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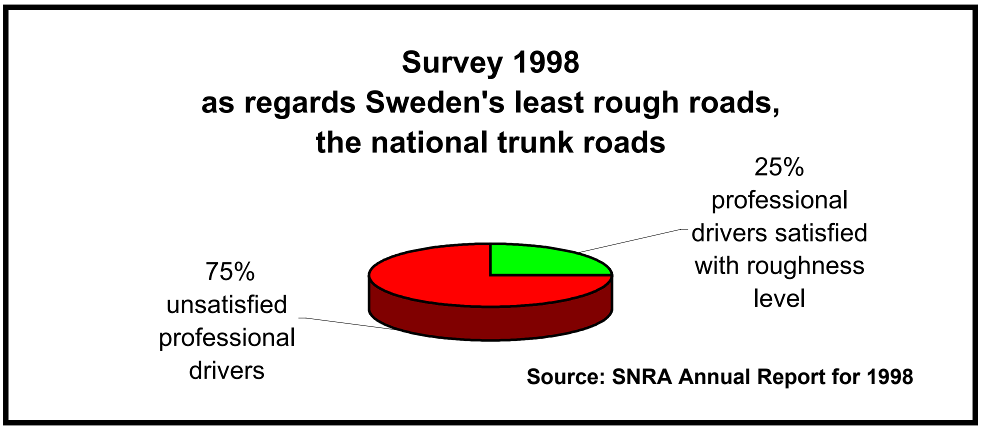
Geometric pavement model for computer-aided design of pavement maintenance actions



Model design and specification of the input data
Interim version

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Authors
Engineering Division.
Contacts: Johan Granlund and Johan Lang.

Document title
Geometric pavement model for computer-aided design of pavement maintenance actions.
Model design and specification of the input data. Interim version.

Main content
This publication describes a geometric pavement model used to support the Swedish National Road Administration method ”Procedures at road repairs”. This method was developed to effectively remedy the road roughness that affects vehicle movement, travel comfort, dynamic loads, drainage and winter maintenance. The output from the geometric pavement model can be used as information in connection with pavement maintenance action. This makes it possible to calculate the resources needed, even where there are stringent requirements on the final surface geometry, and irrespective of whether the road manager intends to assume responsibility for the pavement design or leave this to the contractor. Several of the main contract items can be calculated from the drawings and thus remain unregulated, regardless of the form of contract chosen.

The performance requirements that are placed on the geometric pavement model determine what the data supplier must achieve with his survey equipment, methods and processing of the survey data.

The conditions for using the geometric pavement model, which is important for the road manager and everyone else involved in the road maintenance project to know, are clearly set out.

Both the overall principle as regards tolerance limits as well as detailed tolerance requirements are specified.

Data for the geometric pavement model shall be supplied in the format used in the Swedish National Road Administration’s ”Mill and Fill” CAD program. These formats are specified in this publication.

If any differences between versions are at hand, the swedish version is the correct version.

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Distributor (name, mail address, telephone, telefax)
Vägverket, Butiken, Internal Services Division, SE-781 87 BORLÄNGE, Sweden
Phone: +46 243 755 00, fax: +46 243 755 50

Contents

Road roughness affects vehicle movement, travel comfort, dynamic loads, drainage and winter maintenance. Asphalt concrete fill is the action primarily undertaken in connection with maintenance projects (which simultaneously increases the bearing capacity of the road), with milling as a second choice of action. However, asphalt concrete is by far the most expensive bulk product that a road manager purchases. In connection with pavement maintenance action, the available funds are a major factor in determining the target standard for gradient and roughness. Through surveying the roadway ahead of time, the choice of target standard can be transferred from the implementation stage to a point in time prior to sending the enquiry documents to tenderers. This makes it possible to retain the chosen geometric standard remains fixed right up until the inspection, minimise changes and supplementary works and keep within budget. A well-designed pavement survey can also be used to describe the existing pavement geometry in the contract procurement, regardless of whether the works are contracted as an implementation-, design and construct- or performance contract.

1 Summary

Chapter two shows how the geometric pavement model supports the Swedish National Road Administration's (SNRA) method ”Procedures at road repairs ”. The terminology used is defined in chapter 3. Requirements for the geometric pavement model are specified in chapters 4-11. The performance requirements placed on the geometric pavement model here determine what is expected of the data supplier as regards his survey equipment, methods and processing of the data collected. Where necessary, the Client can decide to adjust the requirement levels after having evaluated the ability of the suppliers to fulfil the requirements set. Chapter 4 presents the conditions for using the geometric pavement model as well as what is important for the road manager and everyone else involved in the road maintenance project to know. An account of the overall principles as regards tolerance limits is given in chapter 5. The survey parameters used in the model are presented in chapters 6-10. The data format that is necessary for being able to use the model in the SNRA's CAD program is stipulated in chapter 11. A reference list is given in chapter 12.

2 Geometric pavement model for designing maintenance actions

The requirements specified in this document refer to the geometric pavement model (Figures 1 and 3) that is used in the computer-aided design of mill and fill works. The detailed design plan that is the outcome of such a CAD (Computer-Aided Design) is used as a bill of quantities in connection with the procurement of works contracts and as support in connection with CAM (Computer-Aided Manufacturing) of the plant and equipment used in the works.

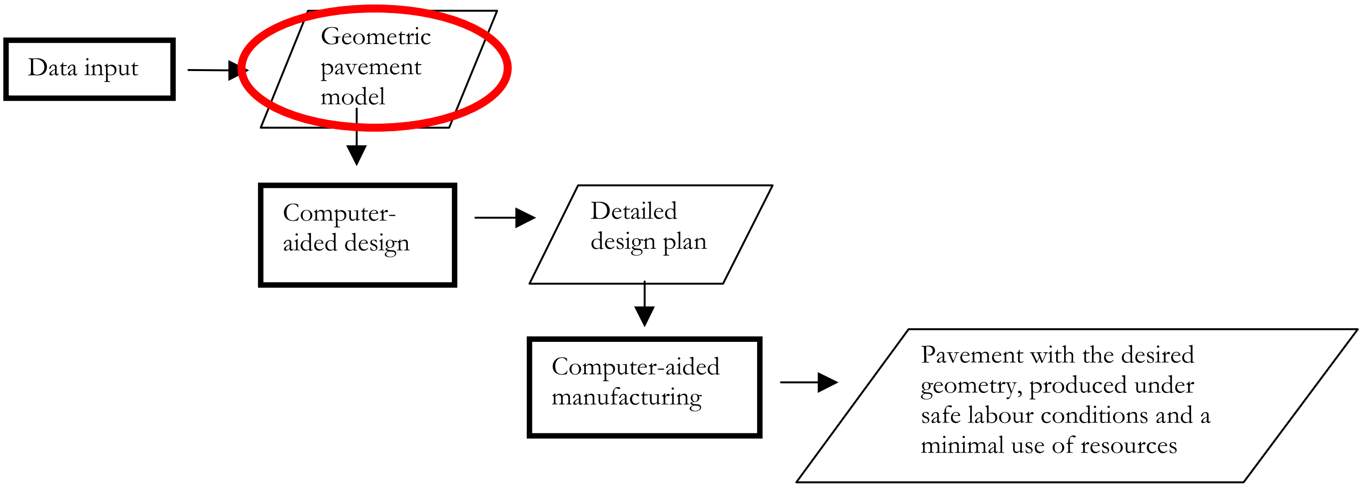

Figure 1 The SNRA's *"Procedure at road repairs "*

Apart from repairing the surface wearing course, the main purpose of mill and fill works in connection with pavement maintenance actions is to expend a reasonable amount of effort, in order to:

- remedy incorrect gradients
- remove roughness
- remove unstable layers, and recycle the materials in a suitable way when doing so
- add material to increase the road's bearing capacity, in order to maintain or raise its bearing capacity class
- ensure that the base under the new wearing course is not unacceptably cracked.

At new construction works, the aim is normally to install height-determined construction components, which has governed the development of geodetic instruments like the total-station used at normal work sites. Creating a wearing course at a set height is not normally part of the objective in maintenance works (see above). Thus, in this connection it is preferable to evaluate the gradient and surface roughness relative to the horizon and the road surfaces that affect undulation, which is of significance to vehicle movement and travel comfort, i.e., roughness over a distance of about 350 m. A suitable survey instrument is a profilometer mounted on a vehicle, which is usually referred to as a "survey vehicle" [7]. In exceptional cases where there is clearly demarcated local damage, a long straight-edge with gradient sensors can be used as a measurement instrument.

3 Terminology

The definitions of the following terminology have been based on those found in the Swedish National Encyclopaedia [1] its appurtenant dictionary [2], Swedish Centre for Technical Terminology glossaries [3], the Transport Research Institute report entitled *Vägtrafikteknisk nomenklatur (Highway Engineering Terminology)* [4] and in the ASTM's *Terminology Relating to Vehicle-Pavement Systems* [5].

Accuracy
The ability of the survey instrument to give results close to the true value for the survey parameter. The greater the accuracy, the less the error.

Amplitude
A. consists of the maximum deviation from the mean position in a sinus-shaped road roughness, see Figure 2.

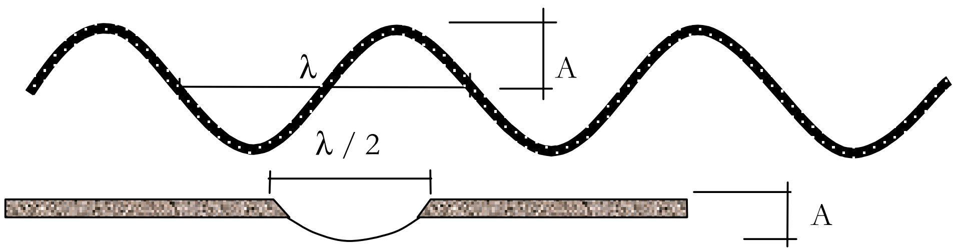

Figure 2 Wave length (λ) and amplitude (A). Above at a corrugation, below at a pothole.

Calibration
The reading of an instrument relative to a standard or to a series of conventionally true values. In this context, a comparison is made between the reading given by the survey equipment and known gauges that represent units of measure or multiples thereof.

Conditions for use
The range (as regards both the survey parameter as well as other factors that influence the result) within which the error and other characteristics of the survey instrument shall comply with the specifications.

Crossfall
The angle between the horizontal plane and the surface of the roadway, carriageway or shoulder, measured at a right angle to the longitudinal direction of the road. The surface studied in every cross-section shall be represented by a line of regression (according to the method of least squares) through a number of points. The survey shall include at least 4 points per metre in the transversal direction of the road. These points shall not be more than 250 mm apart from each other.

Horizon
The apparent boundary between the sky and the surface of the earth, which is most clearly defined above a mirror-like surface of water (which is horizontal by definition).

Horizontal curve
A curve intended for the direction of the road alignment in the horizontal plane.

Macrotexture (matx)
Term for those aberrations in the pavement surface (compared to an ideal plane) which have the characteristic dimensions of a wave length and amplitudes from 0.5 mm up to those that do not affect the interaction between the tyres and the roadway.

Measurement error
Difference between the measurement value and the true value for the survey parameter.

Measurement value
The value for the survey parameter compared to the unit of measure. Can be identical with the survey result.

Microtexture (mitx)
Term for those aberrations in the pavement surface (compared to an ideal plane) which have the characteristic dimensions of a wave length and an amplitude less than 0.5 mm.

Nominal measurement range
The range that can be determined using the survey instrument at hand.

Nyquist frequency
During sampling, values are collected periodically at a sampling frequency of f_s. Half the sampling frequency, $f_s/2$, is designated as the Nyquist frequency (after the physicist Harry Nyquist). Components with a frequency above this cannot be derived from the sampled signal.

> *The high frequency components above the Nyquist frequency of the sample can cause a distorted picture of the signal's low frequency components through "aliasing". This phenomena can be counteracted through using "anti-aliasing" filtering.*

Precision
The degree of compliance between a number of values measured, determined through repeated measurements. Precision has nothing to do with the deviation of the values measured from the true values for the survey parameters. Precision is sub-divided into repeatability and reproducibility.

Random / temporary error
The component in the measurement error that varies during repeated measurement of a given parameter.

Repeatability
The precision of the values measured for a given survey parameter, determined in a uniform way and under similar conditions.

Reproducibility
The precision of the values measured for a given survey parameter, determined in a uniform way but under different conditions. Example of changed conditions could be another survey method, another operator, another instrument or another point in time.

Resolution
Ability of the gauge or survey instrument to register the difference between two close values for the parameter without interpolation.

Road roughness
Term used for deviations from a real plane with characteristic dimensions, which affects vehicle movement, travel comfort, dynamic loads, drainage and winter maintenance.

Roadway
Carriageway together with the shoulders.

Roughness profile
The vertical deviations in the road surface, in relation to an established reference parallel to the direction of travel. See chapter 7. The roughness profile can be determined at different lateral positions across the roadway. The lateral position is chosen according to chapter 6.1.

Specified measurement range
Part of the nominal measurement range where the error in the reading shall lie within specified limits.

Survey
A series of measures to determine the value for the survey parameter.

Survey instrument
Technical device intended to be used for measurement surveys.

Survey parameter
The feature that is being measured.

Survey result
The product of the measurement value and the unit of measure. The measurement value can have been corrected in connection with this through calibration in order to take known systematic errors into consideration.

Stability
The ability of a survey instrument to maintain its characteristics over time.

Systematic error
The component in the measurement error that remains constant or varies in a predictable way during repeated surveys of the same parameter. Can at least be determined approximately through calibration.

Traceability
Entails that a survey result can be related to an accepted normal.

Unit of measure
Reference value for a survey parameter; e.g. in the case of distance, a metre could be used as a unit of measure.

Vibration
Undulation in mechanical systems. This is governed by different kinds of force: mass, restoration, calming and disruptive (impelling, excitation) forces.

Wavelength
The distance, measured in the direction of propagation, between two points of the same phase in consecutive cycles of a wave. See Figure 2.

4 Conditions for using the geometric pavement model

- The geometric pavement model shall reproduce the road pavement surface (not the surface of water puddles or the like) at a point in time when the road is not being subjected to frost actions.
- The road is expected to have enough bearing capacity that the surface is not tangibly deformed during the execution of maintenance works (adding the top load of mix, normal plant and equipment and their vibrations). If this condition is not fulfilled, the actual quantities that will have to be used to fulfil the geometric requirements will be considerably greater than the theoretical amounts.
- The geometric pavement model shall be a reproduction of the road surface between the pavement margins. Surfaces at the side, such as parking spots, entrances, etc are normally not included. The reproduction shall include the stretch between the starting and end cross-sections, as well as the 200 metres immediately ahead of and behind the boundaries of the surveyed stretch of road.
- The geometric pavement model (road environment video) shall show the position of drains and kerbstones.
- Short-wave roughness with large amplitudes, caused for instance by frost heaved boulders, are not included in the geometric pavement model. This kind of road damage requires special attention.

4.1 Short-wave (λ< 10 m) roughness

In those cases where at least 80 kg/m^2 of wearing course is used, roughness up to approximately a 10 m wavelength and amplitudes less than about 25 mm will be evened out through normal variations in the thickness of the wearing course.

If less is used, as for instance in the case of sprayed treatment surface dressing, all that is required is that there is not any significant short-wave roughness in the underlying layer[1], or that the roughness is remedied through comprehensive milling and/or filling before placing the wearing course.

4.2 Long-wave (λ< 350 m) roughness

Roughness with wavelengths up to approximately 350 metres can have a major effect on travel comfort at normal speeds. See [6].

The choice of the resolution of the roughness profile in the geometric pavement model is 5 metres according to chapter 7.1. Taking into consideration the Nyquist frequency (see chapter 3), this means that the model reproduces roughness with wavelengths from 10 metres and upwards with very small deviations[2]. By putting the SNRA's ”Procedure at road repairs ” into application, long-wave roughness can be minimised within the framework of the available budget.

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[1] The macrotexture of the road surface affects the level of noise in the surroundings as well as how much vibration and droning, low-frequency noise and infrasound that occurs inside the vehicle. There can be major differences between an intact road surface and surfaces that are separated or damaged in some other way. Technical specifications and manuals can provide support when choosing the type of wearing course and measures to ensure a good, uniform texture.

[2] If the existing road surface has extensive roughness with wavelengths shorter than 10 metres, where the amplitude is large in relation to the wavelength, the measurement quality in the reproduction of the roughness profile can be abnormally poor; e.g such as where the surfacing consists of paving or cobblestones.

5 Basic principles for statistical tolerance

The geometric pavement model shall be produced with good accuracy and precision. The overriding requirement is that every survey result must lie within a specified tolerance limit with a 95.0 percent probability.

The foregoing probability requirements mean, if the tolerance for a survey parameter studied is ± 5.0 mm for a normally distributed deviation, that:

- if there is not any systematic error, the maximum standard deviation permitted is 2.6 mm
- in the event of a systematic error of either –1.0 mm or +1.0 mm, the standard deviation from this error must be less than 2.4 mm.
- in the event of a systematic error of either –2.0 mm or +2.0 mm, the standard deviation from this error must be less than 1.9 mm.

6 Survey parameters

- Roughness profile in the longitudinal direction of the road
- Cross-section at right angles to the roughness profile shown at specified intervals in the longitudinal direction of the road
- Horizontal curvature
- Road environment video, to show major surface damage and facilitate proper crossfall design.

The following chapters contain more in-depth information about the individual survey parameters as well as detailed requirements concerning these.

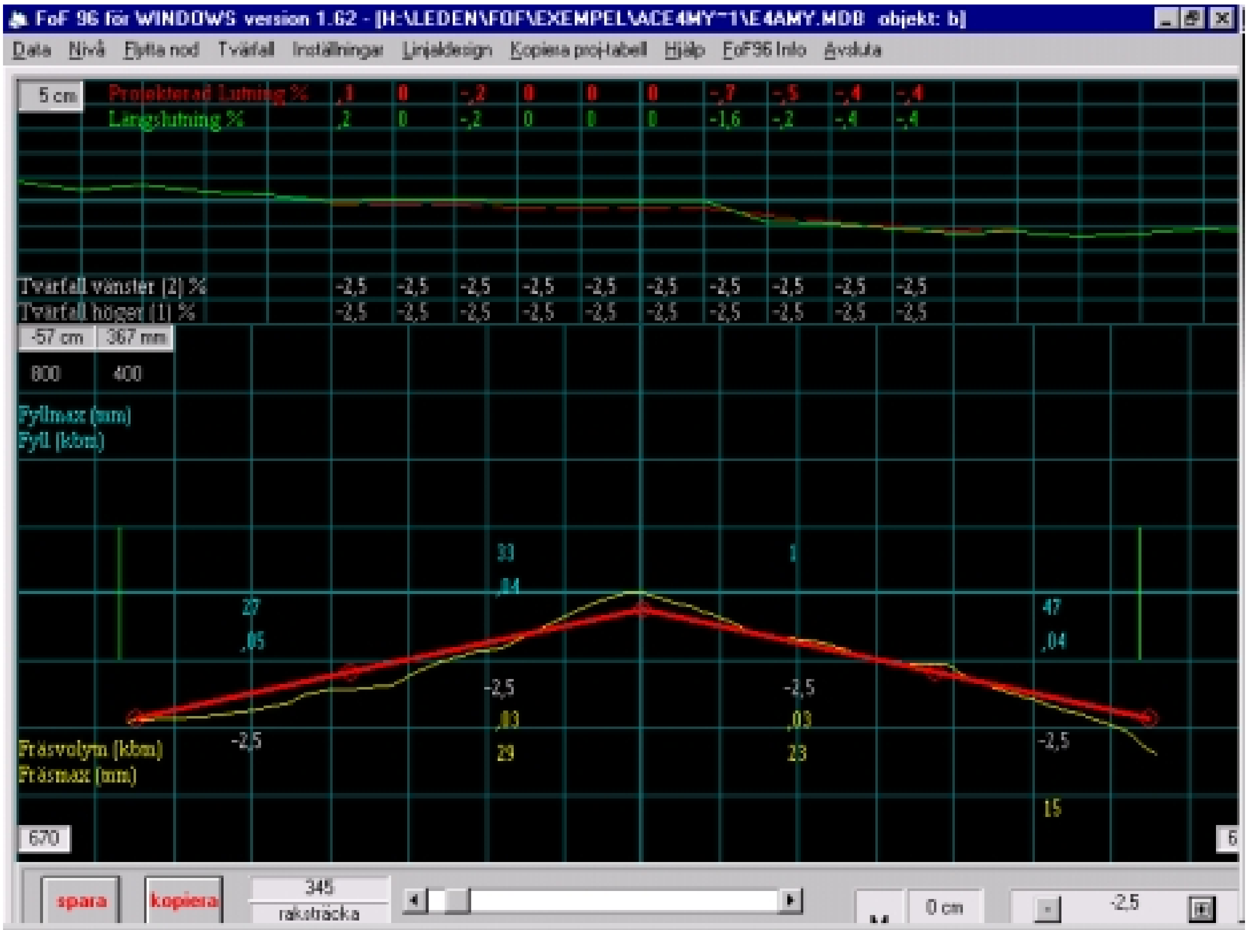

Figure 3 Geometric pavement model (green and yellow thin solid line), excluding the road environment video, used in the CAD environment. Above is the roughness profile, below the cross-section. The dotted and thick red lines show the milling as designed.

6.1 Geographical reference points and specially marked sections

The client/user of the geometric pavement model defines the borders between survey objects and decides the lateral position for the roughness profile. The roughness profile is a reference for both the longitudinal measurements and for determining differences in level. It is often of advantage for the lateral position of the roughness profile to coincide with the existing centre line marking. The starting section shall be linked to the SNRA's longitudinal reference section within a tolerance of 5 m. All positions shall be related to the real longitudinal position along the roughness profile, as well as to the lateral position at a right angle to this. The position shall <u>not</u> be according to the horizontal distance in an (x, y) reference system.

The lateral position of the roughness profile, the starting and end sections, sections supporting longitudinal positioning c/c 500 m, as well as any subdivisions of the survey object (at traffic islands, etc) shall be clearly marked on the road along with the distance indicators and be clearly recorded on the road environment video recording.

The lateral position of the roughness profile and specially marked sections shall be <u>related to permanent reference points</u> in the plan used. Moreover, the starting and end sections shall be <u>related to permanent reference points</u> as regards the height in the RH70 height system or a local height system. Linking to the height system means that the contractor can choose automated and robotics-based techniques that include geodetic instruments such as a totalstation. However, in such a case, it is up to the contractor himself to solve the problem of errors in heigth along the roughness profile.

7 Roughness profile

The measurement values shall show the level of the road along the lateral position that has been agreed upon with the client/user of the geometric pavement model. They shall agree with the differences in level compared to each of the sections 5, 10, 15 and 20 metres ahead, and 5, 10, 15 and 20 m behind. See Figure 3. Normally, the lateral position coincides with the centre road line marking, but there can be exceptions, such as on divided highways. See chapter 6.1.

It should be noted that the vertical position of the end section is given in two ways:

1. The level of this section is given in relation to the previous sections. It is this level indicator that is used to describe the roughness profile. This facilitates the use of simple automated and robotics-based techniques on the existing roadway.
2. The height of the section is given in the RH70 height system or in a local height system. This makes it possible to use automated and robotics-based techniques, which include geodetic instruments such as the totalstation. In this case it is the contractor who is responsible for handling height errors along the roughness profile.

7.1 Resolution

Values for the level of the roughness profile shall be presented every 5 metres along the road. The vertical resolution shall be 1 millimetre.

7.2 Tolerance

- Vertical, in relation to the adjacent sections according to the above: ± 5.0 mm.
- Horizontal, in relation to the lateral position of the roughness profile: ± 100 mm.

8 Cross-section

The cross-section at a right angle[3] to the roughness profile shall be produced from the measurement values (maximum 10 cm intervals in the longitudinal direction of the road) which are based on the average values on a stretch 2.5 m ahead of and 2.5 m behind the actual longitudinal section in case. The survey shall be carried out so as to show the maximum rut depth.

Specific values in the relevant cross-section shall refer to the difference in level in relation to the roughness profile.

8.1 Resolution

Cross-sections shall be presented every 5 metres along the road.
The cross-section shall be presented with a lateral resolution not exceeding 250 mm.
Vertically, these values shall be presented at a resolution of 1 millimetre.

8.2 Tolerance

- Difference in level in relation to the roughness profile: ± 5.0 mm.
- Horizontal, in relation to the lateral position of the roughness profile: ± 100 mm.

[3] Horizontal curves require special attention when producing the geometric pavement model.

9 Horizontal curvature

The design of the crossfall and banking transitions is carried out on the basis of the road environment video, the cross-section measured and the horizontal curvature (curve radius).

The horizontal curvature is produced from values averaged over a distance of 20 metres along the road.

9.1 Resolution

- A radius of less than 100 m shall be presented with a resolution not exceeding 10 metres.
- A radius between 100 and 1 000 m shall be presented with a resolution not exceeding 100 metres.
- A radius between 1 000 and 10 000 m shall be presented with a resolution not exceeding 1000 metres.
- A radius greater than 10 000 m shall be presented as a radius of 99 999 metres (straight stretch).

9.2 Tolerance

The tolerance for horizontal curves is ± 20 % of the survey result.

10 Road environment

The road environment shall be recorded on video (VHS) to make it possible for road designers at the office to relate the survey parameters in the geometric pavement model to the roadside areas. The markings in accordance with chapter 6.1 shall be clearly recorded on the film.

The road surface (orthogonal projection) shall also be recorded on video in order to display larger surface damages, alligator cracks, etc.

The longitudinal positions shall be displayed on the videotape at a resolution not exceeding 1 m.

11 Data format

11.1 Subdivisions

The following shall be delivered in ASCII-format for every subdivision within the project in accordance with the SNRA road databank:

VARIABLE	TERM	FORMAT	UNIT
From node	KNPA	999999999	
Towards node	KNPB	999999999	
Starting section	STARTSEKT	+/- 999999,99	m
Heigth at start	STARTNIVA	+/- 9999,99	m
End section	SLUTSEKT	+/- 999999,99	m
Heigth at end	SLUTNIVA	+/- 9999,99	m
Road network version	VAGVERS	YYYYMMDD	
Date	MATDAT	YYYYMMDD	
County	LAN	99	
Road number	VAGNR	999999	
Lateral position	SIDOLAGE	9	
N^{o}. of values in the profile	ANTALIPROF	99999	

Nodes; are specified with 9 digits: map page (4 digits), A node (3 digits) and M node (2 digits); e.g., 091401200.

Road network version; indicates the date of validity of the road network. If the link has not been re-constructed, the date given on the reference map applies.

Starting section; number of metres from KNPA (node A). Specified with 8 digits, including 2 decimal points; e.g., 000341.72.

Heigth at start; co-ordinate of height in a height system (RH70 or local). Of importance in those cases when the contractor intends to use geodetic instruments in his automated and robotics-based system. Specified with 6 digits, including 2 decimal points; e.g., 0342.47.

End section; number of metres from KNPA (node A). Specified with 8 digits, including 2 decimal points; e.g., 0012681.07.

Heigth at end; co-ordinate of height in the height system (RH70 or local). Of significance in those cases when the contractor intends to use geodetic instruments in his automated and robotics-based system. Specified with 6 digits, including two decimal points; e.g., 0355.69.

County; county number 02-25.

Road number;
Main number 4 digits, sub-number 2 digits; e.g., E4.02 is written as 000402

Lateral position; specifies the lateral position of the roughness profile. 1 for a painted centre line, 2 for a painted edge line on the left-hand side, 3 for a painted edge number on the right-hand side, 9 refers to a specially recorded lateral position.

Number of values in the profile; shall agree with the distance to be surveyed divided by the resolution of the roughness profile, plus one. Specified with 5 digits; e.g., 01457.

11.2 Measurement point (cross-section)

The following shall be delivered in ASCII-format for every measurement point (cross-section) along the roughness profile in accordance with the SNRA road databank:

VARIABLE	TERM	FORMAT	UNIT
Longitudinal position of the section	SECTION	+/-99999	m
Heigth of roughness profile	OJAMNNIVA	+/-999999	mm
N°. of measurement values in the cross-section	ANTALITVAR	999	
Transverse position 1	TVARPOS1	+/-99999	mm
Transverse position 2	TVARPOS2	+/-99999	mm
.			
.			
Transverse position 999	TVARPOS999	+/-99999	mm
Level position 1	NIVA1	+/-9999	mm
Level position 2	NIVA2	+/-9999	mm
.			
.			
Level position 999	NIVA999	+/-9999	mm
Curve radius	RADIE	+/-99999	m

Longitudinal position of the section; number of metres (multiple of 5m) from the starting section. Specified with 5 digits; e.g., 00200.

Heigth of the roughness profile; specifies the relative level of the roughness profile along the section. Specified with 6 digits; e.g., 001043. The level at the starting section shall be the same as the height of the starting section in the height system (RH70 or local). The level of the end section shall be specified in relation to the level of the prior sections, i.e., <u>not</u> as the height of the end section in the chosen height system.

Number of values in the cross-section; shall agree with the width of the cross-section divided by its lateral resolution, plus one. Specified with 3 digits; e.g., 065.

Transverse position 1-999; specifies the lateral position of every value, calculated from the lateral position of the roughness profile. The left side is indicated by a minus sign. Specified with 5 digits; e.g., -00360.

Level position 1-999; specifies the level in lateral positions along the cross-section in relation to the level of the roughness profile in the cross-section. Levels below the level of the roughness profile in the cross-section is indicated by a minus sign. Specified with 4 digits; e.g., 0087.

Curve radius; radii greater than +/-10000 m are given as 99999. A left-hand curve is indicated by a minus sign. Specified with 5 digits; e.g., -00900.

12 References

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Vägverket

SE-781 87 BORLÄNGE, Sweden.
Telephone +46 243 750 00. Telefax + 46 243 753 25. Text telephone +46 243 750 90
E-mail: vagverket@vv.se / Internet: www.vv.se