potential, whereas the significance of the thickness is even smaller when the insulation is at greater depth. Thicker insulation layers involve a somewhat higher risk of icing than thinner layers.

Of equal interest in Sweden has been the relationship between pavement surface material and condition and its susceptibility to icing (Gustafson, 1986). Investigations looked at asphalt pavement, surface dressings, drained asphalt, slurry seal surface dressing, Rubit rubber asphalt and Verglimit (asphalt with salt granules). A double surface dressing with a rubber-modified binder showed especially good friction properties during the first year after construction. Drainage asphalt and Rubit also exhibited favorable qualities. However, surface wear reduced the advantages of many of the pavements after the first year.

In Finland, considerable attention has been paid to the problem of flowing groundwater that is forced to the surface in the winter, causing pavement icing. This condition is often present on roadways with steep sideslopes, where freezing, to some depth, below the roadway prevents continuous groundwater flow. Subsurface pipe drains are installed below the depth of freeze on the uphill side to carry the groundwater through insulated culverts across the road line (Lehtonen, 1991).
2.4 Reducing Snow Accumulation on Roadway

Problems associated with roadway snow accumulation have attracted some interest in Finland and Norway. Personnel reported a tendency to decreasing interest in the use of snow fences in both those countries, with more attention to improved cross section and geometric design for new and rebuilt roadways. If snow fences are used, Finnish practice is to make them at least five to six meters high and "far enough" away from the roadway; the Russian guideline of a distance from the edge of the roadway equal to fifteen to twenty-five times the height is recommended.

In the mountains of western Norway, many kilometers of surface roadways are being replaced with tunnels to eliminate snow accumulation problems. Finnish practice for surface roadways includes (1) building a high embankment, with the surface about 0.5 meters above the highest snow profile occurring once in ten years, (2) providing an aerodynamically smooth profile, with smooth edges, that provides for non-turbulent snow drifting and thus reduced snow accumulation, and (3) using wide and deep berm ditches for temporary snow storage. In the areas of extremely high wind speed and snow drifting in Finland's Northern Lappland, this approach has been used successfully (Saarelainen and Kivikoski, 1990).

2.5 Selection of Snow Moving Equipment

Criteria for selecting snow moving equipment seems to vary from country to country in Scandinavia. In Norway, four types of rotary plows are in use. The Vifte type is used for snows with low hardness; above a certain hardness it is difficult to push the snow into the "dead" zones of the plow. This type is suitable for lighter, colder snow typical of continental regions. The drum, or trommel, type is older and not much used except for very tough snow, such as where a road has been closed for several weeks or months in the winter. It has a low but "flat" productivity, meaning that the productive capacity, while never very high, decreases little with increasing snow hardness. The Rolba plow is a two-step device manufactured in Switzerland. A new type rotary plow currently in use in Norway is a "twin spin" type.
Discussions in Norway emphasized that the relationship between snow blower capacity and hardness must specify the type of blower because the various types have high performance at different ranges of hardness. Ideally, a blower would have high capacity over a wide range of hardness. On behalf of the director of the DOTPF equipment fleet and the 1992 "quick response" project that investigated snow blower capacity as a function of hardness and/or density, the writer inquired in Norway about the relationship of hardness to density. The response was that the hardness/density relationship changes during the year, rising to a peak in early spring and then decreasing. Thus, one cannot use density as a predictor of hardness.

In Sweden, the use of rotary snow blowers is confined to the heavy snow area of northwest Sweden, where 25 to 30 such machines are in use. A common arrangement in most sections of the country is a combination of plowing and sand/salt spreading, often with a single vehicle. The manual of practice for snow control in Sweden suggests the following types of equipment for the types of precipitation indicated:

<table>
<thead>
<tr>
<th>Precipitation Conditions</th>
<th>Suggested Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow slush</td>
<td>Diagonal plow with wheel-supported slush blade on wheels mounted on front of truck</td>
</tr>
<tr>
<td>Light snowfall</td>
<td>Single diagonal blade suspended on front of truck</td>
</tr>
<tr>
<td>Medium heavy snowfall</td>
<td>Wing plow suspended on front of truck or single diagonal blade plus side plow</td>
</tr>
<tr>
<td>Heavy snowfall</td>
<td>V-plow suspended on front of truck</td>
</tr>
</tbody>
</table>

Snow blowers are not used for roadway maintenance in Finland although they are used on airfields. Several types of plows are in use. The V-type plow is used in Northern Finland for heavy snow. The wing plow plows a 3 to 4 meter width and has the advantage of being able to change direction. Two new types are 1) a plow whose width can be changed, and 2) a two-blade combination
which includes a slush blade. A typical combination consists of a side plow, a front plow and a tank for spreading liquid salt. Another plow in use in Finland has a widening blade.

Over a long period, between 1973 and 1989, researchers at Luleå University of Technology have monitored cost factors associated with snow removal from streets and roads. A detailed data base covering 350 km of city streets and 800 km of roads in northern Sweden was developed. A summary report was published in 1989 (Olsson).

2.6 Guidelines for Maintenance and Operations

Sweden has developed a rather complete set of guidelines for the required winter maintenance actions for various classes of roads (Rules for Maintenance and Operations [Regler för Underhåll och Drift], 1990). It begins by describing the classification system, as follows:

A road is assigned to a certain class in terms of standard, which in principle is determined by the road category and traffic flow. Special traffic conditions (e.g. large variations between summer and winter AADT, commercial transport, public transport, proportions of leisure and business journeys) may justify the use of a higher or lower road maintenance standard. When determining road maintenance standard, both the specific conditions and available economic resources should be taken into account. (italics added)

The classes are as follows:

<table>
<thead>
<tr>
<th>Average daily traffic</th>
<th>Trunk roads</th>
<th>Secondary and tertiary provincial roads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary provincial roads</td>
<td></td>
</tr>
<tr>
<td>&lt;500</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>500 - 1,999</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>2,000 - 7,999</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>8,000 - 15,999</td>
<td>A2</td>
<td>B</td>
</tr>
<tr>
<td>&gt;16,000</td>
<td>A1</td>
<td>A2</td>
</tr>
</tbody>
</table>
The objectives of the regulations, with respect to trafficability and safety, which personnel described as "hard rules" or "directions," are stated as follows:

Unless a restriction is specified, a road shall be trafficable by all vehicles that are normally permitted on the particular road network. Exceptions may occur in extreme weather conditions. A road shall have sufficient friction for permitted vehicles to travel on it with safety. Exceptions may occur in extreme weather conditions. Within the road maintenance area, snow deposits or accumulations encroaching on stopping sight distance for which the road has been designed may occur only temporarily.

The requirement for each standard is then set forth. A portion of the statement for Standard Class A1 is the following:

The road surface should be
- Free of ice and snow in fine weather
- Free of ice and snow within 2 hours after precipitation. If the precipitation has only caused icing, the road surface should be free of ice within 1 hour after precipitation. These time limits may be extended in the case of hard shoulders on a motorway.

There follow several more paragraphs covering exceptions for temperatures below -8°C and during snowfalls, and explanations regarding climbing lanes, shoulders and slush. Note the use of the word should in the above quotation; once the "hard rules" are stated, the balance of the document is considered a set of desirable guidelines.

Because of their possible interest in Alaska, the complete translation of the guidelines for each roadway classification, including pedestrian and cycle paths, is included here as Appendix A.
2.7 Computer-based Road Weather Information Systems

Computer-based road weather information systems are in use in Sweden and Finland and are apparently quite effective. In Sweden, 543 road weather stations along the Swedish road network currently monitor the following data:

- Wind speed
- Wind direction
- Air temperature
- Humidity
- Rain or snow
- Road surface temperature
- Road condition
- Freezing point

An illustration of such an installation is shown in Figure 2. The digitized data, collected by sensors by a variety of manufacturers, is communicated via PC's to a VAX 4000-60 central computer. That processed information, together with data from the Swedish Meteorological Agency, is supplied to the Swedish National Road Administration Data Communication Network, which supplies 1500 terminals with information on road conditions that is always current within fifteen minutes. Thus, the "roadmasters" (those responsible for road maintenance), as well as members of the public, have access to current condition information as well as forecasts and can respond much more appropriately than if the information were not available. Such weather changes as those that cause risk of icing are reported immediately to the network (Weather Information, no date).

The system was begun in 1972 and was last revised in 1992. It assists in reducing accidents, deploying road maintenance personnel and equipment more efficiently, and reducing the amount of chemical ice control agents used on roadways. Of all the information provided, it is believed road surface temperature and dewpoint are most important.

The Finnish system is similar to that used in Sweden. It consists of about 150 collection stations. Begun on an experimental basis in the Helsinki area in 1981,
it moved to a production basis in 1985 and was last expanded in 1991. In addition to supplying information to road maintenance managers, it provides current and forecast condition data to gasoline stations and to drivers over the radio. Thermal mapping is used to assist in deciding where collection stations should be located.

An excellent English language videotape describing Finland's Road Weather Service (1992) is a part of the appendix of supplementary materials which is a part of this report (Appendix D).

The two quotations that follow are a measure of the pride and competition involved in developing and operating their countries' systems. The brochure describing the Swedish system (Weather Information, no date) calls it "the most comprehensive road weather information system in the world." In an interview with the writer, a Finn called his system "more sophisticated and more recent than the Swedish system."

Figure 2. Swedish Weather Information Field Station (Weather Information, no date)
2.8 Winter Maintenance Actions, Safety and Trafficability

The final section of this report briefly notes some work done in Scandinavia on the impact of both road alignment and speed limits on roadway safety. This section on winter maintenance describes a summary of investigations in Sweden on the connection between that maintenance and both road safety and trafficability.

As previously noted, the MINSALT project concluded that there was some statistically significant increase in accidents when salt or salt/sand mixtures were replaced with non-salt anti-icing materials (Öberg, Gustafson and Axelsson, 1991). A study conducted by the Swedish Road and Traffic Research Institute and Chalmers University of Technology between 1986 and 1990 reached the following conclusions with respect to safety:

- No statistically significant changes were found in the number of pedestrian and cycle accidents in the residential area of Skellefteå after several maintenance actions were taken to improve road safety for pedestrians and cyclists.

- No tangible changes were found in (1) number of accidents, (2) proportion of accidents occurring in icy/snowy road conditions, or (3) distribution of accidents along the road when the method of anti-skid treatment was changed from salt to sand/grit on an approach road in Borås.

- The accident risk for pedestrians and cyclists is between about five and ten times higher in icy/snowy road conditions than on a clear surface, depending on the location, based on data from Gothenburg and Skellefteå.

- The accident risk for motorists on busier roads and streets is about three times higher in icy/snowy road conditions than on a clear surface.

In terms of trafficability for motorists, the study found that
• The traffic flow, in terms of both volume and distribution over time, is generally the same regardless of road conditions.

• Speed is highly dependent on road conditions; the median speed may decrease by more than 15 kph in a "normal" snowfall.

• The proportion of short headways (zero to four seconds) decreases with decreased coefficient of friction (Möller, Gregersen and Wallman, 1992).
3.0 Pavement Markings

Finland, Norway and Sweden are very much involved in developing new specifications and methods for pavement markings. With a new environmental sensitivity, paints with volatile organic solvent compounds are being superseded by thermoplastic materials that do not contain such solvents. Although paints have lower initial costs, they must be replaced every two to three years, as they generally have less durability under the heavy use of studded tires. By 1995, both Norway and Sweden will use no paints with undesirable solvents.

3.1 Testing and Specifications

Thermoplastics are of two types -- extruded and sprayed-on. Their thicknesses are shown in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Sprayed-on</th>
<th>Extruded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finland</td>
<td>0.4 to 1.0 mm</td>
<td>1.0 to 3.0 mm</td>
</tr>
<tr>
<td>Norway</td>
<td>1.5 mm</td>
<td>3.0 mm</td>
</tr>
<tr>
<td>Sweden</td>
<td>1.0 to 2.0 mm</td>
<td>1.5 to 3.0 mm</td>
</tr>
</tbody>
</table>

A marking thicker than 3.0 mm is avoided because it would form a "dam" that would tend to impound rain and snow-melt water.

In Norway, extruded thermoplastics are used for centerlines when the ADT exceeds 2000, whereas sprayed-on thermoplastics are used for such applications when the ADT is below 2000. For edge striping, the break-point is an ADT of 8000.

Draft methods have been published for use in Sweden for determining properties of thermoplastic road marking materials (Thermoplastic Road Marking Materials, 1992). For determination of wear resistance under cold conditions, a method that uses a needle test apparatus (Tröger test) to simulate the effect of studded tires is conducted at a temperature of -10°C. For several samples, an average value of loss of sample mass after sixteen repetitions of 40 seconds each is reported as the measure of wear. To determine heat stability, a thermoplastic
sample is heated to a temperature of 200°C, which is maintained for six hours. After the sample is then cooled to room temperature, determinations are made of color, luminance, cold impact, indentation, Tröger wear, alkali resistance and ultra-violet aging.

The above test methods, together with others, were used for an extensive series of laboratory studies of thermoplastic road marking materials in Sweden. Twenty-eight materials were tested in the laboratory. Those same materials were subjected to field tests on a section of pavement to validate the laboratory results. The results led to the establishment of a classification system which places any such material in one of three durability classes (Isacsson and Colldin, 1988). The highest class, Class I, contained materials that are "highly durable at -10°C and do not deteriorate notably under the influence of UV light." A material in Class II "is somewhat less wear resistant at -10°C, has a somewhat higher indentation value or deteriorates somewhat in aging." These two classes are permitted for use on the Swedish National Road system. The report says, "On a road with an AADT of 5000 or less, such materials [Classes I and II] should be effective for at least two years under Scandinavian conditions."

Sixteen of the 28 materials were placed in durability Class III. "If there is a demand for the marking to be effective for at least two years on a road with an AADT of 5000 under Scandinavian conditions (low temperature and studded tires), materials in durability Class III cannot be recommended."

The results cited above applied to thick thermoplastic materials. For thin materials (1.5 to 2.0 mm), a Class I material can be expected to last one winter under Scandinavian conditions and with an AADT of about 5000.

Further testing is continuing. A field test on a section of roadway in Finland began in summer 1993.

There are currently three parts to the Swedish performance specification for thermoplastic road marking materials: (1) light reflection in the nighttime, (2) light reflection in the daytime, and (3) skid resistance (Kapitel 13 Vägtrafikanordningar, 1984). A new "1992" specification, implemented in 1993, added a requirement for wearing resistance, to include before-wear and after-
wear test methods. The specification for paint materials specifies only nighttime and daytime light reflection; this specification will, of course, no longer be used when paints are eliminated in 1995.

Pavement marking standards are an issue with the Comité Européen Normalization. Sweden appears to be taking a leading role in the development of common performance specifications and testing methods for conditions of low temperature and studded tires.

3.2 Application Considerations
Specified application conditions for thermoplastic road markings vary somewhat by country. A summary for Norway and Sweden is given in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Norway</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface condition</td>
<td>Wet or dry</td>
<td>Dry</td>
</tr>
<tr>
<td>Surface temperature</td>
<td>As low as -20°C for extruded if surface is dry</td>
<td>No lower than +10°C</td>
</tr>
<tr>
<td>Material temperature</td>
<td>+220 to +230°C for either sprayed-on or extruded</td>
<td>Approximately +200°C</td>
</tr>
</tbody>
</table>

In Norway, experience has shown the following distinctions between the application of extruded and spray thermoplastics:

<table>
<thead>
<tr>
<th></th>
<th>Length that can be applied in one day</th>
<th>Time after application before traffic can cross the new line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprayed-on</td>
<td>50 km</td>
<td>15 seconds</td>
</tr>
<tr>
<td>Extruded</td>
<td>30 km</td>
<td>60 seconds</td>
</tr>
</tbody>
</table>

The Norwegian Public Roads Administration is especially proud of its equipment for applying sprayed-on thermoplastics ("the most modern such equipment in the world"). Two such vehicles are owned by the Roads Administration; their purchase cost is 4.5 million Norwegian kroner, which equates to approximately US$750,000. The vehicle requires a crew of two, one to drive and the other to
operate the machinery. Some smaller such vehicles are owned and operated by private contractors in Norway.

The technology for use of thermoplastics under cold conditions has improved in recent years, although there is still some problem with brittleness at very low temperatures. A problem observed in Norway (not related to cold temperature applications) is that the application of hot thermoplastics to concrete causes crumbling under some conditions.

Norway is considering, on an experimental basis, the use of cold sprayed-on plastic road markings. It is expected that the cost of such applications will be roughly equivalent to that for hot sprayed-on thermoplastics. In Finland, such cold plastics are already in use. This two-component mixture costs between 15 and 20% more than hot sprayed-on thermoplastics, about the same as light (1 to 2 mm thick) extruded thermoplastics, and about 40% less than normal (3 mm thick) thermoplastics, on a cost per square meter basis.

3.3 Glass Beads and Raised Reflectors

Glass beads are dropped onto the road markings during construction to improve reflectivity. The Swedish specification provides for such beads for both thermoplastics and paints. In Figure 3 we show the gradation specification for these beads. Note that the 100% passing diameter must be between 0.5 and 1.0 mm, and the minimum size must be between 0.125 and 0.25 mm. This same specification requires the beads to have a minimum SiO\textsubscript{2} content of 60%, a reflectivity index between 1.5 and 1.6, and a density between 2.4 and 2.6 Swedish tonnes per cubic meter (Kapitel 13 Vägtrafikanordningar, 1984).

In Norway, glass beads with a maximum diameter of 0.8 mm are dropped onto the hot thermoplastic strip during the construction process.

Raised reflectors have not worked well, in general. A decade ago, much research on this subject was conducted by the Swedish National Road Administration, most of which resulted in failure of the samples. Rubberized raised reflectors had especially poor performance. When necessary, Sweden
Figur 13:02-1 Gränser för drop-on-pärllornas kornkurva

Pärllorna skall bestå av soda-kalk-silikatglas. Glaset skall ha följande egenskaper
- kiseldioxidhalt \( \text{SiO}_2 \)-content minst 60 vikt-%
- brytningsindex refractive index 1,5 - 1,6
- densitet density 2,4 - 2,6 t/m³

Figure 3. Swedish Specification for Dropped-on Glass Beads (Kapitel 13 Vägtrafflanordningar, 1984)

now uses a cast iron "Stimsonite 96" "flat cone" that is drilled into the surface; reflective materials are added, as shown in Figure 4.
Reflectors made with either porcelain or steel have been used in Norway with some success.

Another type of "reflector" utilized in Sweden is a "comb-flex" thermoplastic strip applied to the edge of the roadway. As depicted in Figure 5, the strip looks like a comb; it is used to provide improved visibility and therefore better delineation of the roadway edge in rain.

Figure 4. Cast Iron Raised Reflector, as used in Sweden

Figure 5. "Comb-flex" Roadway Edge Marker, as used in Sweden
4.0 Asphalt Pavement Design and Construction

Scandinavian road agencies and researchers have given considerable attention to the design and construction of asphalt pavements. Because of similar conditions in Alaska, several aspects of the Scandinavian program may be of interest here. By far the most important asphalt pavement design consideration is resistance to wear caused by studded tires.

This section begins with some statistics on the relative proportion of asphalt pavements in Scandinavia, followed by a discussion of policies and specifications related to various types of asphalt pavements. We then describe several on-going and completed asphalt pavement research programs and mention some test equipment currently in use. Because Scandinavian roadway agencies have had much interest in split mastic, drainage and rubberized asphalt pavements, we devote a section to each of these topics. Research into aggregate effectiveness is summarized next, followed by a brief discussion of investigations of binders and additives. The section concludes with a brief report on oiled gravel surfaces and current research into alternative tire stud designs.

The large amount of available information and materials makes it necessary to include only summaries of findings in this text. We include a reference list as Section 7.0, and we attach as Appendix D several publications collected as part of this investigation.

4.1 Some Roadway Statistics

The following table provides a breakdown of pavement types for public roads in Finland, Norway and Sweden for the years indicated (Finnish National Road Administration 1991; Berg 1993; Axelson 1993):
<table>
<thead>
<tr>
<th>Pavement type</th>
<th>Finland*</th>
<th>Norway</th>
<th>Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt concrete</td>
<td>16,078 km</td>
<td>29,800 km</td>
<td>46,091 km</td>
</tr>
<tr>
<td></td>
<td>(21%)</td>
<td>(56%)</td>
<td>(47%)</td>
</tr>
<tr>
<td>Oil gravel + surface treatment of gravel</td>
<td>30,877 km</td>
<td>13,000 km</td>
<td>24,341 km</td>
</tr>
<tr>
<td></td>
<td>(40%)</td>
<td>(24%)</td>
<td>(25%)</td>
</tr>
<tr>
<td>Gravel surface</td>
<td>29,676 km</td>
<td>10,400 km</td>
<td>27,295 km</td>
</tr>
<tr>
<td></td>
<td>(39%)</td>
<td>(20%)</td>
<td>(28%)</td>
</tr>
<tr>
<td>Total</td>
<td>76,761 km</td>
<td>53,200 km</td>
<td>97,727 km</td>
</tr>
<tr>
<td></td>
<td>(100%)</td>
<td>(100%)</td>
<td>(100%)</td>
</tr>
</tbody>
</table>

* Includes 35,707 km of local roads

In Finland, the proportion of the roadway network consisting of asphalt pavement ranges from ten percent in a county in northeastern Finland to fifty-five percent in the southernmost county that includes Helsinki.

Wear resistance against studded tires is a major design consideration. Typical is the statement by the Norwegian Road Research Laboratory that this is the primary problem in road surface design, followed by such considerations as flexibility, stability, durability and cost effectiveness. In Finland, it is estimated that 95% of cars and 20 to 30% of trucks use studded tires in the winter. Sweden reports that more than 90% of the cars in the Northern Region are equipped with studs in the winter (Johansson, 1990).

4.2 Specifications and Policies

In Finland, a major policy is that all "main" roads will be paved. In practice, this means that gravel surfaces are used only on roads with an average daily traffic of less than 500. In an interview with personnel from the Finnish National Road Administration, the following guidelines were obtained:

- Gravel surface dressing (SOP) ADT < 300
- Oil gravel (OG) ADT < 1000
Soft ("light") asphalt concrete (KAB)  ADT < 2000

Asphalt concrete (AC)  ADT > 1000

Stone mastic asphalt (SMA)  ADT > 5000

Figure 6 is a more formalized representation of Finnish recommendations (with some variations from the above listing). Another essential part of Finnish paving policy is that rut depths must be kept below 20 mm on main roads.
In Sweden, road surfaces are evaluated in terms of the following characteristics: transverse evenness, longitudinal evenness, transverse crossfall, skid resistance, noise reduction, light reflection and drainage ability. Maximum allowable rut depth and unevenness are specified for each of the several classes of roadways, in terms of allowable means for both 400 and 20 meter distances. The limits are shown in the following table:

<table>
<thead>
<tr>
<th>Class</th>
<th>Rut Depth (mm)</th>
<th>Unevenness (IRI mm/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>400 m</td>
<td>20 m</td>
</tr>
<tr>
<td>A/B</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>D</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>E</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>F1</td>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td>F2</td>
<td>25</td>
<td>35</td>
</tr>
</tbody>
</table>

For Swedish roads with ADT > 2000, both rut depth and unevenness are allowed to deteriorate with age. For rut depth, the limits depend on both average daily traffic and age of the pavement; the unevenness requirement applies to roads with ADT greater than 2000 and depends on age of pavement and whether it is located in south, middle or north Sweden.

For new or renewed asphalt wearing courses on roads with ADT > 4000 in Sweden, "the following requirements apply":

- After 12 hours there must not be any loose stones on the surface.

- Across the road surface, there must not be bigger differences in level than 4 mm.

- The friction coefficient must exceed 0.4 as a mean for a 20 m distance the year when the pavement is done and for the next two years.
• When the binder has been worn away from the surface of the stones there must not be a big difference in color on the surface for one lane or on the whole surface for a two lane road.

(Swedish National Road Administration, no date)

Unlike the other two countries, the majority of the pavement on the Norwegian road system is of the cold mix type. Authorities believe this type of pavement achieves better flexibility at lower cost, with a cost savings of up to 50% compared to hot mix designs. Compared with gravel surfaces, cold mixes provide little increase in strength, but they do give both better protection of the subsurface layers and improved driving comfort.

A helpful English language translation of Swedish bituminous pavement specification was obtained; it is included in Appendix D (Krigsman, 1991). We shall not attempt even to summarize that specification here. It includes specifications for both design and construction and provides complete aggregate gradation curves and binder requirements for eighteen mix designs. Sections include

• General (including construction guidelines)

• Material (mineral aggregate, bitumen and additives)

• Plant Mix (soft and hard asphalt, Topeka, roadbase, drainage asphalt, cold mix with bitumen emulsion and oil gravel)

• Repaving

• Heating

• Mastic Asphalt

• Surface Treatment
A typical Finnish asphalt pavement design consists of crushed gravel or rock with a maximum grain size of between 16 and 20 mm, limestone filler, bitumen of penetration grade 80, 120 or 200, and, for some mixes, sand.

For comparison purposes, we reproduce here the Finnish requirement for Asphalt Concrete AB 20 and the Swedish requirement for AB 16, as Figures 7 and 8, respectively. Both are dense asphalt mixtures, although the dashed lines in Figure 8 provide for an open graded mix as well. Unfortunately, the two countries do not specify a common AB type, so an exact comparison is not possible.

A Norwegian Model for Prediction of Pavement Deterioration (Bertelsen 1990) was developed by the Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology. Since it is expected that this model will be used both as part of the Norwegian Pavement Management System and as the basis for selecting pavement type for new roads, we mention it here. The aim is to predict the pavement performance for normal national roads in Norway, including single, dual and multi-lane roads with different types of layers with both bituminous and unbound materials. The model proceeds by analyzing a series of incremental time periods such that the output state from one period becomes the input for the succeeding period. Structural conditions for each layer include groundwater level, grading, moisture content, frost depth and E-modulus. Surface conditions are characterized by ruts due to both deformations and studded tires, roughness due to frost heave and deformations, frost heave cracks and fatigue cracking. The program also requires geometric and cross-section data, traffic information and climatic data.

The primary results from the analysis are measures of surface conditions for each wheel path of the road at the end of each incremental period, including

- rut depth due to studded tires
- rut depth due to permanent deformations
- total rut depth
- roughness
- fatigue cracking
- frost heave cracking.
### Finnish Specification for AB 20 Dense Asphalt Concrete

#### Mineral Aggregate
- **Filler** MIN: 4.0 weight-%
- **Sand** MAX: 25 weight-%
- **Crushed Stone** MIN: 70 weight-%

#### Binder
- **Bitumen**: B-80, B-120 OR B-200
- **Quantity**: 5.5-6.3 weight-%

#### Diagonal Table

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>0.7</th>
<th>1.1</th>
<th>1.6</th>
<th>2.2</th>
<th>3.0</th>
<th>4.0</th>
<th>5.6</th>
<th>8.0</th>
<th>10.0</th>
<th>12.5</th>
<th>16.0</th>
<th>20.0</th>
<th>25.0</th>
<th>32.0</th>
<th>64.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td></td>
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<td>10</td>
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<tr>
<td>20</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>32</td>
<td>41</td>
<td>55</td>
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<td></td>
</tr>
</tbody>
</table>

#### Void
- 1.0-5.0 vol-%

#### MIN
- MIN: 80 kg/m²
- NORM: 100 weight-%
- MAX: 150 weight-%

---

Figure 7. Finnish Specification for AB 20 Dense Asphalt Concrete
### Concrete Binder Aggregate

<table>
<thead>
<tr>
<th>Sort</th>
<th>Content 1) weight-%</th>
<th>Crushsurface 2) lowest</th>
<th>Flakiness index highest</th>
<th>Impact value highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAB 16 T B 180</td>
<td>6.0</td>
<td>20/40</td>
<td>1.55</td>
<td>60</td>
</tr>
<tr>
<td>MAB 16 Ø B 180</td>
<td>5.1</td>
<td>20/40</td>
<td>1.55</td>
<td>60</td>
</tr>
<tr>
<td>HAB 16 T B 85</td>
<td>6.4</td>
<td>20/40</td>
<td>1.55</td>
<td>60</td>
</tr>
<tr>
<td>HAB 16 Ø B 85</td>
<td>5.7</td>
<td>20/40</td>
<td>1.55</td>
<td>60</td>
</tr>
</tbody>
</table>

1) The amount of binder is based on the specific gravity of 2.66 for the mineral aggregate.

2) Determination on fraction 11.3-16 mm

T = Dense Type

Ø = Open Graded

---

**Figure 8.** Swedish Specification for AB 16 Dense Asphalt Concrete (Krisman 1991)
The current version of the program allows time increments as short as twenty-four hours.

4.3 Research Programs

This section contains general descriptions of research programs related to asphalt pavement design and construction. Later sections describe research findings in particular topic areas.

4.3.1 ASTO

Perhaps the most extensive asphalt research program in Scandinavia has just been concluded (Saarela, no date). Sponsored by the Finnish Ministry of Transport and Communications and the Finnish National Road Administration, the program is designated ASTO, which is an abbreviation of the Finnish name, and was conducted between 1987 and 1992. A total of seventy-eight research projects were undertaken at a total cost of about $US 15,000,000. The lead research agency was the Technical Research Center of Finland (VTT), with contributions from a large number of universities, research organizations and private companies.

The two main objectives were very concise --

1. to decrease the rutting of pavements on major highways by at least 30% and lower annual pavement costs by 20%

2. to increase the service life of low traffic road pavements by at least 20% and lower annual costs by at least 5%.

Ten research areas were investigated, as outlined below.

- Binders
  - 3 bitumen types
  - 5 penetrations
  - 3 road oils
  - 8 viscosity levels
• Aggregates
  35 mineralogically different types

• Additives
  8 polymer modified bitumens
  5 fiber types
  9 fillers
  2 anti-stripping agents
  2 natural asphalts

• Mixtures
  3 hot-mix types
  2 cold mix types

• Hot-mix Pavements
  16 test roads

• Cold-mix Pavements
  6 test roads

• Mixing
• Spreading and Compacting

• Maintenance
  Pothole patching
  Rut patching
  Reshaping
  Remixing
  Recycling

• Rehabilitation
  Stabilization
  Reinforcement
  Repaving

The number of field test sections totaled 250, and two test roads were installed to conduct structural strength studies.

A major conference was held in March 1991 to report preliminary results (Proceedings of ASTO Conference, 1991), and another conference was completed in April 1993 (International Conference on Research Results and
Products, 1993). It appears that the objectives set forth in 1987 have been met (Saarela, 1991). The final report on the ASTO program was issued in mid-1993.

A large follow-up study will follow the completion of the ASTO project. It will focus on the pavement structure and will be funded at a level about one-third higher than the ASTO study.

4.3.2 Swedish Wear Resistance Studies

The Swedish Road and Traffic Research Institute initiated an extensive program in 1988 to investigate the wear resistance of bituminous road surfaces. Relatively small slab specimens measuring 48x75x4cm are manufactured with high precision and then placed in existing roadway wearing courses. Installation began in fall 1988, when sixty such slabs were placed at six sites in central Sweden. This first series was used to evaluate the test method and to determine wear resistance of standard dense graded hot mixes using a variety of aggregates. Twenty-six additional slabs were placed in fall 1989 to evaluate different types of split mastic asphalt and to compare their performance with that of conventional pavements. In fall 1990, twenty more slabs were placed to study several different aggregate properties.

Pavement wear has been measured with the aid of an instrument that uses computer and laser technology. In addition, slabs have been manufactured for testing in the Institute’s 5.3 meter diameter circular test track. In this device, standard studded tires are run over a variety of pavement specimens and the resulting wear is measured. Twenty-eight different sections have been evaluated in this manner, and the test results have correlated closely with those from the field tests.

Results from some of these tests will be reported in a later section. Some major findings are (1) aggregate size has a decisive effect on wear, with the wear on a surface with maximum aggregate size of 12 mm measured at between 33 and 45% greater than the wear on similar sections with a maximum aggregate size of 16 mm, (2) vehicle speeds have equally dramatic impacts, with increases from 75 to 100 kph resulting in increases in wear of between 35 and 40%, and speed increases from 100 to 110 kph giving wear increases between 4 and 7%, and (3)
wear of split mastic pavements is slightly over half of the wear of the conventional dense graded hot mix ("The Wear Resistance of Bituminous Wearing Surfaces," 1991).

4.3.3 Tensile and Fatigue Property Testing

We mention here very briefly two reports on asphalt property testing. The first is the result of doctoral research at Sweden's Royal Institute of Technology which used the indirect tensile method to determine tensile and fatigue properties of three asphalt mixes (Said, 1989). The three mixes were a dense graded asphalt concrete, a rubber granular blended asphalt concrete with 3% rubber content ("Rubit"), and a porous mix that also contained 3% rubber ("Rubdrain"). One conclusion from this study was that the deformation characteristics of the Rubit were such as to "confirm the de-icing effect of Rubit mix at temperatures close to 0°C."

The other study was a review, conducted at the University of Oulu, Finland, of test methods to determine fatigue characteristics of asphalt mixes and a summary of the effects of various mix variables on fatigue resistance (Judycki, 1991).

4.4 Testing Equipment

We list here several pieces of equipment used to prepare and test asphalt pavement samples. Illustrations and descriptions of each are contained in Appendix B.

- Pavement test track at Swedish Road and Traffic Research Institute. This 5.3 meter diameter circular was discussed above. It utilizes standard tires to test the wear resistance of various pavement samples. Normally it operates wet at 0°C with the tires moving at 85 kph.

- Laboratory mixer for manufacturing asphalt-aggregate mixes. Technical Research Center of Finland (VTT).
• Gyratory compactor for compacting and measuring properties of bituminous mixtures. This device may also be used to compact soil and no-slump concrete. It was developed and is manufactured by Invelop Oy, Savonlinna, Finland, and is used extensively throughout Scandinavia. A paper describing applications in geotechnical laboratory testing has been prepared at the University of Oulu (Olli, 1994).

• Steel-tired roller for compaction of asphalt concrete slab in the laboratory. Technical Research Center of Finland (VTT).

• Special saw instrument for sawing samples for laboratory tests. Technical Research Center of Finland (VTT).

• Creep tester for measuring deformation properties of asphalt concrete. Technical Research Center of Finland (VTT).

• Wheel tracking device for deformation studies. Technical Research Center of Finland (VTT).

• PWR-Tester for measuring wear resistance of paving mixtures. Technical Research Center of Finland (VTT).

4.5 Specialized Designs -- Research Results and Current Practice

4.5.1 Split Mastic Asphalt Pavement

Finland, Norway and Sweden have all conducted substantial research into split mastic ("stone mastic") asphalt concrete and have introduced its use as standard practice in many areas of high traffic volume. The mix is characterized by a large proportion of aggregate over 8 mm (often 60%), resulting in a high void ratio in the aggregate skeleton which is filled with a high content of mastic (bitumen plus fines). The addition of mineral fiber, cellulose fiber, rubber powder or polymers makes it possible to achieve a bitumen content as high as 7.5%. An excellent short summary of Swedish experience with split mastic and drainage asphalt concrete has been written by Johansson (1990).
Split mastic asphalt concrete was originally developed in Germany in the mid 1960's to resist wear from studded tires. Even though studs are no longer allowed there, split mastic is still used because of its wear resistant properties. In the late 1960's, split mastic asphalt concrete was introduced into Swedish practice, using asbestos fibers as the binder carrier. Its use decreased when asbestos was outlawed, but the use of mineral and cellulose fibers and rubber powder resulted in the reintroduction of split mastic into Swedish pavements in the early 1980's.

Between 1989 and 1991, the amount of split mastic asphalt road pavements in use increased from about 3.5 to eight million square meters in Sweden. About 300,000 metric tons of the material have been placed in Norway during the past three to four years.

Fibers are used to prevent the bitumen from "bleeding" to the surface after construction and, to some extent, to prevent segregation during the construction process. Polymer modified bitumen can be used instead of fibers to prevent this segregation. In Sweden, NCC Contractors has used either cellulose or steel fibers, with cellulose the more prevalent, while Skanska Contractors currently favors the use of mineral fibers. Norwegian road authorities report the use of both cellulose and mineral fibers, with a tendency toward greater use of cellulose. Similar practice is found in Finland.

Norwegian experience with costs suggests that split mastic asphalt concrete costs about thirty percent more than standard dense asphalt concrete, while Sweden reports cost differentials of between twenty-five and forty-five percent.

Some results from Finnish laboratory test track investigations show the rather dramatic wear resistance of split mastic asphalt concretes, compared with regular continuous graded dense asphalt concrete and gap graded asphalt concrete in both wet and cold conditions. A published result is summarized in the following table, where the wear in SPS is "specific tire wearing" measured in grams of wear per kilometer per vehicle:
Pavement test road studies in Finland produced similar results. Both split mastic and gap graded asphalt mixes with various fibers and binders performed much more satisfactorily against wear than the dense asphalt control sections. Over a two year period, the average wear on the split mastic sections was 59% of that on the dense asphalt section, while the corresponding value for the gap graded section was 46%. Another Finnish study rated split mastic pavements better than gap graded pavements and much better than dense asphalt pavements.

In Norway, road test sections built from split mastic pavements are currently being studied, with a five kilometer section added to the study in 1992. The current test includes cellulose fiber, with bitumen as high as 6%. Tests have been conducted satisfactorily using aggregates with maximum sizes up to 16 mm. Beyond that (22 mm, for example), required thickness increases, and noise conditions tend to degrade. Cold weather performance of these split mastic pavements has been equally as good as regular asphalt concrete pavement. In Norway a small amount of testing of these pavements has been conducted using the Tröger needle test apparatus similar to that used for evaluating the wear resistance of pavement markings.

A sample from Finland is the stone mastic asphalt specification page shown here as Figure 9. Note that this mix is designated as SMA 16, indicating a maximum aggregate size of 16 mm. Crushed material must be at least 75% of the aggregate, filler must be at least 8%, and sand must not exceed 17%. Between 6.0 and 6.8% of 80 to 120 penetration bitumen is required, and cellulose or mineral fibers of at least 0.3% are required. This design calls for "chippings" of size 3 to 6 mm to be dropped onto the surface of the new pavement at a rate of between 2 and 4 kilograms per square meter. The void ratio must be between one and five percent, although this mix will generally have

<table>
<thead>
<tr>
<th></th>
<th>-30°C</th>
<th>+5°C Wet</th>
<th>+5°C Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense AC</td>
<td>25</td>
<td>44</td>
<td>7.5</td>
</tr>
<tr>
<td>Split mastic, 12 mm max</td>
<td>13</td>
<td>40</td>
<td>7.5</td>
</tr>
<tr>
<td>Split mastic, 16 mm max</td>
<td>10</td>
<td>34</td>
<td>6</td>
</tr>
<tr>
<td>Gap graded, avg of two tests</td>
<td>18</td>
<td>39</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Figure 9. Finnish Stone Mastic Asphalt Specification
a three to four percent void ratio. The mix will weigh between 80 and 100 kilograms per square meter.

It may be helpful to compare aggregate gradations of split mastic asphalts with other types. We show in Figure 10 a comparison of aggregates for typical Swedish dense asphalt, drainage asphalt and split mastic asphalt, based on data in the Johansson (1990) paper; Figure 11 gives similar information from the ASTO program for dense, gap graded and split mastic asphalt in Finland.

3 Typical Asphalt Aggregate Gradations
Swedish -- 12 mm. maximum

Figure 10. Three Typical Asphalt Aggregate Gradations -- Sweden (Johansson, 1990)
3 Typical Asphalt Aggregate Gradations

Finland -- 20 mm. maximum

Figure 11. Three Typical Asphalt Aggregate Gradations -- Finland
(Proceedings of ASTO Conference, 1991)

Finally, we give a quote from the Johansson (1990) paper regarding experience in Sweden, and a listing that summarizes advantages and disadvantages.

HABS [split mastic] has very good functional properties, especially concerning wearing from studded tires and stability. So far it has showed excellent performance and very few failures. Sometimes fat spots can be noticed, probably caused by excessive binder.....When we compare a normal dense mix (HABT 16) with a HABS 16, both with the same good rock aggregate above 8 mm, HABS has almost 50% lower wearing, at least during the first winter. The last three years the use of HABS has had rapid growth in the south half of Sweden, where traffic intensity is highest....It is today recommended on roads on which wearing from studded tires is the main reason for decomposition, which normally means roads with an average daily traffic of more than 4000.

Advantages of split mastic asphalt pavements:
• Good resistance to wear from studded tires
• Good resistance to deformation
• Prevention of water from penetrating into the construction
• Low tendency to separation
• Good aging properties
• Increased service life

Disadvantages of split mastic asphalt pavements:

• Sensitive to extra binder
• More complicated to design, mix and lay
• More expensive than standard mixes

4.5.2 Drainage Asphalt Pavement

Drainage asphalt pavement ("porous" asphalt) is being tested and has been introduced in Norway and Sweden with somewhat mixed results. Its primary advantages are an ability to remove water from the surface and considerably reduced noise, especially in the first year. In Sweden, specifications for this material were activated by the Swedish National Road Administration in 1984. Norway seems to be still in the research stage, and no evidence was available of its use in Finland. Figure 12 (Krigsman, 1991) shows aggregate and binder requirements for a drainage asphalt concrete with 12 mm maximum aggregate size from the Swedish specification. The mix features a very small proportion of fines, small filler content, and a large proportion of aggregate above 8 mm. The binder content is low (5.2%) compared to normal dense mixes. To avoid bitumen runoff, the mixing temperature must be kept below 135°C, unless fibers, rubber powder or polymers are used to raise the viscosity of the binder.
The following table summarizes and compares the component proportions of three types of asphalt mixes from Sweden, each with 12 mm maximum aggregate size:
Dense asphalt (HABT12T) | Split mastic (HABS12) | Drainage asphalt (HABD12)
---|---|---
8-12 mm aggregate | 20% | 55% | 55%
4-8 mm aggregate | 21% | 11% | 19%
0-4 mm aggregate | 46% | 18% | 17%
Filler | 6.4% | 9.6% | 3.8%
Fiber | - | (some, but small % by weight) | -
Binder (B85) | 6.6% | 6.4% | 5.2%
Total of above 4 rows (all < 4 mm) | 59% | 34% | 26%
Required void ratio | 2 to 5% | 1.5 to 5% | 15 to 24%

Swedish practice suggests that this type of wearing course requires a dense bed and should not be placed on a hot mix base or old black top pavements without sealing these layers. In terms of maintenance, Johansson (1990) writes that the most satisfactory procedure seems to be to mill away the old surface before replacing it; otherwise, the old layer must be sealed before resurfacing. Encapsulating a drainage asphalt layer between two bituminous layers is not recommended. Remixing to produce a new drainage asphalt mix has been satisfactory.

In practice, Sweden found that the ability to reduce noise decreased with time because small particles lowered the void ratio and wear from studded tires reduced the thickness. Also, the material wore away more quickly than normal dense surfaces; the wear was twice as great during a four year monitoring program of a roadway with an ADT between 8000 and 16,000. Suggested reasons for this faster wearing are (1) less mastic leaves the aggregate more unprotected against studs, (2) high void content causes more rapid binder aging, (3) high void content means a less dense mix and thus less resistance, and 4) more complications in the mixing and placing may lead to decreased quality. Because of problems with wearing and increased noise over time, and because of the satisfactory performance of split mastic asphalts, the quantity of drainage asphalt placed in Sweden declined from 492,000 square meters in 1987 to
115,000 square meters in 1989. During the same period, split mastic asphalt placed per year increased from 1,002,000 square meters to 3,299,000 (Johansson, 1990).

A summary of results of Swedish experience with drainage asphalt lists the following advantages:

- Reduced water spray
- Good wet friction
- Reduced risk for aquaplaning
- Good retroflection
- Low noise generation
- Good resistance to deformation.

The listed disadvantages are the following:

- Reduced resistance to wear
- Decreasing drainage ability
- Decreasing ability to reduce noise
- Increased risk for frost slip
- Increased need for deicer
- Faster binder aging
- More complicated mixing and placement.
Norwegian experience, although limited to small test sections, parallels that in Sweden. Noise reduction early after construction has been reduced to one-half of that for regular dense asphalt. Wear from studded tires is somewhat greater, and dust tends to clog the voids over time and decrease the noise reduction advantage. De-icing agents tend to disappear into the voids. It has been found that a four to eight percent center-to-edge slope is required for proper drainage.

A Swedish contractor reported that this open draining asphalt pavement was difficult to construct; in his experience each thin (3 cm) layer was required to be heat bonded to the layer below.

Finally, a recent report gives summary results of a Swedish test section on E4 that studied the effects of various additives in drainage asphalt. The report states, in part, that “it is fully possible to manufacture drained asphalt concrete at normal mixing temperature if an additive in the form of cellulose fibers or polymer-modified binders is used” ("Drained Asphalt Concrete," 1992).

4.5.3 Rubberized Asphalt Pavement

Limited interest in and experience with rubberized asphalt pavements in Scandinavia has been reported. In theory, the rubber will allow extra bitumen and will provide a flexibility that breaks thin ice layers under tire pressure from passing traffic. In general, the findings have been that the extra costs have not been justified in improved performance. The US Patent for "Rubberized Asphaltic Concrete Composition" is for a material invented by Gustaf Lindmark of Botstrom, Sweden and assigned to All Seasons Surfacing Corporation of Bellevue, Washington (United States Patent, 1985). It is produced in Sweden by NCC Contractors under the name Rubit. An earlier patent was for a process and product in which aggregate is heated to a temperature sufficient for rubber particles to adhere to the aggregate; it was invented by Assar Natanael Svensson of Ersmark, Sweden and is assigned to Skega AB of Ersmark (United States Patent, 1978).

In Finland, the Technical Research Center (VTT) has done some work with both milled rubber powder and with synthetic rubber powder as additives, with the latter proving more satisfactory. Generally the sizes were about 1/2 mm,
although sizes up to 4 mm were used. The Finnish National Road Administration reports only one road test section with rubberized asphalt. Apparently rubberized asphalt is not a subject for study in the current ASTO test program in Finland.

The Norwegian Road Research Laboratory reports the use of rubberized asphalt pavement in a small number of locations in southern and central Norway. The advantage is that a stone mastic aggregate gradation can be used, with the rubber pellets replacing the "missing" aggregate in the range below 4 mm. Problems have been experienced with lack of adhesion to the lower layer. The breaking of ice on the surface from traffic loads was not as great as was expected. The Norwegian Public Roads Administration at Trondheim has conducted one test; the mix did not contain mineral or cellulose fibers. The resulting pavement had a very short life, but this pavement was sufficiently flexible to break thin layers of ice when loaded with tire pressure. Personnel at NPRA are of the opinion that only in the unlikely case that studded tires are eliminated in Norway will rubberized asphaltic pavement be practical.

Sweden's Road and Traffic Research Institute (VTI) has tested a length of rubberized pavement at its facility, with rubber content up to 10%. Performance was generally good, although one section wore badly. Current practice is to use three percent rubber (by weight), with two percent composed of granules of size one to four millimeters and one percent powder under one mm. The source of the rubber is discarded tires. Swedish officials note that this "Rubit" pavement is essentially a stone mastic asphalt in which the fibers have been replaced with rubber granules.

The writer had the opportunity to visit a 400 meter section of rubberized pavement on highway E-4 in the village of Öjebyn, Sweden, constructed in August 1990. The mix is a stone mastic with 16 mm maximum aggregate size; approximately 60% of the aggregate is greater than 8 mm. Asphalt content is 6.6%, which was less than the adjacent dense asphalt pavement. The contractor commented that (1) more mixing was required for the rubberized section, (2) a major difference is better traction on the rubberized section, and (3) wearability against studded tires has been about the same on the two sections.
Two reports of cost differentials were obtained, both from Sweden. The contractor for the project described in the paragraph just above said the unit cost of the small section was about 20 percent higher than for regular dense asphalt. The Swedish Road and Traffic Research Institute suggests a doubling of cost, compared to normal dense asphalt.

One intriguing test program carried out at VTT in Finland involved a one-half kilometer test road that was paved with a mixture consisting of rubber aggregate, bitumen and a urethane binder, but no mineral aggregate. The findings were that this section was (1) very flexible and (2) very quiet, but also (3) not durable to studded tires, (4) very susceptible to destruction by snow removal equipment, and (5) ten times more costly than normal dense asphalt.

4.6 Aggregates

This brief section begins with an interesting conclusion reached by Finnish researchers after studying the resistance-to-wearing characteristics of a large number of asphalt pavement mixes. Figure 13 shows the relative proportions that the various mixture components contribute to wear resistance. The obvious conclusion is that the properties and gradation of aggregates have a very large role in the wear resistance of such pavements. Up to 80% of the wear can be explained by the aggregate.

Figure 13. Proportions that Mix Components Contribute to Pavement Wear (from Finnish research)
Considerable research has been conducted throughout Scandinavia with regard to suitable aggregates for pavement production. In addition, a major effort is underway at the Finnish National Road Administration to locate and map existing sources of aggregates. Easily accessible supplies near locations of need are becoming quite scarce, especially as resistance to "tearing up the ground" grows among major segments of the population.

Reference should be made to work reported from the early phases of the Finnish ASTO program (Proceedings of ASTO Conference, 1991) for the effects on various types of aggregate on wearing resistance against studded tires. Also, we have noted earlier in this report the results from Swedish research on the influence of aggregate size on wear resistance ("The Wear Resistance of Bituminous Wearing Surfaces," 1991).

While in Scandinavia, the writer took the opportunity to inquire about the use of recycled glass and other "exotic" aggregates in roadway pavements. In Sweden, a literature search and some limited laboratory study investigated the use of glass and other materials for both pavements and roadway structural layers. Crushed glass was found to cause problems with stripping of the bitumen, and the material was difficult to handle. A report prepared for the Swedish Road and Traffic Research Institute reported literature surveys of waste materials and by-products from mining, blast furnace, power plant and incineration processes and such manufactured aggregates as expanded clays and local soil coated with Portland cement (Höbeda, 1987b). Another report reported on various methods for upgrading low quality aggregates such as precoating, treatment with binders and "stabilization" with salts (Höbeda, 1987a).

The Finnish National Road Administration reports no use of recycled glass as an asphalt aggregate. There is some use of both steel and blast furnace slag. Flyash is used as a filler to a limited extent. Limestone is the predominant filler material, with approximately 100,000 metric tons used per year. Sand is used in some pavements. Crushed gravel is four times more prevalent than crushed rock as coarse aggregate; in total, about 4,000,000 tons of these components are added to the roadway network each year.
4.7 Additives

We mention here both adhesion agents and fibers. The Swedish specification (Krigsman, 1991) provides for various approved amines as adhesion agents; as a percent of the weight of the binder, the required proportion is 0.4% for use in open graded drainage asphalt and between 1.0 and 1.5% for others, depending on the product (Lilamine EDO, Diamine HBG, Noram SH, etc.). The same specification allows slaked lime as an adhesion agent.

In Finland, diamine is used in the amounts shown below.

- For oil gravel -- Raisamin 8020, a mixture of monoamine (80%) and diamine (20%), manufactured in Finland by Raision Tehtaat Oy: 0.5 to 1.2% by weight of binder
- For "soft" asphalt concrete (between oil gravel and asphalt concrete) -- diamine: 0.5%
- For surface dressing -- diamine: 0.5 to 1.2% (normally 1.0%)

The total quantity of amine used in Finland is approximately 1000 metric tons per year.

We have already noted the use of various types of fibers in asphalt mixes, with both cellulose and mineral fibers in common use and steel fibers used on an experimental basis. Fibers are especially important in split mastic asphalt in order to allow high binder proportions without bleeding. It is common to use 0.3% or more (by weight) of fibers in such a mix. There appears to be some preference for cellulose over mineral fibers. In Finland approximately 500 tons of fibers are used in new and upgraded asphalt pavements each year. A major part of the ASTO program is investigating the wear resistant properties of asphalt mixes with various kinds and proportions of fibers (Proceedings of ASTO Conference, 1991).

A doctoral thesis project at the Technical Research Center of Finland (VTT) investigated, among other things, the use of cellulose fibers in asphalt mixtures
When used and selected newspaper material is re-ground, short cellulose fiber is produced. This quality is most suitable for pavements. This filler-like material has an indirect effect in improving the asphalt pavement quality. The cellulose fiber produces a microscopic network of filaments to which the bitumen is bound and which is more absorbent than mineral fiber and glass fiber surfaces.

0.3% by weight of cellulose fiber is used in the asphalt mass. This mixture contains about 1.5% more bitumen than the traditional mixture, and it is easy to process. Fiber asphalt resists extremely well the wear caused by studded tires. The use of fiber asphalt is becoming a new type of pavement and a permanent additive in road building.

4.8 Polymer Modified Binders

Research in both Finland and Norway has demonstrated the advantages of polymer modified binders in asphalt concrete pavements. Finland reports (Proceedings of ASTO Conference, 1991), "Good results have been obtained at the different test roads, and there is clear evidence that polymer modification gives the pavement"

- better cold properties
- less permanent deformation, and, above all,
- better wear resistance against studded tires.

The ASTO program is testing polymer modified binders of various types and in various proportions, both for wear resistance and permanent deformation. In terms of wear resistance, on a gap graded mixture, "the polymer modified binders give the pavement 18 to 62% less abrasion in cold temperatures (-20°C) compared to the mix made with normal bitumen. The biggest decrease in abrasion is obtained with highly elastic binders (those with higher polymer
contents)." Furthermore, "all polymer modified binders that were tested improved the resistance of the mix, but there seems to be considerable differences between the different PmBs." When testing for deformation, the ASTO researchers found that both the Marshall stability and the so-called flow value increased as the polymer content increased.

In Norway, a test of a polymer modified bituminous binder called Novophalt at an airfield proved successful. The project compared the properties of Novophalt and a conventional asphalt pavement on a taxiway. A conclusion was that the Novophalt pavement has "less tendency to rutting due to insufficient stability in the asphalt [and] ... less tendency to be damaged by oil leakage ..." (although some leakage damage can still be expected). Fatigue properties were found to be similar for the two pavements at +5°C (Slyngstad et al, 1986).

4.9 Oil Gravel

Although we shall discuss oil gravel in a companion report on methods for stabilizing gravel roadway surfaces, we mention briefly here some information that relates to this discussion of asphalt pavements. Figures 14 and 15 present Finnish and Swedish aggregate gradation and other requirements for oil gravel. The binder contents must be between 3.2 and 3.6% for the range of aggregates shown in Figure 14 (Finland); the Swedish requirement varies from 3.6% for 12 mm maximum aggregate size to 3.4% for 25 mm aggregate.

Both specifications provide for adhesion agents (shown in Figure 14 for Finland but not in Figure 15 for Sweden). Sweden specifies at least 1.0 and no more than 1.5%, depending on the product.

As indicated in the discussion in section 4.2 and in Figure 6 (in that section), the general guideline in Finland is to use oil gravel for ADTs in the range between 300 and 1000, although, with maximum aggregate size of 18 mm, it may be used for ADTs up to 1500. In Figure 14, the mass of pavement per square meter is specified for various ranges of daily traffic. Presumably the use of oil gravel for ADT less than 200 is for such special cases as dust control.
MINERAL AGGREGATE
CRUSHED STONE 0–12, 0–16 OR 0–18 MM

BINDER
ROAD OIL
BO–2.

ADHESION IMPROVING ADDITIVE

<table>
<thead>
<tr>
<th>GEO</th>
<th>hiesto</th>
<th>keskihiesto</th>
<th>karkea</th>
<th>sora</th>
<th>keski-sora</th>
<th>kivia</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>hiesto</td>
<td>0.2</td>
<td>2</td>
<td>sora</td>
<td>20</td>
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</tr>
<tr>
<td></td>
<td>karkea</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TRAFFIC
<200  60 kg/m²
200–500 80 kg/m²
>500  100 kg/m²

Figure 14. Finnish oil Gravel Specification
OG 25 (Oil Gravel)

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Binder</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sort</td>
<td>Content 1)</td>
<td>Crushsurface 2)</td>
</tr>
<tr>
<td></td>
<td>weight-%</td>
<td>lowest</td>
</tr>
<tr>
<td>OG 16 B 180</td>
<td>3.4</td>
<td>0/50</td>
</tr>
<tr>
<td>BL 500 S</td>
<td>3.4</td>
<td>0/50</td>
</tr>
</tbody>
</table>

1) The amount binder is based on the specific gravity of 2.66 for the mineral aggregate.
2) Determination on fraction 11.3-16 mm

Figure 15 Swedish OG 16 Oil Gravel Specification (Krigsman, 1991)
4.10 Alternative Stud Designs

Because of the major impact of studded tires on pavement wear, some alternative stud designs, of lower weight or different configuration, have been proposed and tested. Preliminary results are quite favorable (Berg, 1992). The Swedish Road and Traffic Research Institute reported the following in 1991:

In recent years, new, lighter studs have appeared on the market in a number of variants, including a Swedish lightweight plastic stud with a hardened steel core and a Finnish stud with a plastic socket that softens impact. Tests of these new type studs have been started during the year [on the circular road test track described in section 4.3.2]. The first runs with plastic studs have shown that road wear is considerably less than with today's conventional studs. A changeover to these lightweight studs could thereby reduce rut formation on the roads and extend pavement life. Experiments with lightweight studs are continuing on the test road machine.

("Tests with Lightweight Tyre Studs, 1991,"
5.0 Other Topics

In this final section, we mention four topics of possible interest to the Department of Transportation and Public Facilities and give references.

5.1 Road Surface Test Equipment

Denmark reports the acquisition of a "Laser Profilograph" which is installed in a Citroen automobile and is used to measure cross-fall, rutting, longitudinal slope, evenness and geometry. It utilizes seventeen laser sensors mounted on the front of the car. Data is collected at ordinary traffic speeds ("Laser Profilograph," 1991).

The Swedish equivalent is the Laser Road Surface Tester (L-RST). Developed through a cooperative venture between the private organization RST Sweden AB and the Swedish Road and Traffic Research Institute, this device measures seven variables -- (1) rut depth, (2) roughness, (3) cracks, (4) texture, (5) crossfall, (6) curvature and (7) hilliness -- at speeds of up to 90 kph. More recently, a Laser RDT (Road Deflection Tester) has also been developed ("Laser RST," 1990).

Finland uses an RSM (Road Surface Monitoring) system which addresses the same surface characteristics ("Road Surface Monitoring System," 1992). In addition, Finland utilizes a "Mapvision" system which is equipped with a laser scanner for detecting rut formation ("Mapvision Road Measuring System," 1991).

5.2 Road Information Data Banks

In Denmark, a centralized road data bank has been in operation since the mid-1970's as a joint technical and administrative information system of the Road Directorate, the fourteen counties and, in the case of accidents, the 275 municipalities. It has recently been upgraded, and the new generation is called VIS -- the Road (Vej in Danish) Information System. The PC-based system makes information available to road authorities in both alphanumeric format and thematic digital maps ("The Nationwide Danish Road Information System," 1992).
The Road Data Bank of Finland (1990) is a computer-based information that was created for the internal use of the Finnish National Road Administration; it also serves as the official register of public roads. Each road is divided into sections with an average length of 5 kilometers. Appendix C contains a list of the information included in the data bank for each section, as appropriate. The data are updated continuously, and cross sections may be taken at any time to show the current status of the entire road system of any portion thereof.

5.3 Effects of Alignment and Speed Limits on Safety

Section 2.8 noted some investigations of the correlation between roadway safety and winter road maintenance. A study of the relationship between road alignment and traffic accidents in Sweden led to some unexpected conclusions - narrow roads built in recent decades show approximately the same accident rate for the period 1980-84 as wide roads, and 9 meter wide roads showed a higher accident rate than both narrow and wide roads, regardless of the decade when they were built. The study concluded that roads built during the latter decades do not demonstrate any noticeable improvement in traffic safety compared with roads built during the 1950's ("Road Alignment and Traffic Accidents," 1991).

In Finland, the Road Administration has investigated the effects of varying speed limits based on weather conditions (Pajunen and Mänttäri, no date). Peltola (1991) reports that reducing the speed limit from 100 to 80 kph during the winter months resulted in a decrease of 14% in the number of accidents and a decrease of 11% in injury accidents. Also, when the speed limits on a freeway ("motorway") were reduced from 120 to 100 kph, the number of accidents decreased by 10%.

A study of driver behavior at Finland's University of Oulu concluded that drivers have a clear tendency to estimate road conditions as better than they actually are and thus drive faster than road conditions permit. It was concluded that drivers should be provided with a considerable amount of information on weather and road conditions and the predicted future changes in those conditions (Heinijoki, Koivuniemi and Ehrola, 1990).
5.4 Ultra-Violet Headlights for Improved Night Vision

In Sweden an interesting development is taking place that may greatly improve nighttime driving safety. Ultra Lux AB is a joint venture between Saab and Volvo to develop an ultra-violet automobile headlight. Demonstrations show that the distances over which drivers can see objects in front of them are greatly increased using ultra-violet headlights. Under normal nighttime conditions, the sight distance may be increased by as much as 100 meters. Most clothing and light animal fur are naturally fluorescent and are thus enhanced by these headlights. Special paints would be required for markings, posts and other objects.

Saab and Volvo will provide optional UV headlights on some 1995 models. In 1996, such equipment is expected to be standard on some models. The current cost for a pair of these highlights is 1500 skr, equivalent to about $US250. A video tape showing the dramatically increased sight distances is a part of Appendix D of this report (UV Headlights -- Safer Nighttime Driving, no date).
6.0 Meetings Held

The following is a list of meetings held with road agency personnel, engineers, construction contractors, researchers, faculty members, and others during the writer's investigations in Finland, Norway and Sweden:

- October 12, 1992 -- SKANSKA Contractors, Stockholm, Sweden
- October 13 -- Swedish Construction Federation, Stockholm
- October 13 -- CEMENTA Cement Products Company, Stockholm
- October 19 -- NCC Contractors, Boden, Sweden
- October 22 -- Cement and Concrete Institute, Stockholm
- October 23 -- NCC Contractors, Stockholm
- October 26 -- Swedish Geotechnical Institute, Linköping, Sweden
- October 27 -- Swedish Road and Traffic Research Institute, Linköping
- November 2 -- SIAB/SKANSKA Joint Venture, Kiruna, Sweden
- November 6 -- Norwegian Geotechnical Institute, Oslo, Norway
- November 6 -- Norwegian Road Research Laboratory, Oslo
- November 11 -- Norwegian Institute of Technology, Trondheim, Norway
- November 12 -- Norwegian Public Roads Administration, Trondheim
- November 30 -- Swedish National Road Administration, Borlänge, Sweden
- December 7 -- VTT, Technical Research Center of Finland, Building Materials Laboratory and Road, Traffic and Geotechnical Laboratory, Helsinki, Finland
- December 8 -- Finnish National Road Administration, Helsinki
- December 9 -- VTT, Technical Research Center of Finland, Building Production Laboratory, Tampere, Finland
• December 10 -- VTT, Technical Research Center of Finland, Building Laboratory, Oulu, Finland

• December 10 -- University of Oulu, Department of Civil Engineering, Oulu

• December 15 -- NCC Contractors, Piteå, Sweden

• December 18 -- Narvik Institute of Technology and FORUT Technology Ltd., Narvik, Norway

• December 18 -- Narvik College of Engineering, Narvik
7.0 References

Axelson, L. 1993. Personal communication, Swedish National Road Administration.


Kapitel 13 Vägtrafikanordningar. 1984. :01 Vägmarkering med Termoplastisk Massa (Road Marking with Thermoplastics) and :02 Vägmarkering med Färg (Road Marking with Paint). Swedish National Road Administration, Borlänge.


Pajunen, K. and J. Mänttäri. no date. "Varying Speed Limits Based on Weather Conditions." Technical Research Center of Finland (VTT) and Finnish National Road Administration.


Road Information. no date. FFV Business Group Aerotech, Arboga, Sweden.


Swedish National Road Administration. no date. Section for Road Technology.


UV Headlights -- Safer Nighttime Driving. no date. Videotape produced by Swedish National Road Administration.
VTT Road, Traffic and Geotechnical Laboratory Annual Report. 1991. Technical Research Center of Finland (VTT), Espoo.
APPENDIX A

Winter Roadway Maintenance Guidelines for Standard Roadway Classifications


1.2.1 STANDARD CLASS A1

The road surface should be

- Free of ice and snow in fine weather.
- Free of ice and snow within 2 hours after precipitation. If the precipitation has only caused icing, the road surface should be free of ice within 1 hour after precipitation. These limits may be exceeded in the case of hard shoulders on a motorway.

Exceptions from the requirement on road surfaces free of ice and snow may occur when road surface temperatures fall below approximately -8\(^\circ\)C. Under the same time limits as above, the following should then apply:

- no loose snow
- in the event of packed ice or snow, this should be leveled and where necessary deiced

During snowfalls, the road surface should be deiced as necessary and should have a maximum depth of snow corresponding to 2 cm dry snow. Exceptions may occur in extreme weather conditions.

Actions to maintain stopping sight distance should be completed within 2 days.

To achieve the specified standard, the following should be observed:
- On roads with a climbing lane and at times when the hourly flow is \( >100 \) vehicles, the slow lane should be treated at the same time as the fast lane.
- On roads with a hard shoulder and at times when the hourly flow is \( >300 \) vehicles or \( >100 \) vehicles with \( >20\% \) proportion of heavy vehicles, the hard shoulder should be treated within one hour after the adjacent lane.
- A central string of slush or loose snow should be avoided.

1.2.2 STANDARD CLASS A2

The road surface should be:

- free of ice and snow in fine weather
- free of ice and snow within four hours after precipitation. If the precipitation has only caused icing, the road surface should be free of ice within two hours after precipitation. These time limits may be exceeded in the case of hard shoulders on a motorway.

Exceptions from the requirement on road surfaces free of ice and snow may occur when road surface temperatures fall below approximately \(-8^\circ\)C. Under the same time limits as above, the following should then apply:

- no loose snow
- in the event of packed ice or snow, this should be leveled and where necessary deiced.

During snowfalls, the road surface should be deiced as necessary and should have a maximum depth of snow corresponding to 4 cm dry snow. Exceptions may occur in extreme weather conditions.

Actions to maintain stopping sight distance should be completed within 2 days.

To achieve the specified standard, the following should be observed:

- On roads with a climbing lane and at times when the hourly flow is \( >100 \) vehicles the slow lane should be treated within 30 minutes after the fast lane.
On roads with a hard shoulder and at times when the hourly of flow is >300 or >100 vehicles with 20% proportion of heavy vehicles, the hard shoulder should be treated within two hours after the adjacent lane.
- A central string of slush or loose snow should be avoided.

1.2.4 STANDARD CLASS B, NORTHERN SWEDEN

The road surface should be:

- free of ice and snow in fine weather, as well as deiced and where necessary leveled. If the road surface temperature exceeds approximately -6°C for an extended period, the road surface should be free of ice and snow.
- free of loose snow, deiced and where necessary leveled within six hours after precipitation. If the precipitation has only caused icing, the road surface should be free of ice within three hours after precipitation. These time limits may be exceeded in the case of hard shoulders on a motorway.

During snowfalls, the road surface should be deiced as necessary and should have a maximum depth of snow corresponding to 6 cm dry snow. Exceptions may occur in extreme weather conditions.

Actions to maintain stopping sight distance should be completed within two days.

To achieve the specified standard, the following should be observed:

- On roads with a climbing lane and at times when the hourly flow is >100 vehicles, the slow lane should be treated within 30 minutes after the fast lane.
- On roads with a hard shoulder and at times when the hourly flow is >300 vehicles or >100 vehicles, the hard shoulder should be treated within two hours after the adjacent lane.
- A central string of slush or loose snow should be avoided.

1.2.5 STANDARD CLASS C

The road surface should be
- free of ice and snow in fine weather, as well as deiced and where necessary leveled. If the road surface temperature exceeds approximately -3°C and the AADT exceeds 1,000 vehicles, the road surface should be free of ice and snow.
- free of loose snow, deiced and where necessary leveled within six hours after precipitation. If the precipitation has only caused icing, the road surface should be free of ice within four hours after precipitation.

During snowfalls, the road surface should be deiced as necessary and should have a maximum depth of snow corresponding to 8 cm dry snow. Exceptions may occur in extreme weather conditions.

Actions to maintain stopping vision should be completed within three days.

A reduction in standard during the lowest trafficked period of the night may occur.

1.2.6 STANDARD CLASS D

The road surface should be

- leveled in fine weather, as well as deiced if very slippery.
- free of loose snow over most of its area within eight hours after precipitation. No more than 5 cm of dry snow should be permitted along the verges. If the precipitation has made the surface very slippery, it should be deiced within four hours after precipitation.

During snowfalls, the road surface should be deiced as necessary and should have a maximum depth of snow corresponding to 8 cm dry snow (10 cm for road width > 7 m). Exceptions may occur in extreme weather conditions.

Actions to maintain stopping sight distance should be completed within five days.

A reduction in standard during the lowest trafficked period of the night may occur.
1.2.7 PEDESTRIAN AND CYCLE PATHS

The following should be observed in the case of pedestrian and cycle paths:

- A leveled and deiced surface.

- For pedestrian and cycle paths with no direct link to a road, the standard should be adapted to local needs.

- Accumulated snow should not encroach on a pedestrian and cycle path so that pedestrians and cyclists are forced onto an adjacent carriageway.

- The same general advice applies for pedestrian and cycle paths as for adjacent roads, maintenance being arranged so that it is completed at the same time on an adjacent road if the pedestrian and cycle traffic is heavy. Otherwise, a pedestrian and cycle path should be free of loose snow and deiced within four hours after an adjacent carriageway.

- Actions to maintain stopping sight distance for vehicles on the carriageway should be completed within three days.

- A reduction in standard during the night is accepted. However, the standard should not be so low that pedestrians and cyclists are forced to use an adjacent carriageway during the period 22.00-06.00.
APPENDIX B

Illustrations of Several Pieces of Asphalt Testing Equipment
Provvägsmaskinen
är en utrustning för att under
kontrollerade förhållanden genomföra
accelererade provningar av däcks in-
verkan på beläggningsytor.

Maskinen har sex hjul som roterar på en
cirkulär bana med beläggningsmaterialet.
Drivning sker med en motor på varje hjul.
Diametern på banan är 5,25 m, vilket ger
en medellängd för ett varv av 16,5 m. Banans bredd är högst 0,85 m.

Maskinens hjul kan monteras med olika avstånd radiellt från maskinens centrum och under
körningen kan maskinens axel dessutom förskjutas sakta i sidled genom en excenteranordning.
Därigenom kan samtliga hjul förskjutas, sammanlagt ca 60 mm, fram och åter i sidled. Rörelsen i
sidled är särskilt viktig vid körning med dubbdäck, som i annat fall skulle ge smala slitagespår efter
varje dubbad i däcken.

Den belagda ytan kan begjutas med vatten och i hallen där maskinen står kan kylning ske
ned till -20°C. Maskinens hastighet kan varieras men maxhastigheten är begränsad för olika
hjulbelastning. Med nuvarande utformning är högsta hastighet ca 85 km/h för hjullasten 5 kN.
Lastbils- eller personbilsdäck, med konisk eller konventionell slitbana, kan användas. Vanligtvis
körs maskinen med normala dubbade personbilsdäck av dimensionen 185/70 R14.
Samband provvägsmaskin och väg
Provvägsmaskinen har visat utmärkt korrelation med slitaget på vägen. Figuren visar sambandet mellan slitaget på provplattor som lagts ut på vägen och i provvägsmaskinen. Belägningstyp HABT 12 och 16

Undersökningar av beläggningsmaterial
Undersökning av vägbeläggningars resistens mot dubbade däck. Vid provningen testas slitstyrkan på laboratorieväljade provplattor med väl känd packning och sammansättning. Inverkan av belägningstyp, bindemedel, stenmaterialekvalitet, stenstorlek etc. är exempel på parametrar som kan undersökas.

Dubbundersökningar
Utvecklingen av dubb till personbilsdäck har skett mot allt lättare dubbar. På marknaden finns bland annat dubbar där dubbkroppen som omger hårdmetallstiftet är tillverkad av plast eller lättmetall. Prov med dessa lättare dubbar har genomförts i provvägsmaskinen. Resultatet visar att dessa sliter betydligt mindre på beläggningsytan än de tyngre konventionella ståldubbarna.

Exempel på andra användningsområden
- trafikering av mätkablar
- slitageprovning av vägytesensorer
MANUFACTURING OF ASPHALT-AGGREGATE MIXES.
LABORATORY MIXER.
Technical information
2 shafts, 2 x 6 paddles
Capacity 5...50 kg

LABORATORY MIXERS

MICRO-MIXER UNIT
Laboratory mixer is designed to produce mixtures for Marshall compactor and gyratory compactor.

Technical data
Dimensions (L x W x H) 650 x 600 x 1500 mm
Adjustable revolutions 0—50 r/min.
Adjustable mixing time 0—60 min.
Controlled heater up +200°C
Capacity 1000...5000 g

Users:
VTT
UNIVERSITY OF TECHNOLOGY
ROAD ADMINISTRATION
NESTE OIL COMPANY
NYNÄS BITUMEN TECHNOLOGY AB

Manufacturer
VTT Technical Research Centre of Finland
Instrument Laboratory

VTT
Technical Research Centre of Finland
ROAD, TRAFFIC AND GEOTECHNICAL LABORATORY
Asko Saarela & Heikki Jämsä
Lämpömiehenkuja 2 A, SE-02150 Espoo, Finland
Phone intern. +358-0-4561, telex 122972 vtha sf, telefax +358-0-463 251
COMPACTION PROPERTIES OF BITUMINOUS MIXTURES. GYRATORY COMPACTOR.
GYRATORY COMPACTOR FOR BITUMINOUS MIXTURES

Technical specifications, INTENSIVE COMPACTION TESTER (ICT)

<table>
<thead>
<tr>
<th>Dimensions</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>main unit</td>
<td>330 x 430 x 900 mm (W x D x H)</td>
<td></td>
</tr>
<tr>
<td>control unit</td>
<td>410 x 240 x 220 mm</td>
<td></td>
</tr>
<tr>
<td>Compacted sample diameter</td>
<td>100 mm</td>
<td></td>
</tr>
<tr>
<td>Compacted sample height</td>
<td>100 mm</td>
<td></td>
</tr>
<tr>
<td>Maximum angle of deviation from perpendicular between end plates and work cylinder wall</td>
<td>4 mm/100 mm (2°17')</td>
<td></td>
</tr>
<tr>
<td>Working speed</td>
<td>30...120 work cycles/minute</td>
<td></td>
</tr>
<tr>
<td>Air pressure source</td>
<td>7 bar</td>
<td></td>
</tr>
</tbody>
</table>

Operation of the ICT gyratory compactor

1. The material to be tested is placed in the work cylinder. Its weight is recorded.
2. Test parameters are entered into the control unit.
3. The material sample is compacted using the intensive compaction method according to the instructions preprogrammed into the control unit.
4. After compaction has been completed the control unit prints out a test report.
   The sample is removed from the work cylinder and can be used for further testing, e.g. strength testing. Recorded results can be transferred from the control unit to a PC for data handling.

COMPAC TION AND SHEAR PROPERTIES AT DIFFERENT BITUMEN CONTENT

Designed and manufactured by
Invelop Oy, Telakkatie 19, SF-57230 Savonlinna, Finland
Phone Internat. +358-57-557987, telefax +358-57-557959

VTT
Technical Research Centre of Finland
ROAD, TRAFFIC AND GEOTECHNICAL LABORATORY
Heikki Jämsä, Senior Research Engineer
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Phone internat. +358-0-4561, telex 122972 vtha sf, telefax +358-0-463 251
INTENSIVE COMPACTION TESTING

The ICT method is especially suited for research because of its versatility, speed and accuracy. The ICT-100R is already being used in several well-respected research institutes.

The ICT equipment compacts the mass sample by means of pressure and shear movement. The degree of compaction is adjustable.

The density increase and deformation force are recorded during the test. The data can then be transmitted to a computer.

A brief test summary and an accurately compacted sample are available immediately after compaction is completed. Each test requires only a few minutes.
TEST RESULTS
All test data and identifying information are stored in the memory of the control unit.

Density increase, dilation and required deformation force as a function of density are examples of the useful information obtainable from the test data. These results provide a basis for comparison of different masses.

PC-CONNECTION
Test data can be easily transferred to a PC (IBM or compatible) for future analysis and storage.

BRIEF REPORT
The control unit prints out a brief report after a test is completed. This allows the operator to compare tests. Density increase and deformation force are given in the report along with identification information.

CURRENT USES
The ICT has been used in these research programs:

- Compactability of asphalt, soil and no-slump concrete
- Effect of various mixtures on compactability and product quality
- Classification of different masses according to compactability
- Effect of binders and additives
- Feasability of using crushed stone
- Comparison of production machines for compaction effectiveness and production machine development
- Sample preparation for triaxial tests, frost research, permeability, cohesion and strength tests. Strength and durability of compacted masses in different environments.

ICT-100R TECHNICAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compacted sample diameter</td>
<td>100 mm</td>
</tr>
<tr>
<td>Sample height</td>
<td>100 mm</td>
</tr>
<tr>
<td>Sample weight</td>
<td>1500–2000 g</td>
</tr>
<tr>
<td>Sample temperature max.</td>
<td>180°C</td>
</tr>
<tr>
<td>Maximum angle of deviation from perpendicular between end plates and work cylinder wall</td>
<td>4/100 (2°17')</td>
</tr>
<tr>
<td>Working speed</td>
<td>40–160 work cycles/min</td>
</tr>
<tr>
<td>Power supply (standard)</td>
<td>220 V/50 Hz</td>
</tr>
<tr>
<td>Power consumption max.</td>
<td>1100 W</td>
</tr>
<tr>
<td>Air pressure source</td>
<td>6–8 bar</td>
</tr>
<tr>
<td>Air usage</td>
<td>approx. 1 l/min</td>
</tr>
<tr>
<td>Working temperature</td>
<td>+ 0.° + 40°C</td>
</tr>
<tr>
<td>Weight</td>
<td>n. 75 kg</td>
</tr>
<tr>
<td>Dimensions, main unit (WxDxH)</td>
<td>330x430x900 mm</td>
</tr>
<tr>
<td>Control unit</td>
<td>410x240x220 mm</td>
</tr>
</tbody>
</table>

The manufacturer reserves the right to change technical specifications without notice.
Both the ICT method and equipment are patented.

Invelop oy
Teknola 5
57230 Savonlinna
Finland

Telephone +358 57 557 987
Telefax +358 57 557 959
COMPACCTION OF ASPHALT CONCRETE SLAB IN THE LABORATORY. STEEL-TIRED ROLLER.
ROLLER FOR COMPACTING OF BITUMINOUS MIXTURES IN LABORATORY

Technical data

Dimensions: 
1880 x 1500 x 1350 (L x W x H)

Loading pressure (line pressure) is adjustable pneumatically 0—67 kp/cm.

Adjustable vibration system.

Speed of the roller 30 passes/min.

Automatic counting of the number of passes.

Size of the pavement slabs can be changed. Standard sizes are 400 x 470 mm, 480 x 600 mm and 300 x 880 mm. 12 specimens (Ø 100 mm) can be drilled from the slab of size 400 x 470 mm.

Thickness of the slab is 40—100 mm.

A steel-tired roller with vibration is also available to field and laboratory use. The size of a slab is not a limited with this device.

Manufacturer:
VTT Technical Research Centre of Finland Instrument Laboratory

VTT
Technical Research Centre of Finland
ROAD, TRAFFIC AND GEOTECHNICAL LABORATORY
Asko Saarela & Heikki Jämsä
Lämpömiehenkuja 2 A, SF-02150 Espoo, Finland
Phone intern. +358-0-4561, telex 122972 vttha sf, telefax +358-0-463 251
SAWING OF SAMPLES FOR DIFFERENT LABORATORY TESTS.
SPECIAL SAW-INSTRUMENT.
SPECIAL SAW FOR ASPHALT PAVEMENT, STONE AND CONCRETE

The saw can be used to provide smooth, flat and parallel ends for the samples of creep-, wear- and resilient modulus tests. It is also used to cut the slabs for fatigue tests etc.

**Technical data:**

- **Motor:** 11 kW
- **Dimensions:** 2500 x 900 (780) x 1750 mm (L x W x H)
- **Sawing depth:** 250 mm
- **Dimensions of the sawing table:** 700 x 600 mm
- **Also available with automatic feeding**

**Manufacturer:**

VTT Technical Research Centre of Finland Instrument Laboratory

---

*A sawed, drilled and cutted specimen for low-temperature testing.*

---

**VTT**

Technical Research Centre of Finland
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MEASURING OF THE DEFORMATION PROPERTIES OF ASPHALT CONCRETE. CREEP-TESTER.
In the Creep Tester a specimen is loaded uniaxially using 100 kPa stress. Deformation of test specimens is measured as a function of time. Loading time is one hour. During a 10 minute preliminary loading time two percent of test stress is applied. After one hour recovery period the permanent deformation is measured.

Three specimens can be tested simultaneously in the apparatus.

Test temperature of specimens in the water bath is generally +40°C. Measured deformation is recorded in mm.

CREEP CURVES OF BITUMINOUS MIXTURES

(1) Asphalt concrete with standard bitumen
(2) Asphalt concrete with polymer bitumen

A = elastic recovery
B = permanent deformation

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WHEEL-TRACKING DEVICE FOR DEFORMATION STUDIES
DEFORMATION RESEARCH WITH WHEEL-TRACKING DEVICE

Rutting due to deformation is investigated in the laboratory with the wheel-track device. The size of a test sample is $700 \times 500 \times 60$ mm ($\text{length} \times \text{width} \times \text{height}$). A sample is made in a laboratory or at a mixing plant.

Tire size 6.00 - R 9, tire pressure according to load.
Load 7 kN - 25 kN.
Wheel speed 0.7 m/sec.

The device and a sample are in a conditioning cabinet of which temperature can be controlled between $+5 - +60^\circ$C. The movement of wheel and applied load function by means of hydraulic transmission.

Deformation is measured with lasers from 3 cross-sections. Results show the progress of rutting as a function of the cumulative number of wheel passes. Also, deformation speed and the area of deformation are among other things recorded. The measurement data are stored on a microcomputer. Summary information of raw data in the form of reports and graphical outputs are produced.

The wheel-tracking device is used to research deformation characteristics of different mixture types. Information is utilized to check the deformation sensitivity of a mixture and to develop new and more deformation resistance asphalt mixtures.

The wheel-tracking device has been designed by the Road and Traffic Laboratory and Instrument Laboratory at VTT. The Instrument Laboratory has constructed the device. Hydraulic system has been supplied by M-TEK Ltd, temperature box by Meltor Ltd and automatic temperature control system by Kylmäteho Tenhunen Ltd.

INFORMATION
Professor Asko Saarela, tel. + 358 0 4564970, fax. + 358 0 463251
Senior Research Engineer Heikki Jämsä, tel. + 358 0 4564965

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Technical Research Centre of Finland
Road and Traffic Laboratory
P.B. 110
02151 Espoo
Finland
WEAR RESISTANCE OF PAVING MIXTURE
THE WEAR TEST

The wear test is made with an apparatus where three studded rubber tyres wear the sample cylinder sides (d=100 mm, H=40 mm). The sample is worn for 2 h at +5°C. The results is given as wear value, which is the volume of the worn rut in cm³. The method has been described in more detail in the method VTT 3206-87 (TIE 406).

You can also study materials as stone, concrete, thermoplastic road marking materials and epoxies in the wear test. There are three PWR-testers in the Road and Traffic Laboratory and one in the University of Technology. The repeatability of the testers is good.

The connection between wear value and road wear has been shown in the Figure. The observations of road wear have been made on motorway after the first winter season. The traffic volume is 20,000 cars/day. Five sample cylinder at least 50 mm high are needed of the pavement studied for the test.

The recommended maximum wear values on different roads.

<table>
<thead>
<tr>
<th>PAVEMENT CLASS</th>
<th>PWR-VALUE</th>
<th>ADT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 25</td>
<td>≥ 10000</td>
</tr>
<tr>
<td>2</td>
<td>25 - 40</td>
<td>5000 - 10000</td>
</tr>
<tr>
<td>3</td>
<td>40 - 60</td>
<td>1500 - 5000</td>
</tr>
<tr>
<td>4</td>
<td>60 - 100</td>
<td>500 - 1500</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 100</td>
<td>&lt; 500</td>
</tr>
</tbody>
</table>

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APPENDIX C

Road Data Bank of Finland Data Elements
TIEREKISTERIN TIESTÖTIEDOT 1.1.1990


1. Tien nimi
2. Välikohtaiset tiedot

<table>
<thead>
<tr>
<th>001</th>
<th>Tien pätkä</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- tyypit: yleinen tie, lautta, katu, työmaa</td>
</tr>
<tr>
<td></td>
<td>- pituus (m)</td>
</tr>
<tr>
<td></td>
<td>- osoitehistoria</td>
</tr>
<tr>
<td></td>
<td>- hallinnollinen tieluokka</td>
</tr>
<tr>
<td>107</td>
<td>Määräysmäärä (m/km)</td>
</tr>
<tr>
<td>108</td>
<td>Kaarteisuusmäärä (astetta/km)</td>
</tr>
<tr>
<td>109</td>
<td>Nämäät</td>
</tr>
<tr>
<td></td>
<td>- 150, 300 ja 460 m:n näkemät prosenttilta</td>
</tr>
</tbody>
</table>

APPENDIX 1

INFORMATION CONTAINED IN THE ROAD DATA BANK AS PER 1.1.1990

The following lists the type of information in the Road Data Bank, arranged by main characteristics. The number preceding the data indicates the data code. The list also shows dimension and classification of the data. All the data has a DATE which indicates e.g. the day when the pavement was done.

1. Name of the road
2. Data by distance

<table>
<thead>
<tr>
<th>001</th>
<th>Road section</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- type: public road, ferry, street etc.</td>
</tr>
<tr>
<td></td>
<td>- length (m)</td>
</tr>
<tr>
<td></td>
<td>- history of address code system</td>
</tr>
<tr>
<td></td>
<td>- administrative road class</td>
</tr>
<tr>
<td>107</td>
<td>Hilliness (m/km)</td>
</tr>
<tr>
<td>108</td>
<td>Average curvature (grade/km)</td>
</tr>
<tr>
<td>109</td>
<td>Sight distance</td>
</tr>
<tr>
<td></td>
<td>- sight distances of 150, 300 and 460 m, percent of the length of road section</td>
</tr>
<tr>
<td>128</td>
<td>Municipality and county</td>
</tr>
<tr>
<td>129</td>
<td>Maintenance area (of Road Masters)</td>
</tr>
<tr>
<td>130</td>
<td>Functional road class</td>
</tr>
<tr>
<td></td>
<td>- present road network and that corresponding to the 2010 road network</td>
</tr>
<tr>
<td>131</td>
<td>Road maintenance contracts</td>
</tr>
<tr>
<td>132</td>
<td>State Railways/municipality/other district</td>
</tr>
<tr>
<td>133</td>
<td>Maintenance class</td>
</tr>
<tr>
<td>134</td>
<td>Constructive measures</td>
</tr>
<tr>
<td></td>
<td>- construction/improvement</td>
</tr>
<tr>
<td>135</td>
<td>Administrative measures</td>
</tr>
<tr>
<td></td>
<td>- change of the administrative road class</td>
</tr>
<tr>
<td></td>
<td>- change of private road into public road</td>
</tr>
<tr>
<td>136</td>
<td>Number of roadways</td>
</tr>
<tr>
<td>137</td>
<td>Width of roadway (0.1 m)</td>
</tr>
<tr>
<td>138</td>
<td>Pavement of roadway</td>
</tr>
<tr>
<td></td>
<td>- type of pavement</td>
</tr>
<tr>
<td></td>
<td>- method of treatment</td>
</tr>
<tr>
<td></td>
<td>- max. stone size (mm)</td>
</tr>
<tr>
<td></td>
<td>- quantity of material (kg/m²)</td>
</tr>
<tr>
<td>162</td>
<td>Weight limit during thawing period</td>
</tr>
<tr>
<td></td>
<td>- weight limit (tons) and lasting time</td>
</tr>
<tr>
<td>163</td>
<td>Width of shoulder (0.25 m)</td>
</tr>
<tr>
<td>164</td>
<td>Pedestrian and bicycle way</td>
</tr>
<tr>
<td></td>
<td>- type: bicycle way, pedestrian way, both separation from road</td>
</tr>
<tr>
<td></td>
<td>- responsibility of maintenance</td>
</tr>
<tr>
<td>166</td>
<td>Lightning</td>
</tr>
<tr>
<td></td>
<td>- starting and ending point only</td>
</tr>
<tr>
<td>168</td>
<td>Speed limit (permanent)</td>
</tr>
<tr>
<td></td>
<td>- type of limit: differential limit by road, local speed limit, regional limit</td>
</tr>
<tr>
<td></td>
<td>- speed limit (km/h)</td>
</tr>
<tr>
<td>172</td>
<td>Moottori- tai moottoriliikennetiet</td>
</tr>
<tr>
<td>173</td>
<td>Päälystelevys (0,1 m tarkkuus)</td>
</tr>
<tr>
<td>174</td>
<td>Ajoradan päälysteen korjaus</td>
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<td>Liikenneonnettomuudet</td>
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<td>Piirien omat tietolajit</td>
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<td>Mahdollisuus rekisteröidä vain tiettyjä piirejä kiinnostavia tietoja</td>
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APPENDIX D

Copies of Reference Material
(Separate Volume; one copy only, previously forwarded to AKDOT & PF)