

# **VTI särtryck**

**Nr 208 • 1994**

## **Third Sprint Workshop, Exhibition and Demonstrations on Technology Transfer and Innovation in Road Construction**

**The Swedish National State Of The Art Report**

**Edited by Lars-Göran Wågberg**

Reprint from Pavement Maintenance Monitoring,  
Management and Techniques, 8–9 March 1994  
in Barcelona



**Väg- och transport-  
forskningsinstitutet**





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THIRD SPRINT WORKSHOP, EXHIBITION and DEMONSTRATIONS  
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TECHNOLOGY TRANSFER AND INNOVATION IN ROAD CONSTRUCTION

**PAVEMENT MAINTENANCE  
MONITORING, MANAGEMENT AND TECHNIQUES**

**8-10 March 1994 in Barcelona**

**THE SWEDISH NATIONAL STATE OF THE ART REPORT**

Edited by Lars-Göran Wågberg, Swedish Road and Transport Research Institute

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## SESSION 1: MONITORING METHODS AND EQUIPMENT'S

### 1A Surface characteristics:

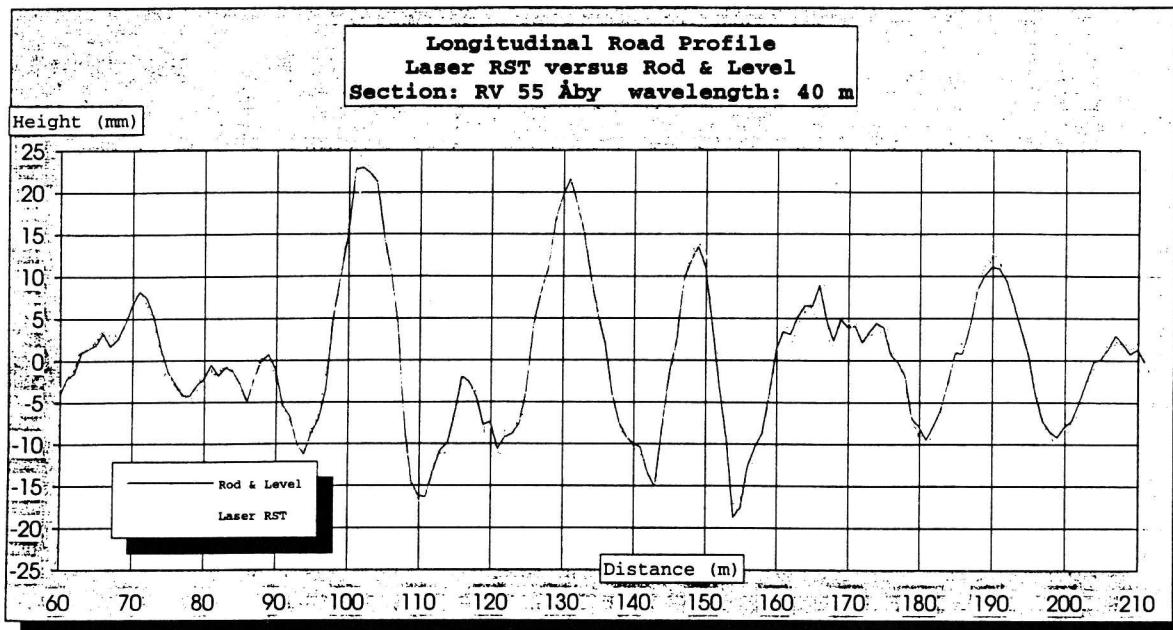
#### **MEASUREMENT OF LONGITUDINAL AND TRANSVERSAL ROAD PROFILES USING THE LASER ROAD SURFACE TESTER**

By Georg Magnusson, Swedish Road and Transport Research Institute

##### **Longitudinal profile**

The longitudinal road profile is measured by the Laser Road Surface Tester (Laser RST) according to the well known so called GMR principle, developed at General Motors Research in the beginning of the 60's, however with certain improvements. This method allows the measurement of the longitudinal road profile using a measurement vehicle travelling along the road at high speed, up to about 100 km/h. Basically the method involves the continuous measurement of the vertical distance between a point on the measurement vehicle and the road surface (in the case of Laser RST by means of a laser), the vertical acceleration of the same point and finally the travelled distance along the road, in the case of Laser RST using a pulse generator connected to a non-driven road wheel. From this information a geometrical description of the longitudinal profile is obtained using a derivating, integrating and filtering procedure. By duplication the measurement system using one profilometer in each wheel track two longitudinal profiles can be measured simultaneously.

This profile information is primarily used for the calculation of road unevenness numbers such as IRI and RMS values for different wavelength ranges. Basically, however, any unevenness number can be derived from this profile information. Another use of the profile is within road research where a detailed "picture" of the road profile may be needed. It should, however, be born in mind that all profilometers working according to this measurement principle, there are some different designs on the market, filters the profile so that the longer wavelengths are taken away. The longest wavelength that can be measured can to some extent be chosen at will. In some cases the longest measurable wavelength is said to be about 90 m, but the accuracy of the measurement of that long wavelengths remains to be demonstrated. In the case of Laser RST wavelengths up to and including at least 50 m has been shown to be measured with good accuracy. The figure on the next page shows a road profile measured by Laser RST compared to the same profile measured by rod and level. The profile contains wavelengths up to 40 m. A special version of Laser RST, the Laser RST Portable, can, however, measure wavelengths up to 150 m with reasonable accuracy.



*Comparison of longitudinal profile measured by rod and level and the Laser RST*

In order to increase the measurable wavelength range a new method has been developed, aiming at the measurement of very long waves, in the order of magnitude of several hundred meters. This method is based on the measurement of the longitudinal inclination of the vehicle in relation to the horizon, using an inclinometer. There are, however, two errors that must be corrected for. The first one is the longitudinal acceleration of the vehicle that affects the inclinometer. As, however, the relationship between the acceleration and inclinometer output is known this error can be corrected for, the acceleration being calculated from rate of change of longitudinal speed which is obtained from the pulse rate from the pulse generator. The second error depends on the fact that the attitude of the vehicle, i.e. the angle between the longitudinal axis of the vehicle and the longitudinal axis of the road, depends on whether the vehicle goes uphill, downhill or on a horizontal road and also on the load status of the vehicle. The attitude is measured using a laser at the rear end of the vehicle in combination with one of the lasers at the front of it, and the error can thus be corrected.

### Transversal road profiles

The shape of the transversal road profile is measured by Laser RST using a number of distance measuring lasers mounted on a bar carried at the front of the measurement vehicle. The standard version of Laser RST uses eleven lasers measuring a 3.2 m wide transversal profile. As the outermost lasers at each end of the bar is angled 45° outwards this can be done within a total vehicle width of 2.5 m. Special versions of Laser RST have been developed using up to 20 lasers measuring a 4 m wide transversal profile, still within the vehicle width of 2.5 m.

In addition also the cross slope of the transversal profile is measured using an inclinometer. In this case the inclinometer is affected by the lateral acceleration of the measurement vehicle when measuring in road curves, but also this error can be corrected. The lateral accelera-



tion is given by the product of the yaw velocity of the vehicle, measured by means of a rate gyro, and the longitudinal velocity, again obtained from the pulse generator, and the output from the inclinometer is continuously corrected in real time for the influence of the lateral acceleration to give the correct cross slope of the road.

The combined information about the shape and cross slope of the transversal profile makes it possible to calculate e g the theoretical maximum depth and width of standing water on the surface. Another application of the cross profile/cross slope measurement in combination with the measurement of the longitudinal profile is as the input to an interactive simulation program "Fill and Mill" used as an aid in road surface rehabilitation work.

## **METHODS AND EQUIPMENT FOR MONITORING ROAD SURFACE TEXTURE AND NOISE**

by Ulf Sandberg, Swedish Road and Transport Research Institute

### **Surveys of surface texture**

Extensive surveys of road surface texture in Sweden makes use of the Swedish RST vehicle (RST = Road Surface Tester, available through RST Sweden AB). The RST vehicle measures the following texture parameters:

- \* RMS of texture profile, encompassing the texture wavelength range 2-10 mm. This value is called "fine" texture
- \* RMS of texture profile, encompassing the texture wavelength range 10-100 mm. This value is called "rough" texture
- \* RMS of texture profile, encompassing the texture wavelength range 100-500 mm. This value is called "mega" texture

For all values, the statistical distribution of RMS in mm is presented along with an overall RMS value for the road section. Measurements are made in both the right wheel track and between the wheel tracks.

Measurements are made contactless, utilizing electro-optical sensors (laser radiators and linear silicon detectors) manufactured by Selcom AB in Sweden.

Texture values according to this are available for essentially the entire Swedish national road network. Surveys are updated annually, using 6 vehicles. There are no formal requirements regarding texture on Swedish roads.

### **Monitoring surface texture in research applications**

For more limited purposes, the following methods may be utilized:

1. In very few cases, the conventional volumetrical method of measuring texture depth may be employed, i.e. the "sand-patch" method or its equivalent using glass spheres rather than sand.
2. In a few cases, the TRL Mini Texture Meter may be employed. It just gives a texture depth value meant to replace texture depth measured according to the sand patch method.
3. In laboratory investigations regarding samples of road surfaces, the VTI Stationary



Laser Profilometer may be employed. This has been available since 1979 and basically gives the same type of measurement as No. 4 below, except that it is limited to measurements over max. 1.2 m length using a tripod to position the device over a laboratory sample. It can also be used on actual road surfaces, in field measurements, however then being more impractical than No. 4 below.

4. Test sections of road surfaces are quite frequently tested making use of the VTI Mobile Laser Profilometer. This device is described in the following chapter.

### **Information about the VTI Mobile Laser Profilometer**

The VTI Mobile Laser Profilometer consists of an electro-optical system, mounted in a road vehicle, which measures the vertical distance between the vehicle body and a small light spot on the road surface, a real-time third-octave band spectrum analyzer, a PC for data processing and presentation of results, as well as a Volvo 245 car in which the equipment is mounted. See further the figures on the next page.

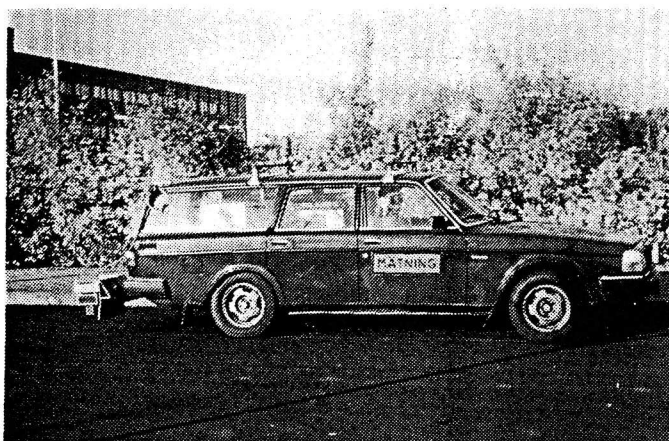
The non-contact measurement is made by making use of an infrared laser beam which creates a light spot on the road surface. An optical lens system projects this light spot onto a certain position on a linear silicon sensor which gives an output current with a certain relation to the position of the light spot on the sensor, and thus to the vertical position of the light spot on the road. When the vehicle moves at constant speed, usually 36 km/h (10 m/s), this light spot moves over the surface profile, thus giving a profile curve which describes the texture of the surface.

After regulation of the signal in order to have an optimum light spot intensity and linearization of the output signal, the output is fed to a frequency analyzer which calculates on-line the texture spectrum of the profile signal. At the same time, the profile curve is used for calculation of the average area under a line which touches the peaks of the surface. This area has a very close relationship with the volume of the sand which fills the surface voids when the so-called sand-patch method is used to measure the texture depth. Based on the texture spectrum, some overall texture descriptors, which have been found to have interesting relationships with road surface characteristics and vehicle performance, are calculated.

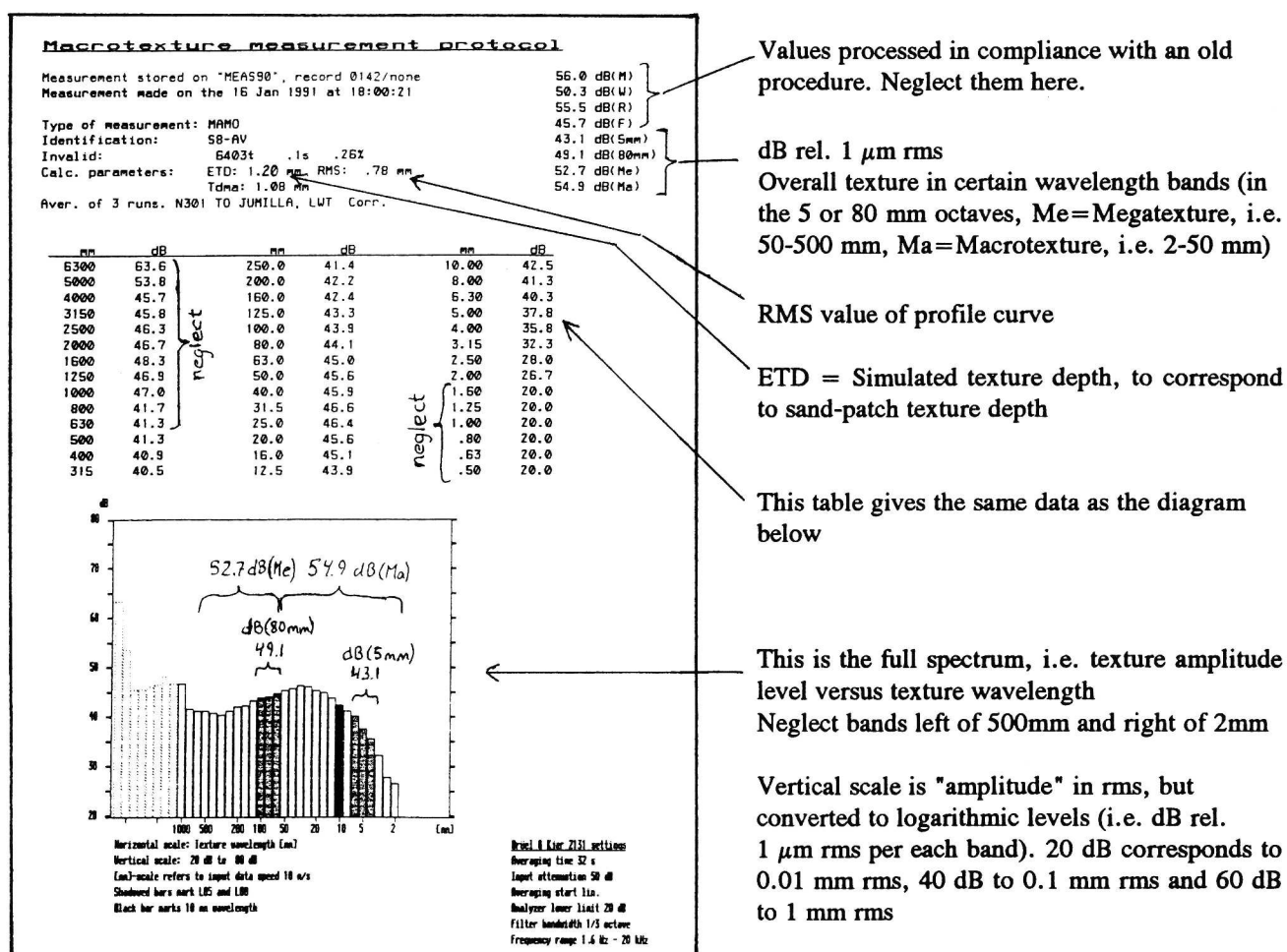
Output data is stored on 3.5" diskettes. Results may be printed immediately after completion of measurements or at a later time.

The profilometer works on all paved roads in dry condition. Measurements shall not be made on wet surfaces. A humid surface (dark due to humidity) reduces the performance of the system, as does a completely new bituminous surface when the surface is still "glossy".

The measuring range (vertically) is max. 63 mm from top to bottom of texture. A texture wavelength range of 2-500 mm is covered. This includes "megatexture" (50-500 mm) and the important range of "macrotexture" (2-50 mm) as these are defined by PIARC. Calibration is made by means of a rotating disc with known triangular profile and texture spectrum.



**Fig. 1** The complete system



**Fig. 2** Typical printout of texture spectrum (diagram and corresponding table) as well as of single overall values of texture depth, etc. In addition, a profile curve can be printed.

### **Comparison of texture measuring devices**

In the International Experiment to Compare and Harmonize Friction and Texture Measuring Devices, conducted in 1992 in Belgium and Spain by a committee under PIARC TC1 (Surface Characteristics), the VTI Mobile Laser Profilometer participated. The results showed that the device was able to predict the texture depth according to the volumetric method (corresponding to sand-patch) with very high accuracy. It is thus possible to replace measurements of the latter type with much more practical, economical and safe measurements by the laser profilometer.

Another result was that the "ETD" value, meant to replace the sand-patch-measured texture depth, had very good correlation with the speed coefficient in friction-speed relations. It means that it will be possible in the future to reduce the number of friction measurements. Macrotexture measurements, supplementing friction measurements, will eliminate the need for tests at multiple speeds.

The laser profilometer also had very good correlation with most of the other participating texture measuring devices.

### **Surveys of noise, as related to road surface properties**

In all the Nordic countries, it is common practice to use a prediction model for road traffic noise which is the same in all these countries. Since this model has been found to give satisfactory relations with actual measurements, it is usually preferred instead of direct measurements. If measurements are made, then there is no general and closely specified method, but measurements are made under the circumstances and at the location of interest.

The mentioned prediction model does not yet take the road surface into account. However, VTI has developed a correction scheme for road surface which may be employed in the Nordic model in the future (possibly on a voluntary basis).

There are no requirements as regards the noise properties of road surfaces in Sweden. However, it is not uncommon among road authorities to consider the noise properties to the best of their knowledge, along with other properties, when surface types are selected in certain noise-sensitive areas.

### **Monitoring noise emission in research applications**

For more limited purposes, the following methods may be utilized, as regards comparison of different road surfaces from the noise point of view:

1. ***The coast-by method.*** Special test vehicle(s) equipped with test tyres are coasted by a road-side-mounted microphone (7.5 m from the centre of the tested road lane) and the maximum noise level in the microphone is recorded. The latter usually includes A-weighted overall level as well as third-octave band levels (spectrum). The procedure is repeated on different road surfaces and results compared.
2. ***The trailer method.*** In this method, a special trailer towed by a car is used. The trailer

has a test tyre close to which one or two microphones are located. The tyre and the microphones are enclosed within an enclosure which protects from outside noise and wind. A-weighted overall levels as well as third-octave band levels (spectrum) are always recorded.

This method has been used extensively at VTI for 10 years now, using 5 very different car tyres as test tyres in order to have a road surface comparison based on a variety of tyres rather than just one type. However, all such measurements have been made utilizing a trailer owned by the Technical University of Gdansk, with which VTI has regular co-operation.

The method is not so suitable for classifying road surfaces of the drainage type. It also has the shortcoming that it classifies surfaces only with respect to car tyre noise.

3. ***The statistical pass-by method.*** This method is presently subject to international standardization (see below). A microphone is located at the road-side, usually at 10 m from the centre of the road or 7.5 m from the centre of the nearest road lane, and the noise of passing individual vehicles is recorded. In addition, the speeds of each vehicle and the type of vehicle are recorded. Only vehicles in the normal traffic passing without disturbance from other vehicles are used in the experiment. Statistical treatment of these data will assign a noise level typical of the surface type, as related to the type of vehicle and the average speed.

### **International standardization**

Sweden takes an active part in international standardization both as regards road texture and noise measuring methods. This concerns mainly:

- \* ISO/TC 43/SC 1/WG 39: A working group under the International Organization for Standardization with the task to develop methods for measuring texture based on profiling methods (essentially mobile and contactless).
- \* ISO/TC 43/SC 1/WG 33: A working group under the International Organization for Standardization with the task to develop a method for classifying road surfaces with respect to traffic noise. It will propose the use of the Statistical Pass-by Method.

Both groups have June 1994 as a target for producing a first committee draft and both are chaired from Sweden.

## METHODS AND EQUIPMENT FOR MONITORING SKID RESISTANCE

by Kent Gustafson, Swedish Road and Transport Research Institute

The method of measuring the skid resistance of roadway surfaces at constant slip was developed at the National Road Research Institute in Sweden, now Swedish Road and Transport Research Institute (VTI), more than 50 years ago. The test vehicles which are in use in Sweden today and measures according to this principle are *Skiddometer BV11*, *Skiddometer BV12* and *SAAB Friction Tester*.

*BV 11* is a small trailer towed by an ordinary car. It is equipped with three wheels of equal size, dimension 4.00-8, connected by means of roller chains and sprocket wheels. The gear ratio forces the centre wheel to rotate with a controlled slip ratio of about 17 % relative to the surface when the trailer is towed. In effect, one might say that the measuring wheel (centre wheel) is braked in a carefully controlled manner. The load on the measuring wheel is 1000 N and maximum speed is 150 km/h. The measurement is controlled and data recorded by a PC computer and normally average and standard deviation of the coefficient of friction is given. *BV 11* is used both on airfield runways and roadways. The difference between the methods is type of tyre, water film thickness and speed. *BV 11* has a self watering system, a pump. Speed governed water pump delivers a waterfilm of 0.3-1.0 mm theoretical thickness. The water tank is installed in the vehicle towing the *BV 11* or in a specially designed trailer which is towed astride of the *BV 11*. For runway purposes a special tyre is used, the waterfilm is usually 1.0 mm and test speed normally 65, 95 or/and 130 km/h. 95 km/h is recommended. For roadway purposes another tyre (tread) is used, water film thickness 0.5 mm and speed 70 km/h.

*SAAB Friction Tester* was developed for use on airfields but is has later on come to use also on roadways. The vehicle is based on a SAAB 900 and is basically the same as the *BV 11*. The measuring wheel is mounted behind the rear axle of the front-wheel car and is operated with a constant slip by the rear wheels. The measuring wheel is of the same size as on the *BV 11* but the slip ratio is said to be 15 %. Maximum speed is 165 km/h and the vertical load on the measuring wheel is 1400 N. In the back of the vehicle there is a water tank of 400 litres and the water-film thickness can be varied normally between 0.5 and 1.0 mm. The latter for runways and the other for roadways. Test speed and tyres is the same as with *BV 11*. For runways normally a high-pressure ribbed tyre "AERO" is used. The coefficient of friction is by means of a PC computer given graphically and as average over sections.

*BV 12* is developed by VTI and manufactured on a truck chassis. The test wheel is mounted between the axles and on the left side. The test wheel is connected to the driving wheels of the truck by means of a couple of transmission units. As the truck moves forward, the test wheel is forced to operate at a reduced peripheral speed and thus develops a braking force which is measured as a torque on the test wheel shaft. The slip ratio can be varied between -3 % (driving) and 53 %, and the wheel can also be locked, 100 % slip. Maximum speed is 100 km/h. The measuring wheel can use rims of 13-15" and tyre widths up to 185 mm. Test wheel load can be 1200 - 1500 N. *BV 12* has a self watering system consisting of a water tank of 2.3 m<sup>3</sup>, water pump and nozzle giving 0.6-1.0 mm film thickness theoretical.

BV 11 and SAAB FT is used operationally on runways and roadways while BV 12 is used mostly for research purposes and for special investigations. For roadways The Swedish National Road Administration (SNRA) a few years ago specified a minimum skid resistance for new wearing courses. The skid resistance monitored with BV11 or SAAB FT at 70 km/h and at 0.5 mm water film thickness should not be lower than 0.4.

In the new Standard Specifications for Road Construction (BYA) from SNRA this value, the average coefficient of friction in an arbitrary 20 m section, should be  $\geq 0.5$ . For shorter sections than 20 m a minimum skid resistance of 0.45, measured with the British Pendulum or a Swedish Portable Friction Tester (PFT), is required. The latter instrument has been developed by VTI and is a lightweight, portable and hand pushed instrument for the continuous measurement of friction at walking speed. It is designed in accordance with the skiddometer principle and the slip ratio can be varied between 0-90 %. The instrument is a small cart with two wheels and a third measuring wheel. Maximum speed is 7 km/h. Because of the small tyre surface area and the low speed the PFT has some limitations compared to BV11 and SAAB FT.



## **THE LASER RST HYBRID SYSTEM, A PAVEMENT IMAGE ACQUISITION AND ANALYSIS SYSTEM.**

by Leif Sjögren, Swedish Road and Transport Research Institute.

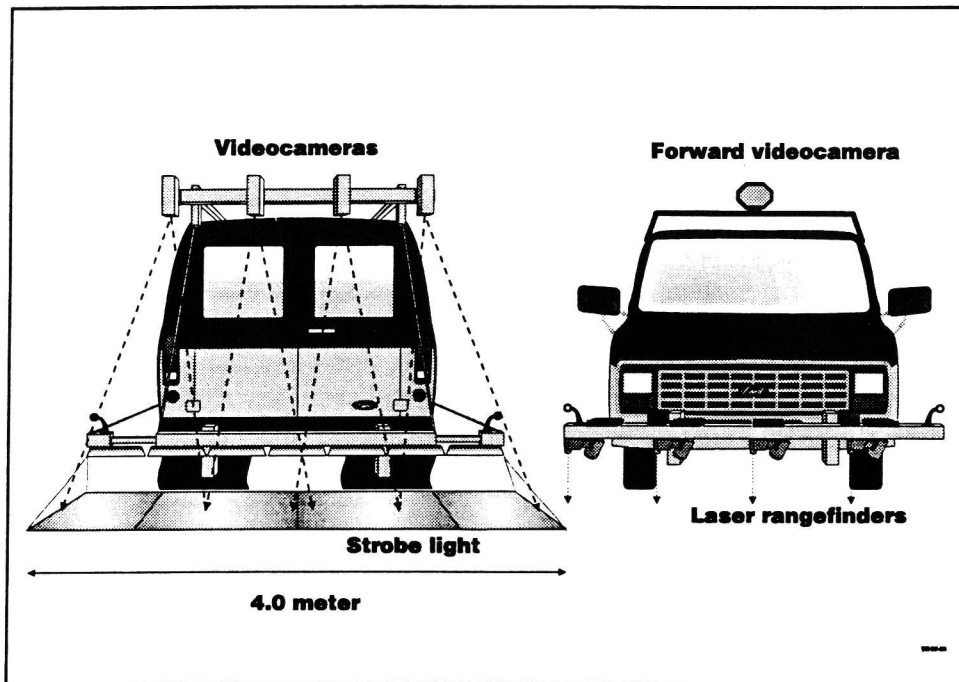
### **Introduction**

A new technique for the detection and classification of road surface cracks, has been developed. This technique involves a combination of measuring laser-range finders (LRF) and video cameras, utilizing real-time pattern recognition. The system is called the HYBRID system. The system has been developed by OPQ Systems (developer of electronics and hard- and software in the Laser RST) together with the Swedish Road and Transport Research Institute, VTI.

The pavement image acquisition and analysis system is developed as a modular add-on option to current and future Laser RST measurement vehicles.

### **Video cameras**

The HYBRID system use four video cameras (PAL 1/10 000 sec shutter speed), feeding video images of four 1-m pavement zones into a bank of four separate S-VHS recorders. The four zones correspond to the pavement edges, right- left wheel path and centreline zone. The video cameras are mounted in the rear of the measuring van and perpendicular to the surface, see picture. The two outer video cameras are special designed so although they are mounted within the allowed 2.5 meter vehicle width the mounting still ensure the image-coverage of four meter surface. The use of S-VHS recorders is required to maintain resolution and allow detection of smaller crack sizes. The vehicle speed is also encoded into a special signal (like a 4-scanline bar code) and mixed with the camera video before recording. Subsequent processing of this signal allows speed independence and synchronization across the S-VHS recorders.



*Picture 1. The Laser RST Hybrid System = Laser Range Finders (LRFs) and Video-cameras.*

To be able to do data acquisition in daylight (sun and shadow) a lightning system has been developed. This consists of up to nine strobe lights synchronized to the high speed shuttered cameras, see picture. Special optical filters are used on the video cameras to reduce the influence of shadows even further.

### **Forward video camera**

As a help for the analysis of the videotapes a fifth video camera are mounted to record forward road environment, see picture. This is recorded on a fifth S-VHS recorder that also is synchronized with the distance signal. If desired information of the measures from the Laser RST can be incorporated in the picture.

### **Workstation for analysis**

The video tapes are returned to the road administration office for analysis on a special designed workstation. The tapes are played on a bank of four S-VHS players, which feed the video into the four parallel processing channels of the HYBRID analyzer. Each channel applies the speed-compensation algorithms, noise reduction, and filtering adaptive thresholding (to control for uneven lighting and varying pavement types), feature extraction, and feature measurement. The outputs (measured features) of the four channels are then combined into a single composite result for the full-lane width in the pattern recognition module. This module makes the decision about the type of cracking present, its severity and extent, and accumulates this data over the road sections. The output is a set of statistics about the type, severity, and extent of cracking present in each section. In the next step of the analyse this output are combined with information from the LRFs. The LRFs give data about the cracks width and depth and the video image describes the pattern of the cracks. This explain why the system is called the Laser RST Hybrid system.

The analysis is done using hardware ( special-purpose image processing boards ) to bring the processing speed up to real-time (90 km / h). The system is relatively easy to retrofit to existing Laser RST systems. Of course, this extra processing power that are applied to the analysis of video-taped data, could be used in a solution with real-time analysis of the video data directly from the cameras in the Laser RST vehicle, without the bulky, mechanical, and costly intermediate videotape storage step. The pavement distress data would be analyzed "on-the-fly," with the resultant statistics printed out and stored on disk, the same as is currently done with rutting texture, etc., data from the LRFs.

## **FILL AND MILL, A METHOD OF CALCULATING ADJUSTMENT VOLUMES WITH THE LASER RST**

by Leif Sjögren, Swedish Road and Transport Research Institute.

### **Introduction**

For roads with poor cross fall, a combination of milling and filling of the road surface is often needed to achieve the desired cross fall. Until now, the amount of adjustment required has been determined by manually measuring the road surface with a rod and level and then calculating the volume adjustment, a very time-consuming and expensive process. Another disadvantage of this method is that it is nearly impossible to compare adjustment volumes for different cross falls because of the complexity of the calculations. Therefore, there has been a need to find a faster and more cost-efficient way of determining adjustment volumes.

A group comprised of members from The Swedish Road and Transport Research Institute (VTI) and The Swedish National Road Administration (VV) has been working with this problem since 1990. After comparing the rod-and-level method with the Laser RST's measuring capabilities, they decided that it was possible to use the Laser RST to do the necessary measurements of the road without altering the Laser RST's normal measuring procedure in terms of speed, accuracy, what is required of the Laser RST personnel, and traffic-user and traffic-safety conditions. To calculate the adjustment volumes using data obtained by the Laser RST, a PC-compatible program was developed. The program, called Fill and Mill is able to (1) determine the volume adjustments needed to restore the cross fall to an acceptable level, and (2) present the results in a graphic format acceptable to the maintenance workers.

This new method, can be divided into four components:

- Data collection (Laser RST)
- Data input into a data bank (off-line)
- Calculation of volume adjustments (Fill and Mill program)
- Presentation of the results (Fill and Mill program)

### **Data Collection**

Of the variables measured by the Laser RST, those that are used to determine volume adjustments are cross profile, unevenness, cross fall, curvature, distance, and distance from a reference point to the centreline. Of these, the latter two need special processing.

- Distance.  
Distance is important because each object is measured several times with some lateral displacement between the measurements. A section is measured two to three times for each traffic lane and once for each shoulder. The data obtained from all of these measurements is combined into one file which then describes the road geometry. The amount of information obtained with this method (using the Laser RST's 11 laser range finders over a 20-km section of road) is:

(2 lanes) x (3 separate measurements of the section) x (11 laser range finders)  
x (200,000 decimetre sections) = 13,200,000 points

This should be compared with:

The rod-and-level method of determining adjustment volumes is based on:

(5 lines) x (1000 20-meter sections) = 25,000 points, with this method

To establish a precise and common starting point between the measurement passes over the same section of road, a photocell is used when the data collection is begun. At the starting point, there is a reflector. The ending point, always a multiple of 20 meters, then becomes the starting point for measuring in the other direction.

- **Distance from a Reference Point to the Centreline.**

A video recording of the road is made at the same time the measurements are taken. A video camera is mounted on the Laser RST, and its position is not changed between the measuring passes over the same section of road. After the measurements have been completed, the distance from the camera to the road marking along the edge of the pavement or to the centreline is determined; the distance from the camera to the centreline from the different measuring passes can then be found. This assumes, of course, that the video system records a distance measurement that is calibrated with the Laser RST. After the measurements have been taken, the data relating to the distance from a reference point to the centreline must be combined with the data from the Laser RST. Normally, at least 3 measurements of the same section of the road (11 meters in width) in each direction are required (two of the traffic lanes and one of the shoulder). The measurement passes over the road section overlap.

Other uses of the video film's distance information are that (1) the pavement edge can be identified and a measurement from the reference point to the edge determined and (2) special occurrences such as bus stops and turn-offs can be identified correctly and stored in an information file. Lastly, it is planned to store still video pictures for every 20 meters in the computer so that these can be viewed when desired during the maintenance planning phase with the (Fill and Mill) program.

### **Data Input into a Data bank**

In addition to the above-mentioned adaptation of the data related to measuring the distance from a reference point to the centreline (which complements the data collected through the normal measuring procedure), other relevant Laser RST data is adapted, transformed, and stored in a data bank. This data bank contains the information that forms the basis for determining the adjustment volumes that are needed. The adaptation of the data consists of different steps that refine the original data quantity (the Laser RST's mean files) so that the data can be used in the Fill and Mill program.

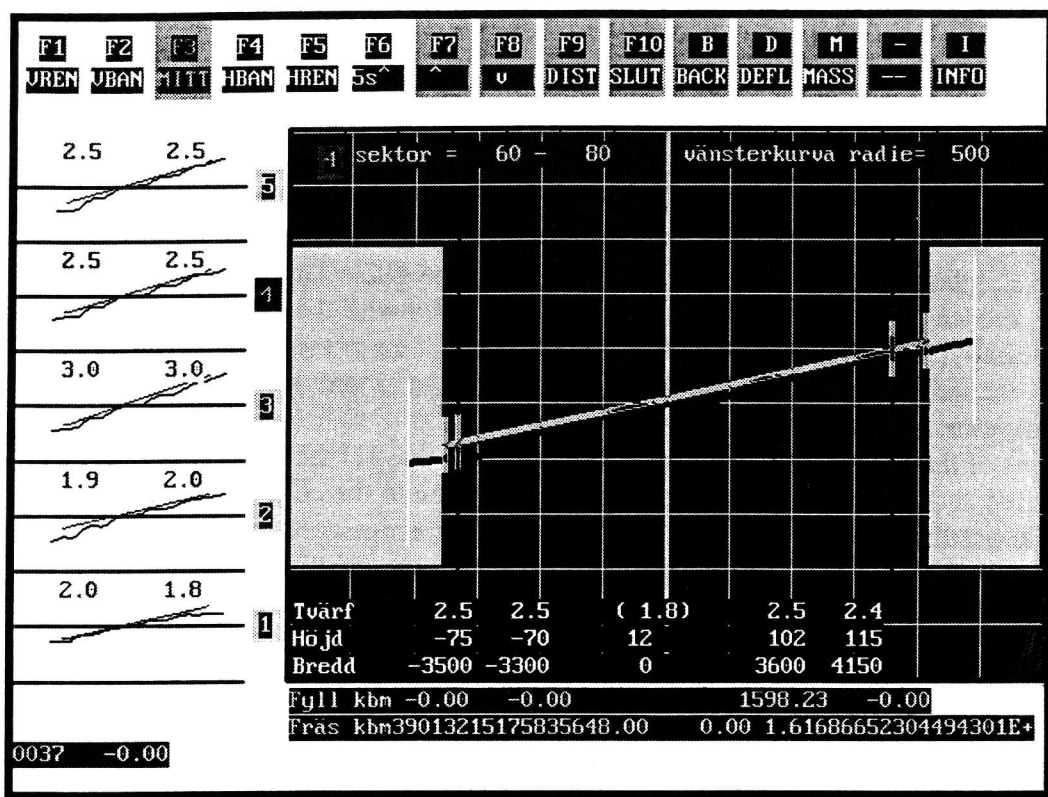
From the data related to unevenness, curvature, and cross fall, the x, y, and z co-ordinates for the road's actual centreline is calculated. Separate profiles from the different measuring passes over the same section of road (values from the Laser RST's 11 laser cameras) are integrated to produce a cross profile of the road. The profile's height variation is calculated relative to the road's centreline.

### **Calculation of Volume Adjustments: The Fill and Mill Program**

The Fill and Mill program is capable of handling data from the Laser RST, as described above.

The program has been developed into a realistic tool for maintenance planning in the PC environment. The program's design was guided exclusively by the user's needs, goals, and ideas.

The Fill and Mill program uses computer graphics and a data bank to determine adjustment volumes, see figure 1. The program creates a data file that contains information on desired cross fall, new longitudinal profile, road width, and adjustment volumes. This information is stored for every 20-meter section of road. Updating can be done as often as desired. Changes that concern a certain section but also affect adjacent sections (e.g., changes in the longitudinal profile) automatically update the data file.



Picture 1. A view of the Fill and Mill software worktable.

## Presentation of the Results

Presentation of the information is based on the Fill and Mill program's data bank and planning files. Data can be presented graphically on a PC screen or printed out on a dot matrix or laser printer. Among the kinds of information that can be presented graphically on screen or printed together with data on the different variables are (Figure 2):

- Adjustment volume contour maps
- Adjustment volumes
- Height of the new traffic lanes relative to the existing road or relative to a horizontal line through the existing road's centreline
- Existing and desired cross falls, separate for traffic lanes and the shoulders



## Summary

Although this new method is not fully developed yet, it has strong potential in maintenance planning and should provide a much faster and more cost-efficient way of determining adjustment volumes compared to the manual rod-and-level method. It is a safe and fast method. Measurement can be done in normal traffic and there are no need to close the road. The method gives a high precision estimate of the adjustment volumes thanks to the high amount of measuring points. It is easy to present more then one suggestion because of the user-friendly interactive software, Fill an Mill.

## **1B: Structural characteristics**

### **LOAD BEARING CAPACITY**

by Clas-Göran Rydén, Swedish National Road Administration

#### **Methods for Determination of Bearing Capacity**

##### *Bearing Capacity of Bridges*

Bearing capacity of bridge structures are generally determined by means of design calculations prior to construction. However, prescribed design values for traffic load on bridges are increased from time to time, due to the increasing trend in maximum vehicle weight. This leads to a considerable number of existing bridges being designed with traffic load assumptions which have suddenly become obsolete or inadequate. This situation is taken care of by revised or renewed design calculations for such bridges. This procedure will identify any load carrying deficiency within the structure being "re-designed". Maintaining this procedure, it is possible to keep an up-to-date load carrying classification of the entire bridge stock.

Current development work will lead to future possibilities of characterising structural properties (such as load carrying capacity) by means of dynamic measurement methods, coupled with modal analysis.

##### *Bearing Capacity of Roads*

The bearing capacity of road structures are not calculated. This is due to the inability to correctly determine the mechanical properties of the materials in an existing road structure. Without the necessary material data, meaningful bearing capacity calculations cannot be carried out.

A considerable amount of FWD measurements (Falling Weight Deflectometer) is also carried out every year. The principal aim of this is to select potential problem areas within a given road network. Theoretically, FWD data can also be used for determination of the load carrying capacity of a road structure. However, the lack of *one* generally accepted FWD-based design model for road structures (there are several "competing" design models) effectively prevents full-scale calculation of consistent bearing capacity data for our road network.

Current research is development of fast deflection measurements methods, and refinement of numerical methods for description of structural behaviour of road materials.

*Bearing Capacity Classification of the Road Network*

Based on what is described above, it is self-evident that current bearing capacity classification of the road network is based on load carrying classification of the bridges alone.

Three principal classes exist, with allowed vehicle weights roughly as follows:

- BK1: Maximum 60 ton vehicle weight at 24 m length  
Maximum 11,5 ton static single axle force  
Maximum 19 ton static twin axle force
- BK2: Maximum 51,4 ton vehicle weight at 24 m length  
Maximum 10 ton static single axle force  
Maximum 16 ton static twin axle force
- BK3: Maximum 8 ton static single axle force  
Maximum 12 ton static twin axle force

## **HIGH-SPEED MEASUREMENT OF ROAD DEFLECTION USING THE LASER ROAD DEFLECTION TESTER**

by Georg Magnusson, Swedish Road and Transport Research Institute

The high-speed Laser Road Deflection Tester (Laser RDT) is a new instrument being developed at the Swedish Road and Transport Research Institute. The measurement principle involves the comparison of two transversal profiles measured at the same cross section of the road. One transversal profile is measured in a non-loaded condition while the second profile is measured when the road is heavily loaded. The transversal profiles are measured using profilometers consisting of a number of distance measuring lasers mounted along two beams which are mounted across the measurement vehicle. The non-loaded profile is measured by means of such a transversal profilometer mounted between the axles of a two axle heavy vehicle, behind the deflection basin caused by the lightly loaded front axle and in front of the one caused by the rear axle. The loaded profile is measured by another profilometer of the same sort mounted immediately behind the heavily load rear axle. The difference between the two profiles is the deflection caused by the rear axle of the vehicle.

Tests using an experimental vehicle, not optimised for this type of measurement, have shown good repeatability and good agreement with the Falling Weight Deflectometer. The ability of the Laser RDT to detect the changes in deflection caused by changing the rear axle load and/or measurement speed has also been demonstrated. A research program has been suggested involving the building up of an optimised measurement vehicle as well as the development of a bearing capacity inventory method involving the measurement not only of deflection but also other parameters needed in order to be able to convert deflection to bearing capacity, e g layer thicknesses, temperature and water content.

## **METHODS AND EQUIPMENT FOR MEASURING LAYER THICKNESSES IN ROAD PAVEMENTS**

by Hans G. Johansson, Swedish Road and Transport Research Institute

### **Introduction**

The measurements of layer thicknesses in road pavements are important in assessing the performance and condition of the roads. Generally the layer thickness and the material in the pavement is measured and identified by drilling and sampling followed by laboratory analysis determining the grain size distribution of the material. However, coring or sampling in a road provides only point measurements and the work is dangerous for the operating staff. It is also a destructive technique.

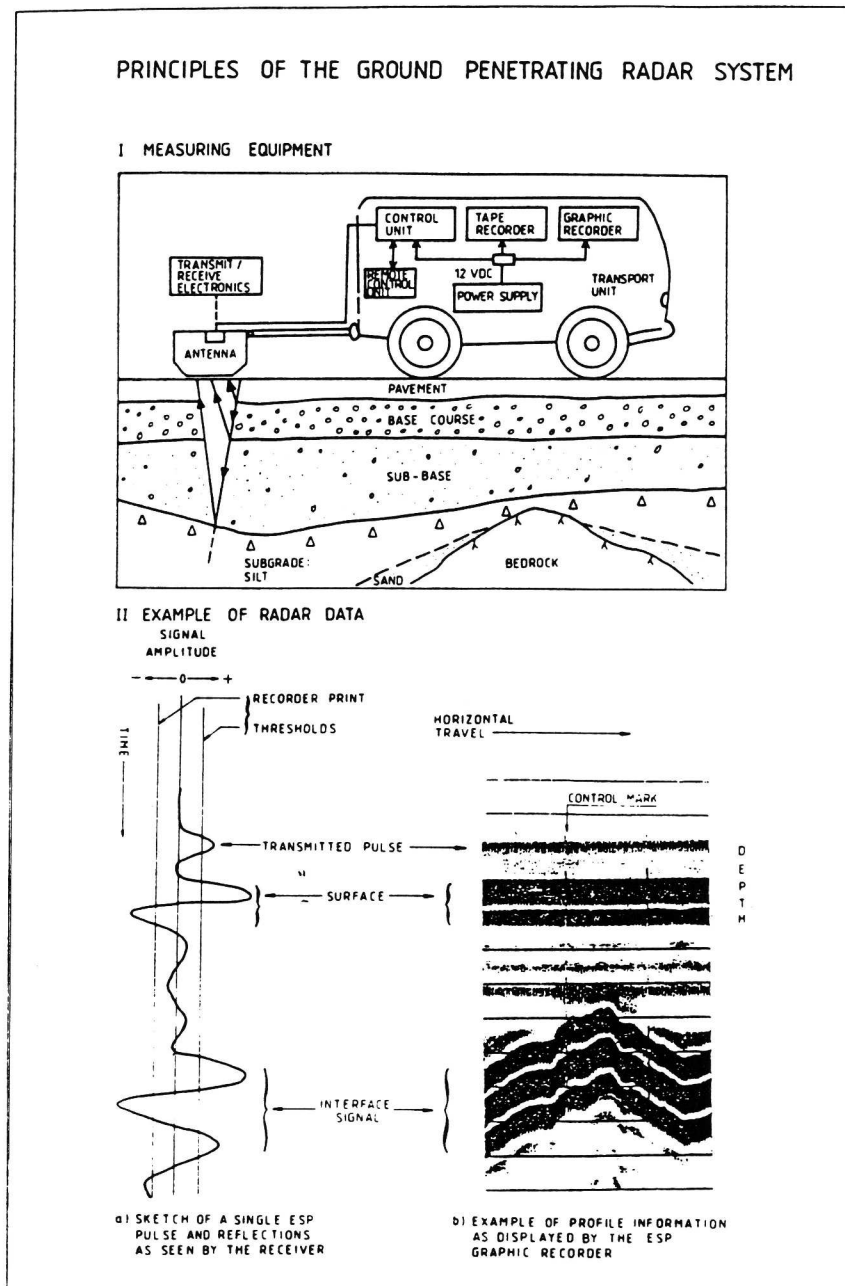
In order to find a non-destructive technique and to allow pavement assessment without serious disruption to traffic flow and damage to the structure ground penetrating radar (GPR) has been in use in Sweden since the mid 1980's. Before the practical application of measurements especially of road pavements the GPR had been used for various purposes e.g. measuring thickness of overburden, reconnaissance of natural resources, calculating volumes of materials, investigations of peat land and identification of boulders in roads.

### **Ground Penetrating Radar (GPR)**

The theoretical principles in GPR operations are relatively simple, based on wavelengths and frequencies of the electromagnetic waves. The radar antenna (seen in Figure 1) transmits an electromagnetic pulse of radio frequency into the pavement. Depending on differing dielectric properties of materials one portion of the signals is transmitted through the electric interface between the materials while the rest of the signals is reflected at the interface in other directions. The time elapsed between the transmission and the reflection of the waves is recorded. The radar wave form contains a record of the properties and the thicknesses of the pavement layers (Picture 1).

By moving the antenna either by a Van (Picture 1) or by hand the output signals, "scans", are plotted on the recorder producing a continuous profile of the electric interfaces in the subsurface. The velocity of the radar waves is a function of the dielectric constants of the material. It is therefore recommended to identify the materials by drilling and sampling in some reference points. Such calibrating bore-holes also improves the interpretation of the depths of different layers along a survey profile.

The depth of radar penetration depends on the wave frequency transmitted by the antenna. High frequency antennae, 500 MHz to 2.5 GHz, permit resolution of thin layers. The highest frequencies of antennae are therefore recommended for determination of the thicknesses of bitumen layers in a road. Lower frequencies penetrates deeper into the subsurface but reduces the resolution capability.



Picture1. The principles of ground penetrating radar sounding (1).

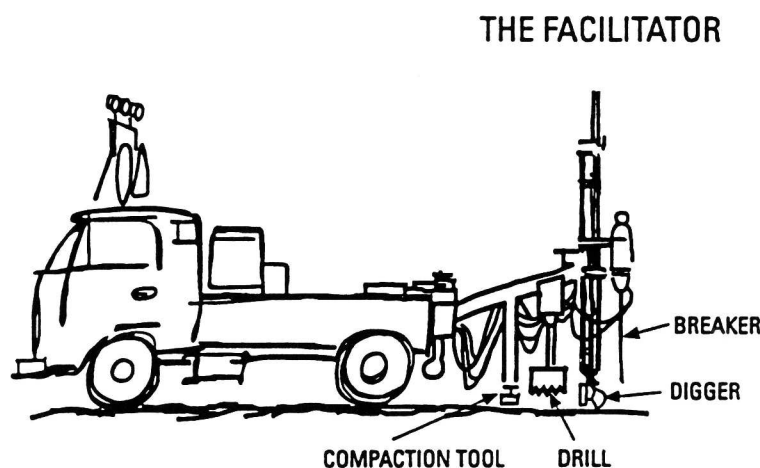
The use of GPR for determination of thickness of various layers in roads and highways has increased during the last years. By developing the process of data from field investigations the accuracy of interpretation of materials, structures and layer thicknesses has been higher. It has been shown in the SHRP that using only GPR without calibration bore-holes the accuracy of predicting various asphalt thicknesses, 25 -230 mm, is within -8 mm. By drilling only one core per site the accuracy improved to - 3 mm. For base thicknesses (100 - 300 mm) with one calibration bore-hole the accuracy is 25 mm. It is always difficult to interpret transition zones in the unbound pavement material.



By using a Van for transportation the GPR-measurements can be performed in quite high speed. Up to 65 km/h in survey speed is not impossible. When measuring cross-sections of a road a hand-moving antenna connected to the control unit and the recorder/printer can be used.

### **The Facilitator**

Even though GPR has been successfully used to identify many problems associated with road structures coring, drilling, digging and sampling in the pavement and the subgrade is needed. These methods increase the accuracy and the quality of an investigation. In order to identify the thicknesses and the mixture of asphalt layers coring is generally used. Since the mid 1980's the Swedish National Road Administration has developed methods and techniques to check the depth of pavement layers and to take samples for laboratory analysis. The development has resulted in the Facilitator ( Picture 2).



*Picture 2 The Facilitator fitted to a small lorry.*

The Facilitator has been designed and constructed taken into consideration the operating staff and their working place. The whole device unit is based on the cassette principle and it is placed at the backside of a small lorry.

When drilling, the control panel can be turned out, placed and connected to the hydraulic system of the lorry. The drill is fitted and a drill bit with various diameters, 35 - 500 mm, can be selected. After drilling through the asphalt layers the drill bit is removed from the hole and the bituminous material is removed and sampled for further analysis.

The breaker is carefully used to release the material in the base. Sampling by hand of the material is recommended. The interfaces between the asphalt layers, the base and the subbase can be identified and measured.

The unique shovel tool can move through the different layers down to a maximum depth of 1,2 m. The diameter of this tool is 350 mm and depending on the subsequent analysis the quantity of the dug samples can be selected. A rough estimation of the composition of the material below 1,2 m can be done by attaching a screw to the drilling unit.

After finishing the drilling, breaking and sampling, the bore-hole is filled in correct way. The refilled material is compacted with a tool attached to the same drill rig used for the breaker. The surface of the road is also adjusted by the compaction tool.

**Reference**

1. GROUND PENETRATING RADAR. Geophysical Research Methods.-- The Finnish Geotechnical Society. The Finnish Building Centre Ltd. 1992.

## TRAFFIC LOADS

by Mats Lundström, Swedish National Road Administration

### Principles for weight measuring

To accurately calculate traffic load on a road surface you have to measure the weight of the vehicles using the road. There are two main methods for this.

The first method is to stop vehicles and measure their weight on a scale. This gives a very accurate static vehicle weight, but the method has several other disadvantages and is mainly used for law enforcement. First, it is very costly as it is time consuming and needs several people at the site. Second, you can only weigh a small sample of the traffic which tends to bias the result unless the measurement is spread over a long time.

The second method is to weigh all vehicles at full speed, using Weighing-In-Motion (WIM) equipment. The accuracy of measurement is significantly lower but in all other respects this method is superior to static weighing as far as pavement management is concerned.

The weighing can be performed with fixed equipment over a longer period of time or as a sample survey system using portable or semi-portable equipment.

WIM scales could roughly be divided into two groups. The first (and oldest) type uses weigh pads with some 30 to 50 centimetres active width. This width means that the whole tyre force will be loading the weighpad at one instant. The calculating algorithms will thus be rather simple. The result from the scale is the dynamic axle load which in turn is dependent on vehicle speed, suspension type and road conditions. The static weight of the vehicles cannot easily be calculated with this method.

The weighing system in the weigh pads are usually load cells or strain gauges. Load cells are considered more accurate, but are more expensive and require a more elaborate foundation in the road due to their larger thickness. With strain gauges in the weigh pad the foundation can be made thinner, some brands can simply be cut into the road surface and secured with expanding bolts, providing the paving is thick enough.

The second (and more modern) type of WIM scales uses narrow strip sensors. As only a small portion of the tyre width will load the sensor at one time, the calculating algorithms will become significantly more elaborate. Vehicle speed is an important factor in the weight calculation. It is therefore convenient to use two or three sensors in each lane with a certain spacing between them, thus obtaining speed measurement. The dynamic weight figures given from the sensors can also be used to calculate the static weight of the vehicle. (prof. D. Cebon, Cambridge).

The strip sensors can be of piezo-electric or capacitive types. They can be secured in slots in the paving with adhesives or bolts for permanent WIM-sites, or attached to the road surface for temporary measurements (sample surveys).

## **WIM - Present situation in Sweden**

Following some earlier tests by the Swedish National Road Administration, SNRA, and the Swedish Road and Transport Research Institute, VTI, the need for information on vehicle weights became evident during the late 1970:s. The SNRA consequently built a test WIM site with equipment from PAT in Germany. In 1983 a WIM program was launched that meant erecting some 40 permanent WIM sites throughout Sweden. Eventually 14 of these sites were built during 1984 and 1985. The equipment differed in some important parts from the original PAT design. The PAT weighpad foundation is secured by bolts in the paving. Swedish paving is considerably thinner than the PAT recommendation, so a poured concrete foundation was constructed. The PAT system at the time consisted of a preamplifier and signal conditioning equipment plus a memory unit on site. Data transfer was by means of a cassette unit where data was recorded on a standard compact cassette tape. The tapes had to be sent to Germany for evaluation and processing. SNRA instead developed their own data processing and storage unit, which via a modem and a telephone line transferred data directly to the SNRA mainframe computer for processing and final storage.

Some problems were found concerning WIM data quality. A lack of knowledge about static weight versus dynamic weight caused a lot of concern about calibration methods. A very large variation of the weight data with temperature was found. Eventually knowledge of dynamic forces got better, but the problem with the temperature dependability was never really solved. (It was probably a combination of temperature movements in the concrete foundation and built-in tension from welding in the steel frame).

Over the years maintenance costs rose rapidly as the foundations corroded from salt used during winter to melt snow. Before the whole system was closed down in 1992 it had though given very useful information on vehicle and axle weights in Sweden.

In 1989 prof. D. Cebon of Cambridge, England, presented his research results on the dynamic tyre forces and their influence on the road. He also designed capacitive WIM-strips to accurately measure tyre forces over a certain length of road. SNRA decided to test the WIM-strips which were then commercially available through Golden River Ltd of Bicester, England. The first WIM-site ever built using this method for other than test purposes was built near Sandoe bridge in the northern part of Sweden. The bridge has a limited bearing capacity and the WIM scales control variable message signs (VMS) that reroute the heaviest vehicles from the bridge. On an island in the middle of the bridge is a third WIM scale located. It controls a Traffipax camera that takes pictures of overweight vehicles which disobey the VMS and illegally crosses the bridge. This system does not function well due mostly to bad ground conditions under the road and due partly to bugs in the camera control software. After reconstruction and repaving of the road, scheduled for 1994 this site will hopefully be in good working order.

The GR WIM system is also used in a couple of places in Sweden for special purposes. They provide data on axle and vehicle weights as a means to calibrate models for bridge construction. Apart from this no regular weight measurement system is in operation in Sweden now.

The WIM-strip is a very promising method for weight measurements. The GR equipment has had some initial problems in both hardware and software, but nothing that could not be corrected. We are not yet ready to start a full scale weight measurement program even though there is a great demand for it. We want to put the system to still more tests and preferably test similar systems from other suppliers as well. A weight measurement system that covers the whole country of Sweden is a very costly affair and we want to be perfectly sure that we use our money in the best way.

## SESSION 2: MAINTENANCE MANAGEMENT

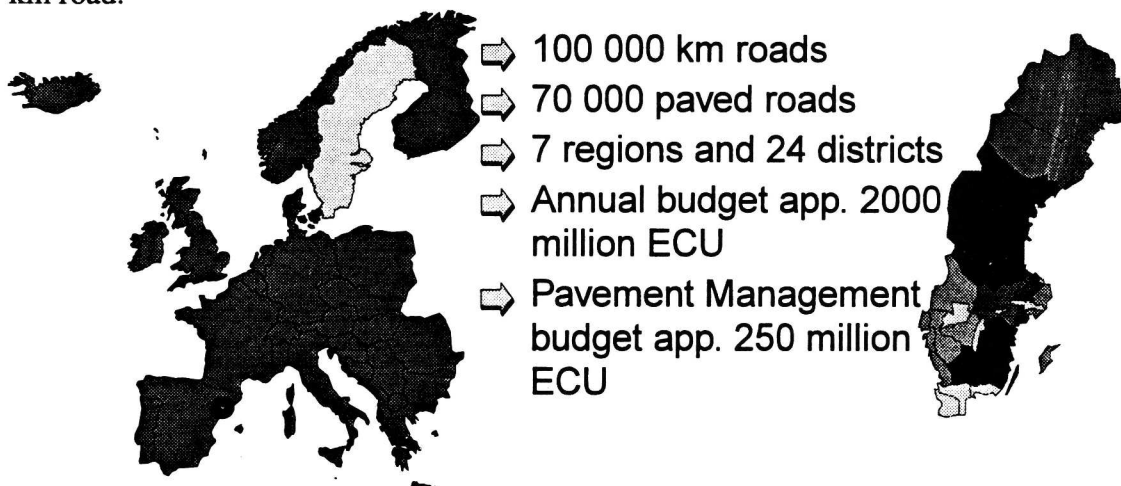
### THE SWEDISH PMS

by Johan Lang, Swedish National Road Administration

#### Background

The development of a Swedish PMS started 1985 with a establishment of a framework of PMS. Due to reorganisation of the SNRA and the establishment of a new EDP-concept throughout the organisation, the development was slow the first two years.

In 1987, the development of the PMS subsystem "PUB" started. PUB is a tool for local pavement engineers to get objective information of the condition of the roads. The system was implemented in the 24 counties 1988 and used as a support in activity programming on 70000 km road.



#### The main pavement problems in Sweden

The main pavement problems in Sweden are:

- Wear of studded tires. This occurs on all roads but is very significant on high volume traffic roads. The interval between application of new wearing coarses can be as short as five years (ADT 10000).
- Rapid deterioration during the spring thaw loss. During this period the water content in the pavement can be very high.



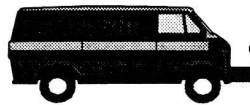
## The PUB-system - Step 1 in a PMS

The PUB system is based on measurements with Laser-RST (rut depth, roughness IRI, cross fall, curvature, hilliness etc.) and information from the Road Data Bank (functional classification, traffic, road width, road length, asphalt layers etc.). Since 1987 a total length of 500 000 km roads have been measured with the Laser-RST. Each individual road section has been measured at least three times.

In the PUB-system is data prepared in basically two databases.

- ✓ Mean values for each 20-m section measured since 1987
- ✓ Segmented in homogeneous sections, based on age, asphalt layers, traffic and road width

### Parameters



- ⇒ Rut Depth; max, left, right
- ⇒ Roughness IRI (International Roughness Index); max, left, right
- ⇒ Cracks
- ⇒ Roughness in different wavelengths; 0-3 m, 3-7 m, 7-13 m, 13-40 m
- ⇒ Crossfall, curvature, hilliness
- ⇒ Texture

The PUB system started as a pavement condition monitoring system with the basic objectives:

- ✓ Get acceptance of measured parameters among users.
- ✓ Get acceptance of used models.
- ✓ Increase user EDP-competence.
- ✓ Change decision methods from engineering judgement to a more analytical approach.
- ✓ Get a platform for a more comprehensive PMS
- ✓ Get a base for model development.

PUB has resulted in:

- ✓ Objective measurements are used and accepted throughout the SNRA
- ✓ The user can use measured data 4-6 weeks after measurements
- ✓ Data interfaces between available databases
- ✓ A user friendly system that fulfil the local engineers needs of today
- ✓ Users are closely involved in further development
- ✓ A good base for further analysis, model development and improvements

Since the first implementation 1988, the system has been developed continuously. The system now includes the following modules:

- ✓ A prioritization model based on established criteria.
- ✓ A short term prediction model
- ✓ An action planning module
- ✓ Network overviews based on interactive selections
- ✓ Project prioritization

- √ Detailed project information
- √ Actual deterioration rate.

PUB is based on large amounts of data. To get user-friendly outputs, one basic consideration is therefore been that output as far as possible should be graphical. The PUB system generates output as bar charts, pie charts, plots, maps and some lists.

Large efforts have been made to assure a good data quality. All measured data are controlled, both during measurement and before it is stored. Therefore, we know that we have consistent condition data that can be used to follow up road performance and in model development.

Large efforts have been made to build up a database that is integrated with other databases within the SNRA. This means that condition data can be used to e.g. correlation studies accidents vs road condition.

The first year PUB after the implementation, the system was used most by the younger engineers. The older engineers had doubts and trusted there own engineering judgement. To introduce a computer based analytical approach to be used by older engineers was a critical factor the first years after the implementation. The attitude and knowledge has changed and today the system is well used. In the beginning we (the main office) argued for further development. Today we have hard to fulfil the users need of further development. We use the user to specify modification and new development.

PUB is intended to be used by local engineers. Parts of the system and the systems database has been used to serve the main office with information.

The PUB system of today is a useful planning tool but lacks some parameters and models that are considered essential. The approach is that new parameters will be added along with development of new measurement methods. New models will be implemented along with analysis of measured data. Fast methods will be used for network measurements and slow more detailed measurements will be used for detailed project analysis. For the SNRA it is of a great concern that a system should contribute to better decisions and therefore a better management. It is of no use to implement inaccurate models based on limited parameters if it does not improve the decision making process. A PMS is a decision support system and not a decision system. The PMS development strategy in the SNRA is considered to be strongly dependent on the quality requirement of the decision support information.

Examples of outputs:

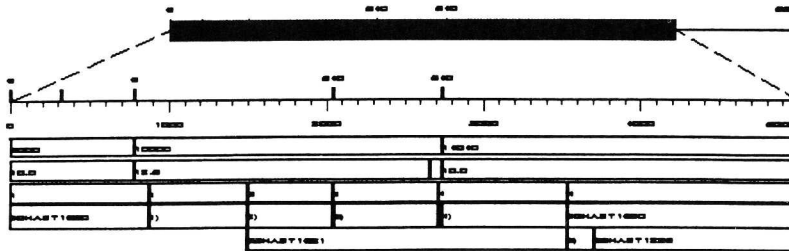
**PUB**

**County of Gothenburg and Bohus**

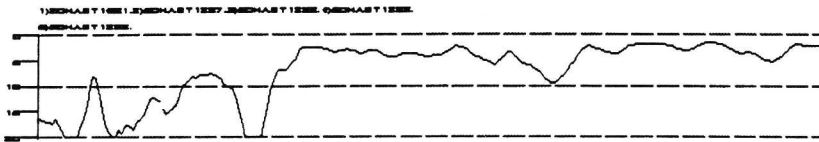
RDB date 920101  
Measured 910827

Väg 40 0-6000  
Bakal 10  
Rikt 1 Sida B

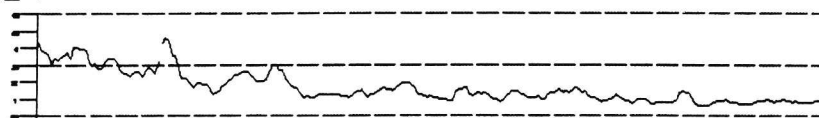
Traffic (ADT)  
Road Width  
Priority  
Layer



Spår djup  
(mm)



Djornhet  
RI (mm/m)

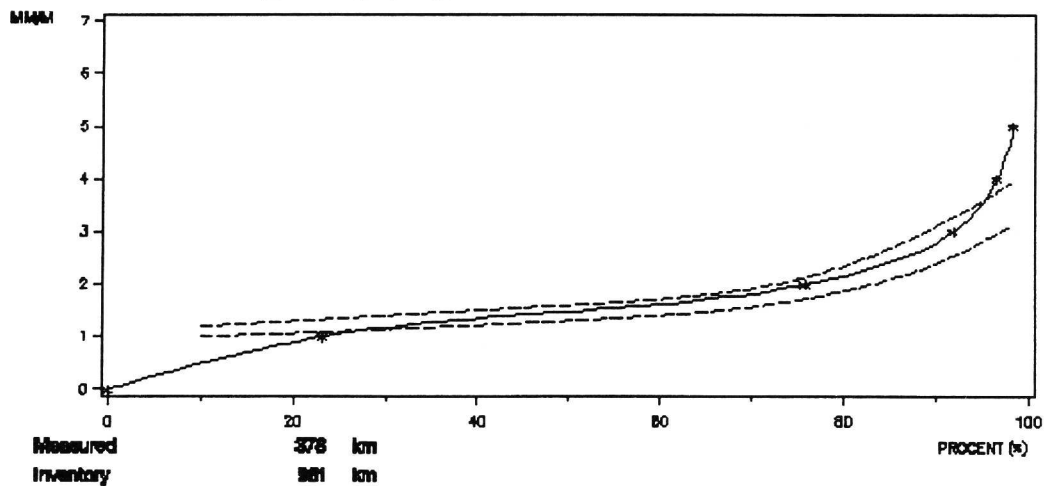


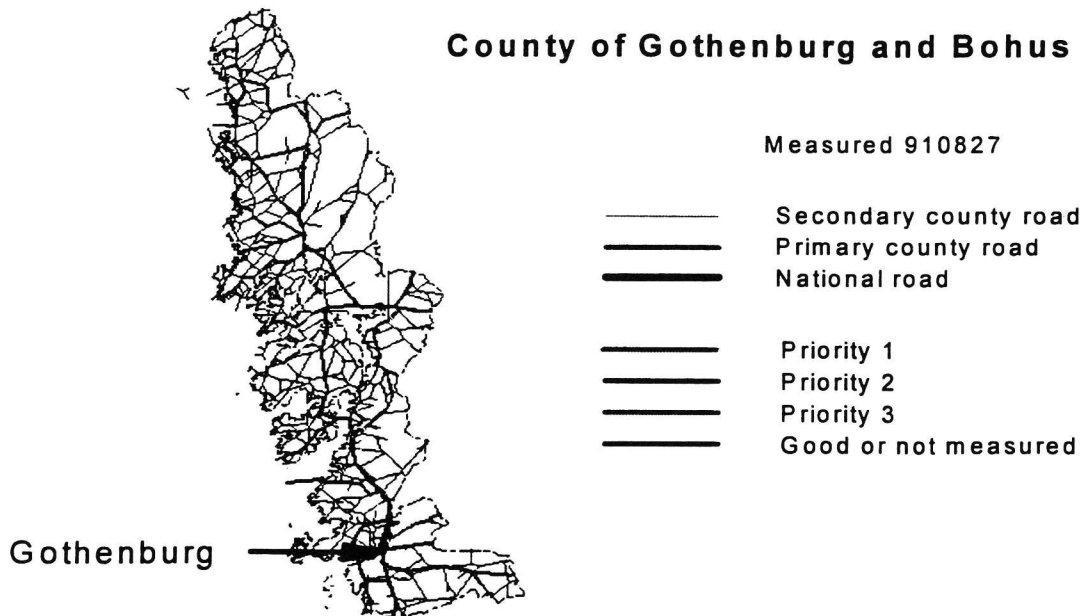
**PUB**

**County of Gothenburg and Bohus**

Road Data Bank 920101  
RST date RV910827

**Roughness (IRI) High Volume Traffic**



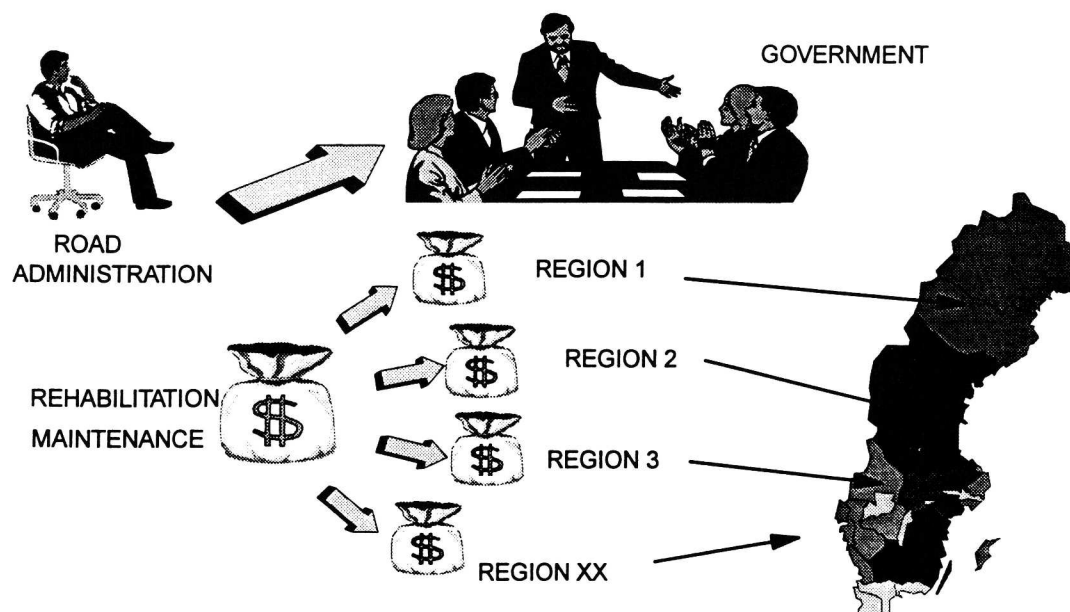


### **The Swedish Pavement Management System**

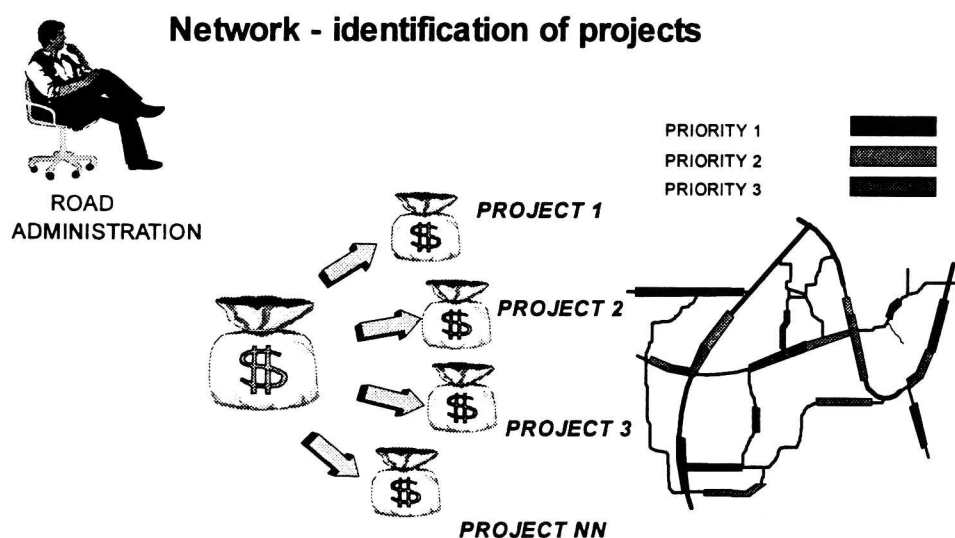
On the basis of the PUB system the system will be further developed and modified during 1993 and 1994 . The system will be divided in two levels:

- ✓ PMS network overview which will provide information to argue for funds and to allocate available funds. This system will be implemented during 1994
- ✓ PMS network - identification and prioritization of projects. This system will be implemented during 1994 and 1995.

## Network level - Overview



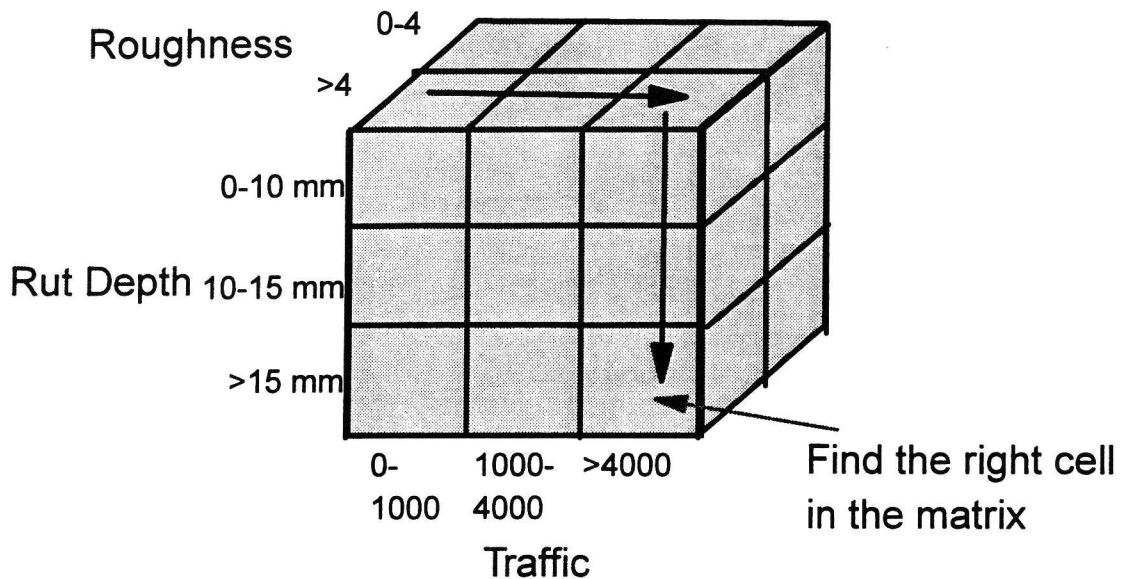
## Network to project level



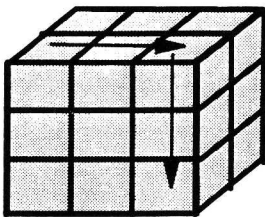
Both levels will consist of the following improved or new modules:

- ✓ Performance prediction model
- ✓ Strategy selection model
- ✓ User costs
- ✓ Cost estimation model
- ✓ Optimization model

## Strategy Selection



## Each cell contains a strategy



### Example

- Rut repair
- Medium thick asphalt layer

Cost and performance after improvement is estimated

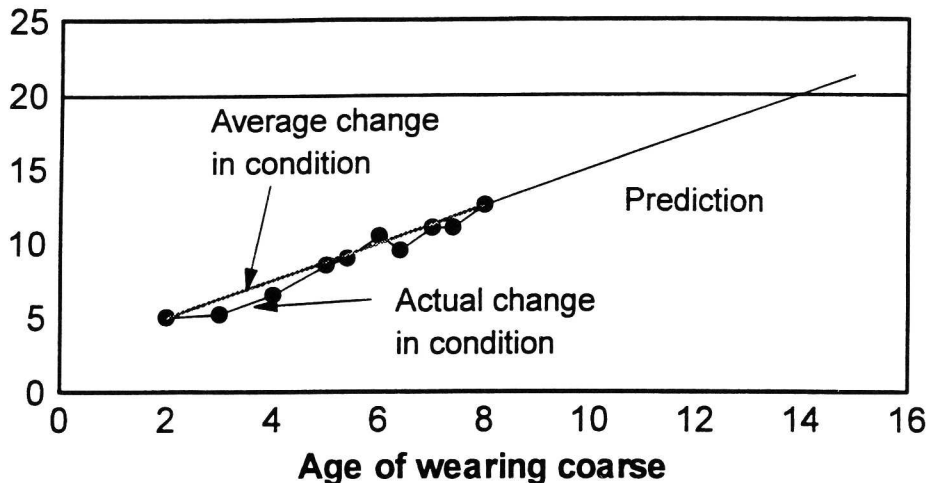
## Change in Rut Depth

Road 27 in county of Älvsborgs

HABT12 85

ADT 7910

Rut Depth in mm



The main difference between the two PMS levels is the detail of information. The network overview level will use aggregated information and statistical models. The network - identification and prioritization will use detailed information and more accurate models.

New modules and modifications in the existing PUB-system will be made based on the SNRA Information Technology strategy. We work hard to get a "Open system" strategy, which means:

- ✓ Updates of technical and economical models in the system will be possible to make without reprogramming of the system. So called "plug-in" modules will be used.
- ✓ All data will be stored in a format that makes it possible to exchange data, experience and research results both within different road authorities in Sweden as well as other countries road authorities.

Modules to analyze deflection measurements will also be added. Deflection measurements is not considered to be realistic to measure on the whole network, because of time consuming measurements. The deflection module will be based on the experience from an extensive pilot study of analysis of bearing capacity. In this study approximately 5000 km randomly selected roads have been measured with the Falling Weight Deflectometer (FWD), visual surveys (distresses, drainage, subgrade material) and some coring have been conducted. Models to be used are developed by the Swedish Road and Transport Research Institute (VTI).

With the development of the high-speed continuous Laser Road Deflection Tester deflection measurements will be conducted on the whole network.

With the development of the Pavue-Hybrid system crack parameters will be added.

The PMS development will also be integrated to the ongoing development of a GIS (Geographical Information System) and to the video logging of the road network that will be conducted during 1994.

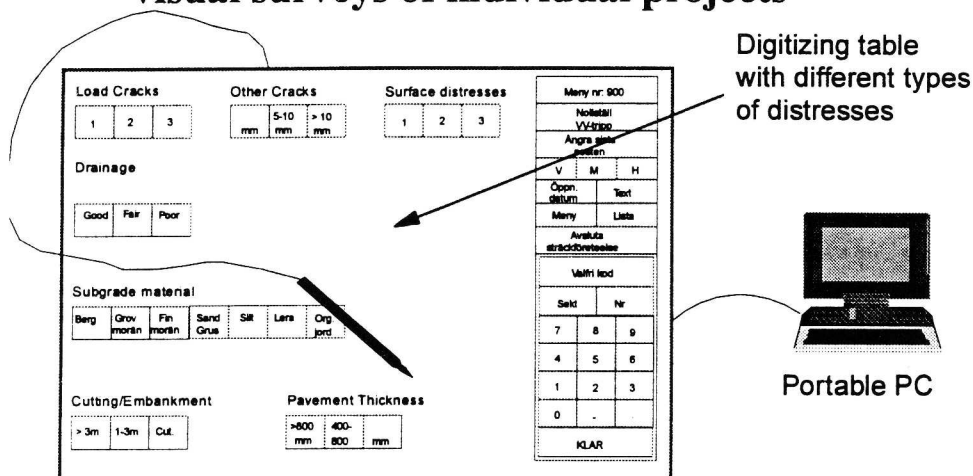


## PMS project level

In the existing PUB-system and in planned development is the PMS project level not considered. This level is and will be handled by contractors with the help of tools from the SNRA. These tools are:

- ✓ Fill&Mill. - Adjustment of road longitudinal and transversal profile based on measurements by Laser-RST.
- ✓ Visual Survey based on a manual developed by the Swedish road and Transport Research Institute. A PC-based program with a digitizing table has been developed to support the visual condition survey.

### A laptop and digitizing table is used for visual surveys of individual projects



- ✓ Falling Weight Deflection measurements
- ✓ Overlay design method
- ✓ Manual for project analysis
- ✓ Coring with the "Facilitator"

## MANAGEMENT OF PAVEMENT MAINTENANCE

by Hardy Wikström, Swedish National Road Administration

### Pavement operations - an introduction

The national network of public roads in Sweden is paved to approximately 75 %, corresponding to 75,000 km. A paved road is defined as a road with a bound wearing course of asphalt, grouted macadam or cement. The annual cost of pavement wear is SEK 1,200 – 1,400 million. This sum includes every type of pavement, from high quality pavements on roads with an AADT (average annual daily traffic on one lane of a multilane road) of 60,000 vehicles to very simple grouted surface treatments with an AADT of 150 vehicles.

The aim of planned pavement maintenance is to perform the right action at the right time.

- Monitor and report damage, including performing RST measurements
- Analyse and propose measures
- Produce a time plan
- Remedy the damage

Status measurements are carried out annually on the paved road network using an RST vehicle to measure rutting and unevenness.

The technical evaluation of status measurements is performed by at least 10 independent engineers, each with his own geographical area of responsibility. In this phase, it is the technical evaluation for the corrective action that is the most decisive for their part. The allocation of priority, which is dependent on the size of the funds available, does not take place until the next phase.

The funding method applied in Sweden is not controlled by needs in the sense that each area of operations is given funds according to its actual need. Instead, the road management authority makes a central allocation of priorities between different operating measures, after which the regional road management authority allocates further priorities for maintaining a satisfactory maintenance standard within the region.

Regardless of the funds available, there are factors in pavement maintenance that the purchaser can influence and which produce an effect on the road, i.e. through the form of negotiation and choice of strategy.

Negotiation of a pavement maintenance can take place in many ways, e.g. through function-oriented or general contracting.

If function-oriented contracting is chosen with the status description as a basis, it is assumed that the contractor will produce the appropriate technical solution. In this case, the purchaser must be both technically and financially competent to make a proper evaluation of tenders.

If, however, a conventional contract of a general nature with a technical description is chosen, technical skill on the part of the purchaser and an evaluation of the price in relation to the written requirements will be necessary.

The aim for the purchaser is to create a market that favours competition, technical development, method development, etc. One way of achieving this is for the contractor or maintenance company to accept greater responsibility for the operations and the product.

All maintenance is negotiated in function-oriented terms. A function requirement need not be the same throughout the country, since needs are often determined by traffic and climate. Another important factor is the size of the road maintenance funds and the priority given to pavement maintenance over other operations.

### **Involvement of private companies**

#### ***The Swedish market***

Within the pavement sector, a number of major actors compete for the pavement contracts of the National Road Administration and the municipal authorities.

From the purchaser's viewpoint, it is desirable to influence pavement operations through control and development. The competitive situation is unsatisfactory since there are so few actors in the market.

External contractors' market shares in hot asphalt mixes amount to about 90 %, of which two major contractors have 80 %.

In the case of cold mixes and surface treatments, the situation is the opposite, since the National Road Administration's own production accounts for about 90 %. In Sweden, there are some 125 permanent asphalt plants with 21 owners, of whom two own 80 plants. The locations of the permanent plants are chosen entirely according to the forecast volumes of the purchasers, with the National Road Administration accounting for 2,000,000 tonnes.

In the case of mobile plant, it is estimated that there are 15 within Sweden.

Extraction of gravel or mineral aggregate in Sweden is examined by a supervisory authority, the County Councils, who continuously review the extraction volumes. The intention is that the community's interests must control housekeeping with the country's natural resources.

Therefore, it is of great strategic importance for a contractor to own a licensed source of material, i.e. to have the right to extract a certain quantity of gravel. Smaller landowners with such licences must often lease out or sell their material sources to contractors with asphalt manufacture.

This environmental conservation test counteracts the purchaser's aim of creating a market with competition on equal terms. Therefore, it is important that in the long term the technique leads to a reduced need for new raw materials. Instead, methods of recycling existing materials should be sought.

As well as leading to general housekeeping with resources, this would also stimulate competition.

The same problem exists with bitumen products, emulsion, asphalt solution etc., where the small number of suppliers contributes to a monopoly of the market.

### ***Research and development***

Operations involve a large turnover and should therefore be the object of intensive technical development from the contractor's side, not least from the aspect of competitiveness.

Unfortunately, this has not been the case, and existing permanent plants appear to have led to the preservation of tested methods.

This may be interpreted as indicating a good level of profitability. Despite this, contractors have not made a significant contribution to technical development. However, they have introduced various technical improvements already in use for a long time in other countries.

The larger part of research and development has been carried out by the National Road Administration, the VTI and the Institute of Technology.

### ***What is the reason for this?***

Probably, the form of contracting is part of the explanation.

### ***Is the purchaser also responsible for inquiring after new products?***

Probably, we have not done this to a sufficient extent, and technical product development has often taken second place to development projects linked with new planning models, such as PMS and so on.

The future is very much a question in which strategic decisions must be made by the purchaser to hasten and improvement.

### ***Is it to be the price, the environment or local factors that influence the product?***

Examples of products that the purchaser should inquire about include the application of cold recycling technique using milled material removed during maintenance operations. This should make it possible to remedy long delayed pavement maintenance on medium and low traffic roads, at the same time as it contributes to environmental improvement.

## **Long-term maintenance contracts**

### ***Function-oriented negotiation***

Negotiation which imposes requirements on function, as mentioned in the introduction, is a strategy for long-term control. Function-oriented negotiation is automatically accompanied by long contract periods.

Function requirements must be clearly defined and measurable. Requirements failing to meet these conditions must not be applied.

Function-oriented negotiation of pavement maintenance is not self-evident among purchasers. The reason is that there are two types of purchaser, the technically informed and the administratively informed.

The technically informed purchaser usually knows what he wants and sees no problem in formulating a technically specific request for tenders. The administratively informed and formal purchaser prefers to formulate such a document in function-oriented terms and rely on the technical knowledge of the contractor.

Both types of purchaser are needed, since this combination provides skill in negotiation.

Pavement maintenance with function requirements should only be applied to roads built on the basis of complete contraction documents and documented reference data for wheel track wear and IRI.

The function requirements may be: rut depth, comfort value, cross fall and friction.

Measuring methods must be established in the request for tenders, together with penalties of bonuses when evaluating production.

The advantages of function-oriented negotiation are:

- The solution chosen is one of many alternatives proposed by different contractors. This should broaden the technical discussion.
- Increased capability on the part of the contractors and stimulus for technical development.
- Simplified purchaser organisation.

The disadvantages of function-oriented negotiation are:

- Elimination of certain smaller contractors. Limited competition.
- Increased purchaser administration as a result of different duration's of functions, etc.
- Long-term decrease in the purchaser's technical ability.
- Demands on continuity of funds.

Choosing a general contract as the usual form of negotiation within the National Road Administration results in the following advantages and disadvantages:

Advantages of a general contract:

- The purchaser retains technical negotiating ability.
- Request for tenders can be defined more closely.
- Evaluation of tenders is relatively simple.

Disadvantages of a general contract:

- The purchaser organisation probably expands.
- The contractor's technical ability is not utilised.
- Technical development is largely carried on by the purchaser.

Summing up, it can be seen that control and planning of pavement maintenance always starts out with good intentions, i.e. catching up with the maintenance backlog.

However, it has always been difficult to reconcile technique with funding or needs with actual measures. This will continue to be difficult also in the future.

This does not prevent the road management authority from adopting a target and strategy for its operations.

- A long-term approach in evaluating needs and measures, regardless of the level dictated by funding.
- an organisation which is always flexible and which supports implementation.
- Attentiveness and openness to new techniques, and ability to change strategy when necessary.
- Continuous influence of the market by inquiring for new solutions.

## SESSION 3: ORGANISATION OF MAINTENANCE OPERATIONS

### WORKING ENVIRONMENT – PAVING WORK

by Arne Andersson, the Swedish Construction Industry's Organization for Working Environment, Safety and Health

#### Introduction

Asphalt paving work in Sweden employs some 3,000 persons. Of these, some 2500 are employed in private companies. The remainder are employed by the Swedish National Road Administration and in independent operations by municipal authorities. The majority of the asphalt workers are organised in the same trade union.

Matters relating to the working environment are taken very seriously in Sweden. Employees are affiliated to Bygghälsans AB (the Swedish Construction Industry's Organization for Working Environment, Safety and Health), which is the largest company health care association in the industry. FAS (the Association for Asphalt Pavements in Sweden) deals with questions concerning the working environment in a committee containing representatives of trade unions, Bygghälsan and asphalt contractors. This work is characterised by a high level of co-operation and agreement.

The climate in Sweden permits paving only during a limited part of the year. On the public road network, paving is carried out mainly during the period May–October. Consequently, the work is subject to great pressure of time.

#### Bitumen and additives

The binders that are used are well defined and are produced mainly in Sweden using crude oil from Venezuela. In some cases they are modified with substances such as polymers. Bonding agents such as amines are added on a limited scale.

Tar-based products have not been used since 1975. Fibre is added in certain types.

#### Diesel

Measurements in Sweden show that fumes from paving work largely originate from sources other than bitumen. Diesel contributes to a large extent to the fumes. In particular, the use of diesel as a lubricant and cleaning agent for tools, truck platforms and asphalt pavers is a problem.

When hot mix comes into contact with these surfaces, the diesel evaporates and large amounts of fumes are created. One litre of diesel generates as much fumes as 20 tonnes of asphalt mix. Therefore, it is essential to use as little diesel as possible. The best solution is to use products with a high boiling point.



Emissions from diesel engines are working environment problem especially in poorly ventilated areas such as tunnels and multi-storey car parks.

Well-tuned engines, environmentally suitable fuels (low aromatics, low sulphur), effective cleaning with catalytic control and particle filters minimise the hazards.

Emissions from engines driven by alternative fuels based on rapeseed oil, for example, are subjectively regarded as less irritating. At present, there is insufficient data to prove that emissions from rapeseed oil are less hazardous. Research is in progress.

### **Recycling**

Milled material and crushed pieces of paving can be recycled in various ways. Part is reused immediately as a roadbase or as a pavement layer on minor roads. Hot or cold remixing is carried out in asphalt plants, after which the material is often added to new mix.

Direct recycling on the road is carried out with remixing, repaving and heating and totals some 3-5 million m<sup>2</sup>/year.

### **Working in the traffic environment**

Working on roads is accompanied by a permanent risk factor from passing vehicles. Comparatively simple barriers are used for protection from vehicles which frequently pass at high speeds. A natural requirements is that the road worker should be able to work without the risk of being run over.

Effective work to ensure a safer workplace must be based on understanding of different interests on the part of the road worker and the road user (especially occupational drivers).

It must be regarded as an excessive demand for the road user to understand fully what it means to work eight hours a day on the road. It is easier for the road worker to understand the point of view of the road user. a positive attitude, disciplined use of signs and wearing of high conspicuity clothing will create better relations to drivers of passing vehicles.

For various reasons, certain work must be performed at night time. The demands on conspicuity are naturally greater. Vehicle lighting, reflector materials, etc. must be adapted to each situation. Rerouting of traffic is the safes method.

In built-up areas, attention must be paid to local regulations concerning noise, vibrations etc. These may require machines to be specially adapted to the norms.

### **Effects on health**

Apart from the increased risk of accidents due to surrounding traffic and the risks from the hot asphalt mix, adhesive etc., the effects on health may be acute or they may occur after a long period of exposure to oil-based products.

Wear on the body due to heavy, monotonous work and a poor driver's environment is common.

Acute problems are caused by substances that irritate the mucous membranes. These may be given off by the hot mix and the fumes created through evaporation of diesel oil. Other sources may be emissions from vehicles and machines, bitumen additives etc. Investigations indicate the presence of aldehydes, which are well known as being highly irritating to mucous membranes.

The problems appear in the form of itching, inflamed eyes, irritation to the throat and coughing. Other problems are abnormal fatigue, nausea, dizziness and temporary loss of memory. The problems are well known and disappear when exposure ceases.

Health risks after a long period of exposure in paving work have been discussed for many years and have led to many investigations both in Sweden and abroad. Some of the investigations have focused on determining whether there is an increased frequency of cancer among asphalt workers. Others indicate a slightly increased frequency in lung and intestinal cancer.

It must be emphasised that those who were affected were exposed to fumes from asphalt containing tar. It is well known that tar contains considerably higher contents of PAH (polycyclic aromatic hydrocarbons) than found in bitumen. PAH are well known for being carcinogenic. As mentioned earlier, no tar or tar-based products are used in Sweden.

Cold milling generates large amounts of dust. Measurements made by Bygghälsan show that the hygienic limit for dust containing quartz dust is greatly exceeded. This is a serious matter, since quartz is recognised as a contributory cause of silicosis.

Milling of pavements containing quartzite is especially problematic. Development of machines with dust extraction is required. The use of water as a dust binder is not satisfactory.

Asphalt workers who mostly lay asphalt manually have more physical complaints than others, especially in the neck and shoulders. A change in the organisation of work is needed so that repetitive monotonous tasks are avoided.

Development of tools and labour-saving aids is necessary.

Drivers of mobile plant also suffer from physical wear. Traditionally, the same machines are driven by the same driver. A working day with 10-15 hours in the same position increases the risk of occupational injury. It is difficult to break the traditional pattern and encourage employees to alternate between driving and other duties.

Development towards more driver-friendly machines is slow. Progress so far has been limited to adjustments of existing proposals.

## Relevant reports

Doctor Göran Nordström of Bygghälsan has made a genotoxic study of PAH. In this study, air samples were taken and biological samples obtained from 28 asphalt workers. A reference group comprising 30 joiners of comparable ages was used.

The measurements showed a low content of polyaromatics in the air. No effects on chromosomes were found. The report will be published in the journal "Arbete och Hälsa".

During autumn 1993, Bygghälsan was commissioned by the National Road Administration to perform work hygiene measurements in remixing work.

The interim results indicate high contents of oil mist, well above applicable limits. A report is expected during winter 1993-94.

## Proposals for actions

- Product development so that the asphalt mix can be handled at a lower temperature (<150°C).
- Reduced usage of diesel as release agent.
- Vehicles and machines must have effective emissions control. The same requirements apply as to on-road vehicles.
- Better planning of ventilation in indoor work.
- The driver's environment must be designed so that the driver can change driving position while maintaining a proper view of the work.
- Increased usage of mechanical aids in minor tasks.
- Better ergonomic design of tools and implements.
- Job rotation to counteract monotonous loads.
- Attention to the working environment must be integrated in product development.

## SESSION 4A: MAINTENANCE TECHNIQUES FOR BITUMINOUS PAVEMENTS

### MAINTENANCE TECHNIQUE FOR BITUMINOUS PAVEMENTS IN SWEDEN METHODS, EQUIPMENT AND APPLICATIONS

by Rolf Lindroth, Swedish National Road Administration

#### **Background and current status**

Swedish roads on which chemical deicing is carried out demonstrate the great pavement wear in winter. The wear is caused by the use of studded tyres on wet road surfaces. On the minor road network, with an AADT of <1000, pavement wear is negligible owing to lower speeds and infrequent use of chemical deicing. On the other hand, problems of reduced bearing capacity are encountered as a result of frost heave during the winter.

Roads with an AADT of >1000 are usually surfaced with hot mix. Repairs are carried out with cold milling and hot mix.

Roads with an AADT of <1000 are surfaced either with hot mix, surface treatment, grouted macadam or oil gravel and are often repaired with some type of sprayed treatment, such as sealing coat, surface treatment or grouted macadam.

In Sweden, some 20 repair methods are in use on different roads, depending on traffic volume and type of wear.

In repairs on wearing courses, the first step is always to apply a sealing coat over the damage. The sealing coat provides a sound basis for the next step and is never a wasted precaution while the wearing course is awaiting repair, even if this should be a considerable time. Sealing coat should be used on paved surfaces which are used only by cars.

A satisfactory result always requires careful work, whatever the repair method used.

#### **Quick repair methods**

##### ***Cold mix repairs***

Cold mixing of mineral aggregate and slow setting bitumen solution provides a pliable, storable and stone-rich asphalt mix which can be used during winter for quick repairs to small potholes developing suddenly in wheel tracks.

The mix must be stored at temperatures above freezing to be usable during winter. Therefore, it may be appropriate to keep a suitable quantity of the mix in a warm storage area.

The mix is produced in an asphalt plant, usually with mineral aggregate having a stone size of 12 mm.

Equipment:   LPG burner  
                  Adhesive (BL20RK or BE60M)  
                  Cold Mix  
                  Compaction tools.

During winter, very durable repairs can be made with cold mix, even on heavily used roads, if the following procedure is used:

Loose fragments, gravel and water are brushed away.

The damaged area is dried with the LPG burner if BL20RK is to be used as adhesive.

Adhesive is applied.

Cold mix is used to reshape the damaged area.

The mix is heated and compacted.

Other cold mix repairs are to be seen as a temporary measure which will probably have to be replaced by other material during the summer.

### *Application*

Potholes

### *Spray Treatment*

Repairs with bitumen emulsion and mineral aggregate are a highly advantageous alternative on all types of pavement, being both durable and as strong as the surrounding areas.

The mineral aggregate should be 2-5 mm, 4-8 mm or of a similar open fraction. The binder must be Be60M, which is specially produced for good storage properties and easy handling at work sites.

Equipment and repair methods are usable throughout the year and offer equally good results at all times.

#### – Repairs with a hand spreader

Using a conventional spray sealing tank, equipped with a hand spreader for binder alone, potholes are repaired with grouted macadam by spreading BE60M on a mineral aggregate adjusted to the desired thickness. For thin repairs, surface treatment is used, with BE60M being spread before the mineral aggregate is applied. Finally, the binder must always be covered with mineral aggregate to protect the repair and road users until the emulsion has broken.

#### – Repairs with pothole repairer

The equipment is placed on a truck, with the driver able to perform the whole operation alone from the cab. The pothole repairer blows air, mineral aggregate and binder either separately or in any desired combination.

Repairs are made by cleaning the damaged area with compressed air and sealing it with binder. Mineral aggregate is then sprayed through a binder curtain in the nozzle so that each particle is covered with bitumen. The bitumen-coated aggregate is sprayed to the desired thickness and finally aggregate alone is sprayed to cover the binder.

The pothole repairer has very high capacity and offers a well-protected working environment.

Repairs with this method produce a considerably improved result compared to the hand spreader method.

#### *Application*

Potholes, cracks and sealing of areas <20 m<sup>2</sup>.

## Methods for planned repairs

### *Cold Milling*

- Plane milling is often used in combination with a new wearing course to obtain an even base with the correct cross fall and smoothing occasional rough areas on the pavement surface.
- Box milling is used to replace a wearing course on carriageways with more than two lanes. The box is milled to the depth corresponding to the new wearing course.
- Rut milling on heavily used roads with more than two lanes. Instead of laying a fully covering layer of asphalt, only the ruts are milled (2 x 1.0 m). The material removed is then replaced with new, high quality material.
- Milling-in of macadam in existing courses.
- Deep milling. The existing pavement is recycled after milling and new binder is added.

### *Application*

Roads with unsatisfactory cross fall, multi-lane roads where only one lane requires repair and as reinforcement on roads with reduced bearing capacity.

### *Mastic asphalt repairs*

Repairs of minor damage are often carried out with a mastic asphalt boiler in which the asphalt is heated and stirred. Larger repairs are made with a mastic asphalt spreader.

The repair mix for the mastic asphalt boiler can be stored in blocks which are broken up before melting and heating. For faster heating when starting work, the boiler is filled only one third full with mix which is heated to a working temperature of 200-250°C. The mix is replenished continuously during work. The mastic asphalt is spread evenly with an asphalt rake over the damaged surface and is immediately covered with chippings which are rolled in to prevent skidding.

With a dry surface and preferably the application of adhesive produce, good results are achieved, especially in thin repairs. In cold weather, it may be difficult to achieve good bonding to the existing pavement. Repairs with mastic asphalt produce the best results in summer.

Owing to the high working temperature, all work with mastic asphalt must be carried out with the great caution.

### *Application*

Repairs around manhole covers and bridges and in extreme rutting.



### ***Heating***

The surface in front of the asphalt paver is heated up indirectly by LPG burners mounted on wheeled frames. The new mix is laid immediately on the heated surface. It bonds very satisfactorily to both the underlying surface and the existing pavement and it is therefore sufficient to repair only the lane that is damaged.

The paving run is normally positioned between the road markings to reduce costs further by avoiding the need for repainting.

Heating offers lower costs when performed in warm weather.

### ***Remixing***

Remixing is performed with a special machine which mills the pavement, mixes recovered material with new materials and relays these. The surface in front of the machine is heated indirectly by LPG burners mounted on wheeled frames.

### ***Repaving***

Repaving entails a combination of milling and mix spreading performed in a single action with a special machine. The surface in front of the machine is heated indirectly by LPG burners mounted on wheeled frames. The heated pavement is milled and smoothed, after which the new mix is laid. If the existing pavement has a deficit of binder, new binder can be added.

### ***Application***

Roads where the pavement is heavily worn and the wearing course sets high demands on the mineral aggregate used.

### ***Reshaping***

Reshaping deformations with asphalt mix having a maximum particle size of 12 mm should be performed only on slightly worn surfaces such as paths for pedestrians and cyclists. Other reshaping should be performed with coarser materials to ensure bearing capacity of the repair.

The repairs are made with an asphalt paver, a grader equipped for reshaping, an asphalt auger or by hand. The mix must be well compacted. Careful gluing must always be performed before laying the mix. A cracked pavement should first be sealed to prevent cracks spreading upwards through the new layer, which would mean that the work was wasted.

Reshaping of the mix should be performed as early as possible in the spring so that the reshaped layer is compacted further by the traffic.

### ***Application***

Reshaping of deformations, layers to improve bearing capacity and sealing.

### ***Reshaping with grouted macadam***

Because of its draining effect sideways through the macadam, this method enables surplus water on the surface of the underlying layer to be transported to the ditch, thereby considerably reducing the risk of damage to the surface. The method allows a lower thickness of the reshaping layer than conventional gravel reinforcement with a similar reinforcing effect.

The method used is the same as in roadbase reinforcement. The damage is adjusted to the desired height with mineral aggregate having a 6-25 mm fraction. A certain amount of binder is spread on the macadam layer and is immediately covered with mineral aggregate having a 0-8 mm fraction. Further compaction is carried out until the mineral aggregate no longer moves noticeably during compaction work.

The surface should be sealed after 2-5 years, depending on the traffic volume.

Large areas are paved with a macadam spreader or grader and the binder is spread with a ramp spreader. Minor damage (<20 m<sup>2</sup>) can be repaired with a hand ramp and grader. Reshaping of small deformations (<5 m<sup>2</sup>) can be performed manually.

#### ***Application***

Reshaping of rough areas and layers for increasing bearing capacity on roads with an AADT of <1000.

## **Preventive action**

### ***Sealing coat***

Spreading bitumen emulsion and chippings does not provide a wearing course but a simple and inexpensive measure to replace the binder that disappears through washing out or oxidation of paved surfaces. The purpose of the chippings is to protect the binder and at the same time to protect the road user from splashes of binder. Therefore, no special requirements are set on the mineral aggregate.

Sealing coat is applied with truck-mounted equipment which spreads the binder and chippings while driving. The equipment is operated by the driver in the cab. Sealing coat applied before potholes appear keeps the pavement's stone skeleton intact. It also seals and binds cracks, including alligator cracking, separations and other open or damaged surfaces. Water is prevented from penetrating the road structure and reducing bearing capacity.

Bitumen emulsion BE60M is used as binder, while the chippings must be in the 0-8 mm fraction. Rolling speeds up the breaking sequence of the emulsion somewhat, but otherwise has no practical importance and can therefore be excluded. Fractionated chippings, 4-8 mm or similar, should be used only exceptional cases when there is a risk of skidding or when motivated by transport and/or spreading costs.

The method is widely used in Sweden.

### ***Application***

As preventive action on all paved surfaces with car traffic alone before damage has developed into potholes. Examples include cracks, alligator cracking, oxidised areas, separated areas and areas where there is a risk of loose stones.

### ***Slurry Seal***

Bitumen emulsion, water, mineral aggregate usually 0-2 mm and standard cement are mixed as a mixer mounted on a truck, which also tows a spreading box. the emulsion slurry is laid as an even layer immediately after mixing. Slurry sealing should be performed during spring and summer.

### ***Application***

Areas with light traffic and loss Of surface materials, e.g. car parks, streets, school yards and airports.

**SESSION 4B: MAINTENANCE TECHNIQUES FOR CONCRETE PAVEMENTS****IMPROVEMENT OF EVENNESS AND SURFACE TEXTURE ON SWEDISH  
CONCRETE ROADS**

by Bengt-Åke Hultqvist, Swedish Road and Transport Research Institute

**Background**

In recent years, concrete roads have attracted growing interest in Sweden. One of the reasons is the increased traffic loads that set demands on stiffer pavements. In addition, a solution has been found to the problem of poor driving comfort. Concrete roads can now be built with the same evenness as asphalt roads. At the same time, new and improved maintenance methods have been developed for concrete roads.

On the concrete roads built in Sweden during the fifties and sixties, problems often occurred in the form of settlements and frost damage. These roads were built with long concrete slabs (10-17 m) on an unbound gravel roadbase. The long distances between joints led to large joint movements. The unbound roadbase was partly eroded beneath the joints, resulting in settlements and unevenness. No special requirements were set on frost resistance of the concrete, which led to damage when salting was introduced as a deicing measure in the sixties. During the eighties, repairs were carried out on these concrete roads. The pavement was broken up and covered with a 10-15 cm thick layer of asphalt.

The concrete roads built in the seventies were of an improved design. Beneath the pavement was a roadbase of cement-bound gravel. The joint distance was made short, about 5 m, resulting in limited joint movements and low convex stresses in the slabs. The concrete roads of the seventies demonstrate good bearing capacity and have performed very well, with limited maintenance and low maintenance costs.

**Results from the concrete roads of the seventies**

During 1989, an investigation was made of the status of the two concrete roads built in Sweden during the seventies. Both are located in southern Sweden: the E6 at Malmö, which was built in 1972, and the E4 at Helsingborg, dating from 1978. The two roads have performed very well without any extensive maintenance.

Both the roads had good bearing capacity and had very good longitudinal evenness. Their structural status was also good. An inspection showed that 3-5% of the concrete slabs had some form of damage. Usually, this consisted of wild cracks which were not considered serious. On the Malmö road, a large proportion of the cracks had occurred during construction as the joints had been sawn too late. Both the concrete roads had good evenness and driving comfort. Unevenness was measured and recorded with the International Roughness Index (IRI), which showed a value of 1.0 - 2.0. Joint maintenance was performed every seven years. Certain problems have occurred with bonding of the jointing compound to the concrete. The joints have therefore not been considered completely watertight.

After 18 years and 14 years respectively, the concrete roads began to require maintenance owing to rutting from studded tyres. The rut depth was then 10-15 mm, corresponding to a increase in rut depth of less than 1.0 mm per year. Rutting of Swedish concrete roads is due exclusively to studded tyres. The traffic volume on the road at Malmö is about 22,000 vehicles per day and on the road at Helsingborg about 17,000 vehicles per day. In recent winters, 30-40 per cent of passenger cars in southern Sweden have used studded tyres.

### **Maintenance method**

Several different maintenance methods exist for rutted concrete roads. During an international seminar in Malmö in 1989 entitled "Concrete Highway Grinding Demonstration and Seminar", a maintenance method was tested which smooths the rutted pavement by grinding the surface. The demonstration took place on the E6 concrete road south of Malmö and two diamond grinders were used: a Target PRM 3804 and a Cushion Cut PC-500. The two machines are similar in design. The grinding unit, with a width of about 1.0 m, consists of a rotating drum holding about 180 diamond cutting discs, each 3 mm thick. During grinding, the drum is cooled with water sprayed from a series of nozzles. A dust extractor enclosing the drum sucks up the water and concrete dust.



*Diamond grinder*



Diamond grinding was tested on two sections 100 m and 300 m long. The sections were located one after the other in the same direction of travel towards Malmö. The concrete pavement consisted of 20 cm thick slabs with a size of 4 x 5 m. Apart from rutting, the surface was in good condition. The concrete was of strength class K40 (compressive strength at least 40 kPa) with mineral aggregate of hard quartzite and maximum particle size 35 mm. The mineral aggregate has good abrasion resistance (aggregate abrasion value 1.4). The roadbase beneath the concrete pavement consists of 15 cm cement-bound gravel.

Grinding was performed in the right-hand lane (the slow lane) where the rut depth was about 15 mm. Since the grinding drum was about 1.0 m wide, five runs were needed to cover the whole carriageway. The grinding depth was adjusted so that about 90 per cent of the rutting disappeared. A surface with a fine longitudinal grinding pattern was obtained after the thin cutting discs.



*Diamond-ground surface*

Surface properties of the concrete road at Malmö before and after grinding

The surface properties on the test sections were measured before and after grinding with regard to longitudinal and transverse evenness, surface texture, friction and noise. The wear resistance of the concrete pavement was measured after diamond grinding.

### **Longitudinal evenness (IRI, International Roughness Index)**

Prior to grinding, an IRI of 1.3 was measured, which is a very good value for a concrete road 18 years old. After grinding, evenness was found to be improved and an IRI of 0.6 was recorded, which is a very low value found only on the most even pavements in Sweden.

### **Transverse evenness**

The reason why the road was in need of maintenance was that ruts had formed in the pavement after 18 years of use. Prior to grinding, a rut depth of about 12 mm was measured on the test section. After grinding, transverse evenness was measured. The variations in evenness between different grinder runs were usually less than 3 mm, which had been set as a requirement.

### **Surface texture**

The diamond grinder produced a surface with a longitudinally patterned surface texture. A raw pavement surface with good surface texture was obtained immediately after grinding. In measurement with the Sand Patch method, a mean texture depth of 0.5 mm was recorded. After the pavement had been used for one winter by vehicles with studded tyres, a change in surface texture was observed, especially in the wheel tracks. When measured after one year, the mean texture depth had decreased to about 0.3 mm. The surface texture of the pavement affects friction and tyre/road noise, among other properties.

### **Friction**

The longitudinal friction of the pavement has been measured with the Saab Friction Tester at a speed of 70 km/h on a wet road surface. Prior to grinding, friction values of about 0.55 were measured. Diamond grinding improved the friction to 0.8-0.9. After one year, the friction had returned to about 0.55. The change in friction is due to the change in surface texture of the pavement.

### **Tyre/road noise**

Tyre/road noise has been measured with a mobile measuring trailer before and after grinding was carried out. Before grinding, the noise level with summer tyres was 101.5 dB(A) at 90 km/h. After grinding, a reduction in the noise level of about 1.5 dB(A) was measured on the treated surface. The fine longitudinal grooves have a positive influence on the noise level. After a time, the grooved surface becomes worn and after about one year the noise level has increased again.

### **Wear resistance**

Abrasion from studded tyres has been measured with a very precise laser profilograph after grinding of the pavement. The first winter after grinding, abrasion was twice as great on the treated surface as on an adjacent untreated surface. After two winters, the abrasion was similar on both surfaces. The difference during the first winter is due to higher initial wear after grinding, when the grooved surface is worn level.



Abrasion has been comparatively low on the concrete road at Malmö. During recent winters, the mean abrasion in the lanes has been as low as about 0.1 mm. A significant cause may be the low usage of studded tyres. Other explanations may be favourable climatic factors (temperature, precipitation) during these winters.

Another method of recording abrasion that takes into account the usage of studded tyres is to calculate the specific wear (SPS). SPS is defined as the quantity of abraded pavement material in tonnes per km road and million passages by vehicles with studded tyres. In the second winter after grinding, the SPS value has been calculated as 6-8, which indicates very good wear resistance.

## **Conclusions**

The two concrete roads built in Sweden during the seventies have performed very well in regard to bearing capacity, comfort and rutting. After 18 years and 14 years respectively, the concrete roads were in need of maintenance owing to rutting from studded tyres. The maintenance method chosen was diamond grinding of the surface. This method improved the evenness of the road surface both longitudinally and transversely. Improvements were also obtained in surface texture, friction and noise. After about one year, the grooved surface became worn, which reduced friction to the same level as before grinding. The noise level also increased when the treated surface became worn. Longitudinal evenness was not affected by wear during the first few years after maintenance.

The positive results from the test sections have led to the use of diamond grinding on other concrete roads in Sweden. During 1990 and 1991, diamond grinding was carried out on the right-hand lane of the entire concrete road at Malmö (13 km motor way). During 1992, diamond grinding was used on the right-hand lane of the concrete road at Helsingborg (7 km motor way). On the new concrete roads being built in Sweden, the thickness of the concrete pavement has been increased by 15 mm to allow for future diamond grinding.











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