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Road quality service levels and innovations to meet user expectations

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SUMMARY

The Pavement Management System (PMS) is an important instrument for a road management, aimed at the serviceability of pavements, with an important objective – to maintain the service level with respect to road users.

The experience with the implementation and application of PMS is, that it is necessary to differentiate between the use of diagnostic devices for measuring parameters of serviceability on pavements, for evaluation of road network condition, or measurements dedicated to become the inputs of the pavement rehabilitation design for a particular road section. The measuring of quality parameters on pavement is possible by means of quite a wide variety of efficient measuring devices and equipment. The criteria for the assessment of meeting needs were derived, with the priority put to a traffic safety. Comparing the evaluation of asphalt pavement condition on motorways and 1st class roads gives the results that rutting and longitudinal unevenness occur on motorways in a small proportion, only 0.5 % of the motorway length is in an emergency condition, whereas for the 1st class roads this extent is up to 1.9 % of their length.

The results of theoretical designs as well as the calculations of permanent deformations on asphalt pavements became the basis for the rehabilitation planning for asphalt pavements. The asphalt pavements, based on its mechanics, can be divided into flexible and semi-rigid pavements. The depth of rutting is derived from the permanent deformation.

The PMS requires a permanent development of diagnostic technology, as well as the accuracy verifications of criteria for a condition evaluation. The highest importance is given to aggregated evaluations of measured parameters.

A SERVICE QUALITY INDICATORS

A road user requires a good quality of road communication, which provides him a fast, safe, continuous and economical drive. These parameters, at the same time, represent the main criteria of serviceability, defining the quality of road communication in the consideration of its administrator. The serviceability is represented by these 4 basic characteristics of surface properties – a skid resistance, longitudinal unevenness, cross unevenness (depth of rutting) and pavement surface deterioration.

All the main parameters of serviceability, except for roughness, are related to the parameters of operation performance of pavements, describing the sufficiency to resist the impact of traffic.

Systematic measurements of pavement condition parameters, in Slovakia, has been performed since 1997, even though the first measurements of pavement bearing capacity were done in 1993.

Pavement diagnostics

The measuring by means of various diagnostic devices, as well as the elaboration and evaluation of measured data is done by the Road Data Bank Department at the Slovak Road Administration. Diagnostic measurements are being performed throughout the whole road network of the Slovak Republic. Several technical regulations were developed either for the operation of particular measuring devices or for data evaluation.

A1 Skid Resistance

Skid resistance of pavement is characterised by the interaction of a particular road surface and a tyre on physical base of the surface texture. It is described by a longitudinal friction coefficient. The basic elements of this interaction are micro-texture and macro-texture. The high values of both textures are desirable, concerning the friction force. Generally speaking, the micro-texture provides the high level of friction and macro-texture is necessary for drainage of surface water from pavement surface.

Commonly used methods of measuring and evaluating of pavement skid resistance are the friction measurement by TRL portable skid resistance tester and texture measurements by means of sand patch test. These methods are not susceptible for the large scale data collection. They have a local character and the sand test is influenced by a human factor. From this point of view, the development tends to continually working devices for the evaluation of long sections. In the Slovak republic, the SKIDDOMETER is used for skid resistance measurements.

A1.1 Skid resistance evaluation

The evaluation of skid resistance and creating of classification levels are based on the known standard criteria. As the SKIDDOMETER is not yet included in Slovak standards, the evaluation criteria were determined on the base of combined regression analyse. The TRL skid resistance tester values and sand patch test values were taken into consideration. The values were recalculated to 80 $km.h^{-1}$ speed, selected in accordance with the comparable Slovak standards.

The evaluation of surface skid resistance is created in accordance with the requirements of the Pavement Management System (PMS). The five-grade scale evaluation is applied for each variable parameter, except for skid resistance, where the three grade scale evaluation is used. The classification of pavement for the speed of measurement 80 $km.h^{-1}$ is presented in the Table 1.

Table 1 - Classification of skid resistance

Evaluation	Design speed $v_n >= 80\ kmh^{-1}$	Design speed $v_n < 80\ kmh^{-1}$
Unsatisfactory pavement	Mu < 0.53	Mu <0.53
Satisfactory pavement	0.53 < Mu ≤ 0.79	0.53 < Mu ≤ 0.68
Good pavement	Mu >0.79	Mu >0.68

In many cases it is not possible to provide the measuring speed 80 $km.h^{-1}$. For this reason, the recalculation equations to the most commonly used speed, 60 and 100 $km.h^{-1}$, were developed. The equations for recalculation to a different speed are:

Mu (80) = 0.944 x Mu (60)

Mu (80) = 1.007 x Mu (100)

A1.2 Homogeneous sections

In accordance with the other variable parameters, the basic evaluation step is 20 m. The final value of skid resistance for a particular section represents an average value, obtained from twenty values one-meter long portions. The homogenisation is based on the comparison of adjacent values. The limit for the creation of a new homogeneous section is 25% difference of values. This percentage rate was based on comparison of the various statistical methods for a homogenisation process. The above mentioned approach pointed the best coincidence with the minimum length of homogeneous section from the point of view of pavement rehabilitation.

A2 Pavement Distress

The condition of pavement surface is evaluated based on an extent and variety of pavement distress. Survey of road surfacing defects can be performed by means of the device VideoCar, as a rapid visual condition survey with recording a limited number of distress groups directly into computer. Detailed visual condition surveys are performed as a survey of operators on site with graphical record of defects into a standardised form. These graphical records are consequently recorded into the database of computing program followed by statistical elaboration and evaluation. Whereas the majority of pavements in Slovakia has an asphalt surfacing, the further analysis are performed with this type of pavement only.

A2.1 Visual condition surveys

The methodology of detailed visual condition surveys defines 23 types of defects in extravilan and 9 types occurring usually on roads in an intravilan.

General types of defects were elaborated to create the Catalogue of Defects. According to the pavement distress evaluation they can be divided into four main groups:

1. defects, that must be repaired immediately: pothole and subsidence,
2. failures of surfacing: insufficient skid resistance (surface bleeding and polishing), stripping of binder and stripping of aggregate,
3. failures signalising the distress of pavement structure: cracks, ruts, planar deformation, pavement rupture,
4. other defects: defective edge of pavement, wrong drainage, bad condition of shoulders, incorrect construction joints.

The above mentioned dividing of defects into four groups was developed for the purpose of the utilisation of visual condition survey data for evaluating pavement distress. This represent one of the main data sources for optimal disposal of financial means for road maintenance and repair. In the process of selecting sections, that need to have the bearing capacity measurements performed and the necessary overlay thickness designed, only the defects from the third group, that signalise the insufficient bearing capacity, are taken into consideration. It is assumed, that the defects from the first and second groups will be replaced immediately, so they are not taken into consideration. This way of evaluation is called a SELECTIVE EVALUATION.

Forasmuch as the road administrators need to know the actual and complete road condition and they are supposed to evaluate it, in some cases only based on visual condition survey. For this reason, the COMPLEX EVALUATION includes all the regarded defects. At the complex evaluation the overall condition is markedly much worse, than at the selective evaluation, as it expresses the pavement condition based on all the defects. The complex evaluation differentiates the defects, based on their seriousness, as follows:

- dangerous defects – e.g. pothole and manhole subsidence,
- serious defects – e.g. cracks, ruts, deformation, surface deterioration and surface disintegration,
- less serious defects – e.g. defective edge of pavement, other defects and incorrectly performed repair.

At the evaluation of defects, their extent was taken into consideration, i.e. the percentage of their impact to an overall quality of pavement. As for dangerous defects the use of classification degree 5 is assumed by 15-20% occurrence of such defects on a particular pavement. As these defects usually have quite small surface area, their importance at the calculation is evaluated by a multiplex coefficient. The serious defects represent the crucial element in calculation, according to this methodology. Such defects are weighted by their actual value. The less serious defects do not have any direct impact to the serviceability of pavement. They express the danger of occurrence of some more serious defects. For this reason they are in the methodology weighted by coefficient less than 1.

The evaluation of pavement surface condition is performed whereby IPSV (Pavement Distress Index). The evaluation criteria were proposed separately for following groups of communications:

- *Criteria for motorways, expressways and 1st class roads:*

$$IPSV = 5{,}03 - 0{,}07\ (P + O) - 1{,}53\ z^2$$

- *Criteria for 2nd class roads:*

$$IPSV = 5{,}03 - 0{,}0625\ (P + O) - 0{,}855\ z^2$$

- *Criteria for 3rd class roads and municipal roads:*

$$IPSV = 5{,}03 - 0{,}0625\ (P + O) - 0{,}19\ z^2$$

Where: IPSV is Pavement Distress Index
P - surface area of defects in %,
O - surface area of repairs in %,
z - depth of rutting in cm.

In addition to the pavement surface condition evaluation, based on an IPSV parameter, it is possible to evaluate a pavement condition, based on failure density as an independent parameter. The criteria for both approaches are shown in the Table 2.

Table 2 - The evaluation criteria for the pavement surface condition, based on the results of detailed visual condition survey

IPSV	***Failure density for section (%)***	***Classification degree***	***Evaluation***
5,03 – 4,00	0, 00 - 16,00	1	Excellent condition
3,99 – 3,00	16,01 – 32,00	2	Good condition
2,99 – 2,00	32,01 – 48,00	3	Satisfactory condition
1,99 – 1,50	48,01 – 56,00	4	Unsatisfactory condition
< 1,50	> 56,00	5	Emergency condition

A2.2 The evaluation based on the results of measurements by the device VideoCar

For the pavement distress evaluation by means of the device VideoCar, the defects are classified in six aggregated groups. The aggregated groups have associated the following codes, that are used for data logging while performing data collection:

- Longitudinal crack – code 1 – parallel with the centre line of pavement. It can be caused by the insufficient bearing capacity of pavement. The insufficient interactions of structural layers can cause its combination with alligator cracking. This aggregated group also includes a defective edge of pavement and repaired longitudinal cracks.
- Transverse crack – code 2 – has predominantly perpendicular direction towards the centre line of pavement. It is caused by the thermal contraction of pavement, as reflective cracks from the cement bounded base courses, or as the combination of frost cracks and reflective cracks. Repaired transverse cracks are also reported as defects.
- Surface distress – code 3 – it includes alligator, mosaic and block cracking and disintegration of pavement surface. The typical attribute of these defects is the system of, at first narrow, less accentuated cracks, followed by their gradual widening, and afterwards scaling into small potholes. The size of the crazing is from 0.15m to 0.40m. This group also includes the massive longitudinal snapping off the edge of pavement combined with the alligator cracking, strong scaling, deep polishing, stripping of binder or aggregate outgrowing into a total surface disintegration. The pavement disintegration is characterised by an abnormal stripping of binder or aggregate, at several places outgrowing into small potholes.
- Pothole – code 4 – includes potholes – either in wearing course or base course. They result from an intensive stripping of aggregate as the effect of moving vehicles. Following the impact of load and climatic effects (atmospheric water, frost, etc.) potholes can deepen to the joint of a wearing course and base course.
- Deformation – code 5 – into this aggregated group of failures belong – corrugations, side humps, local depressions, transversal subsidence, ridging and slippage of surface layer, area flows, local humps, disintegration of pavement and longitudinal rutting.
- Local repairs (patches) – code 6 – this aggregated group consists of all the local repairs of surfacing or the whole structure of pavement.

- Longitudinal wheel tracking (rutting) – code 7 – an apparent rutting in a wheel track.

At performing a visual condition survey, particular aggregated groups are logged into a computer by the above-mentioned codes by means of a special console. Failures are recorded as:

- linear failure - 1 longitudinal cracking
  - 7 longitudinal rutting
- spot failure - 2 transversal cracking
  - 4 pothole
- area failure - 3 surface distress
  - 5 deformation
  - 6 local repairs

Area failures are entered as linear, if their width is within one carriageway only. If a particular failure was entered for the width of one traffic lane, its beginning and end would be entered. If the failure occurs in adjacent lanes too, it would be entered as a double record.

Area of failures subsuming:

- scattered cracks, transversal and longitudinal, are multiplied by the width 1,0 m, at which the impact of a crack to a road structure is expected,
- area failures (failures of surfacing, pavement deformations and local repairs) are defined by a beginning and end of failure, which specifies its length. They have the width associated of either one traffic lane or a whole pavement. Regarding the impossibility of correct evaluation of the area of failure, it is summed by a half of the marked area, representing a whole width of traffic lane,
- potholes are divided into small with the area of 0,5 m^2 and large of 1 m^2,
- a total percentage contribution of the area of repairs and failures is defined as their proportion from a total area of section,

Considering an information efficiency and accuracy of rapid visual condition survey data, the pavement distress evaluation is processed into three classification degrees. Evaluation criteria are shown below in the Table 3.

Table 3 - Evaluation criteria for pavement distress based on IPSVcar
(for motorways, expressways, 1^{st} and 2^{nd} class roads)

IPSVcar	Classification degree	Evaluation
5,03 - 3,76	1	Excellent condition
3,75 - 2,50	2	Satisfactory condition
< 2,50	3	Unsatisfactory condition

A3 Surface Deformation

Longitudinal and cross surface deformations represent important parameters of service ability of pavements, however the longitudinal unevenness has a significant contribution to a decline of driving comfort. On the other hand, a wheel tracking in combination with water creates a possibility of aquaplaning, which represents a significant element of road safety degradation. This was an important issue for an evaluation of above mentioned parameters, regarding the operational ability.

A longitudinal unevenness is characterised by its length and its amplitude. Crossing particular unevenness causes an oscillation process, as a relation of damped and undamped masses of vehicle, followed by a noticeable variation of drive comfort. This phenomenon became a basic component in the elaboration of operational ability based on a longitudinal unevenness. However, a specific combination of a wavelength and its amplitude can also cause an evident reducing of contact pressure of a tyre towards pavement, possibly followed by a loss of their contact.

An evaluation of longitudinal deformation is performed in two ways. For the evaluation, except for the PMS, a double-mass measure is used, which evaluates longitudinal deformations by a parameter called – Inequality Index – C. Within the PMS the continually working device Profilograph is used. This device measures a spatial image of pavement surface using a system of laser sensors. An evaluative factor of longitudinal deformation is the International Roughness Index – IRI.

A3.1 Measurement and evaluation of longitudinal deformation by means of the device Profilograph

The maximal IRI value from all the values, measured by 2nd to 14th lasers, is treated as a representative value of longitudinal unevenness for a particular traffic lane. Data from utmost laser sensors (1st and 15th), in regard to their position towards the wheel track of a particular traffic lane, are excluded from this evaluation.

Longitudinal unevenness is classified in a 5-grade classification scale. The evaluation is performed for 100 m-long-sections with specified extremes obtained from an evaluation of 20-m-sections. Such specification of extremes supports a searching for local defects of pavement evenness, e.g. bridge dilatations, railway crossings etc. The classification is shown in the Table 4.

Table 4 - Evaluation of a longitudinal deformation based on IRI [m.km^{-1}] for the length 20 m

Classification degree	Motorways and expressways	1st and 2nd class roads	3rd class roads and municipal roads
1	< 1,90	< 1,90	< 3,30
2	1,91 – 3,30	1,91 – 3,30	3,31 – 5,00
3	3,31 – 5,00	3,31 – 5,00	5,01 – 8,00
4	5,01 – 8,00	5,01 – 10,00	8,01 – 14,00
5	> 8,00	> 10,00	> 14,00

A3.2 Evaluation of transversal deformation

A transversal deformation is interpreted as a depth of rutting. Measurements are performed by the device Profilograph and are elaborated along with a longitudinal deformation. The criteria consider the particularity of measured parameter. From the safety point of view, the water depth in a wheel track is regarded as the most substantial. It is not evaluated till now. Its value is markedly lower than a depth of rutting.

A specific value of rut depth for a traffic lane is interpreted as a higher value from both average depths of left and right wheel track. For the evaluation of a pavement en block, the representative value is defined as a maximum of representative values from carriageways. (This approach is not applied on motorways, where every traffic lane is evaluated separately). An average depth is calculated statistically from 20 1m-long-section values obtained from laser sensors. The evaluation includes data from all (15) of the laser sensors. Transversal deformation of pavements is classified according to a 5-grade scale as well as other parameters for the PMS. The classification for different types of communication is shown in the Table 5.

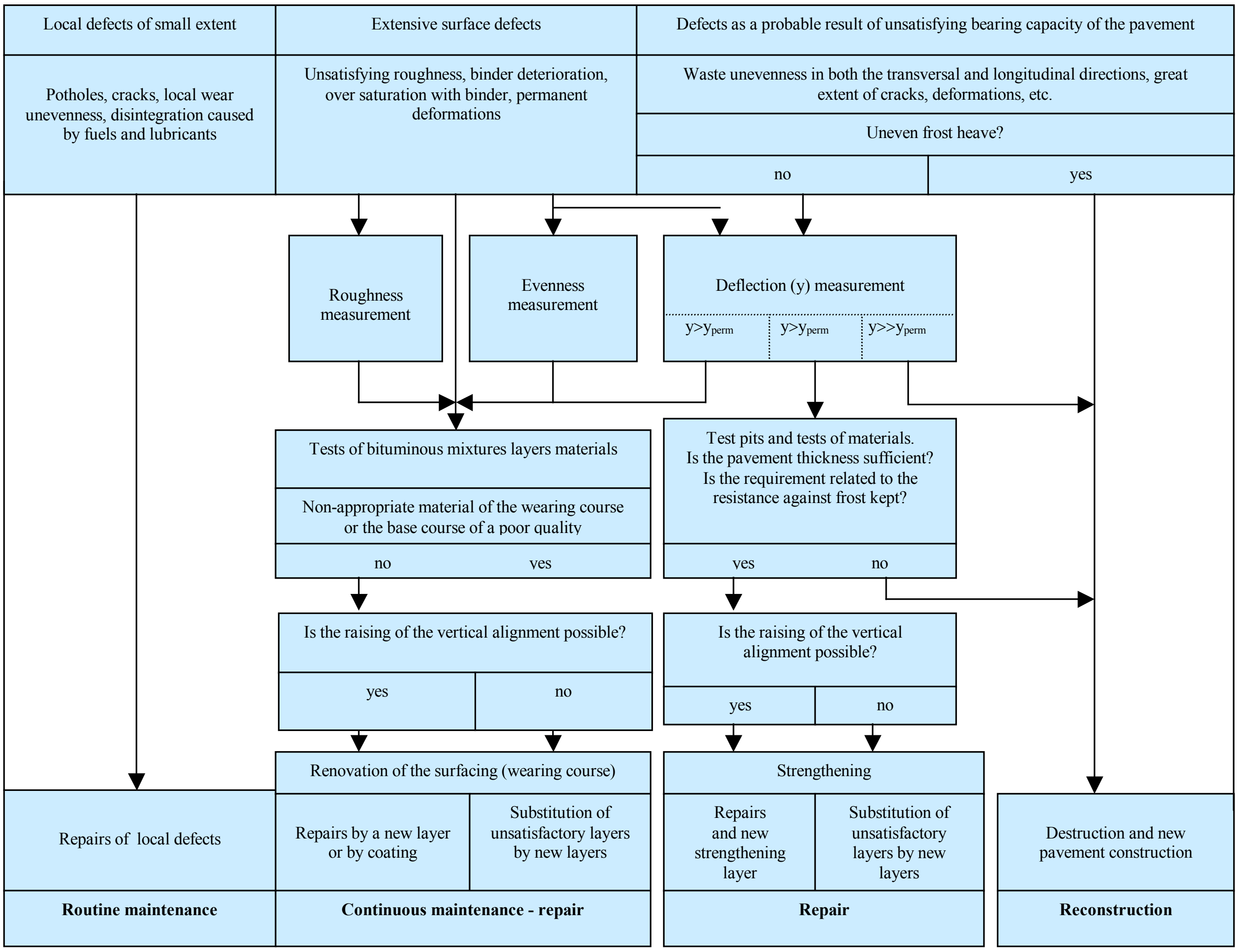
Table 5 - Evaluation of a transversal deformation based on rut depth [mm]

Classification degree	Motorways and expressways	1st and 2nd class roads	3rd class roads and municipal roads
1	< 5,00	< 5,00	< 10,00
2	5,01 – 10,00	5,01 – 10,00	10,01 – 15,00
3	10,01 – 15,00	10,01 – 15,00	15,01 – 20,00
4	15,01 – 20,00	15,01 – 25,00	20,01 – 30,00
5	> 20,00	> 25,00	> 30,00

The homogeneous sections for the evaluation of both parameters are created together with a data conversion, based on a 25% difference between the representative value of a particular parameter for the homogeneous section and the new value, already being converted.

A3.3 Serviceability evaluation regarding the depth of rutting

The cautionary value for the evaluation of serviceability is the classification degree "4". Provided the value of rut depth over 15 mm (motorways, expressways, 1st and 2nd class roads) or over 20 mm (3rd class roads and municipal roads) it would be necessary to impose speed limitation to 80 km.h^{-1}. The boundary value is the upper boundary of the classification degree "4". When exceeding this value (20, 25 or eventually 30 mm) the pavement would be, as for its cross unevenness, unable to serve road traffic.



Picture 1 - Scheme of decision process

Elaborated data of different parameters of serviceability are used for the decision procedures in the Pavement Management System. For its complex utilisation it is necessary to attach to it some additional data of its operational capacity, represented by the value of pavement bearing capacity. A consequential analysis within decision procedures serves the assessment of urgency for a particular repair or eventually re-construction of section. Economical analysis consequently enables the design of optimal technology and time, meanwhile is the rehabilitation essential. The whole scheme of this decision process is shown in the Picture 1.

Pavement Diagnostics

Systematic measurements of pavement distress parameters are being performed in Slovakia since 1997. Measurement of deflexion, by which a bearing capacity is evaluated, are being performed since 1993. Surveys with particular diagnostic devices, as well as the elaboration and evaluation of data is performed by a specialised department at the Slovak Road Administration. Diagnostic surveys are performed throughout the whole road network of Slovakia. These activities proceed in compliance with the appropriate technical regulations, developed in the co-operation with universities – the University of Žilina and the Slovak University of Technology in Bratislava.

KUAB 2m-150

The diagnostic device KUAB 2m-150 is used for deflection measurements dedicated to the determination of pavement bearing capacity. These measurements serve the several purposes:

- repeated measurements of long term observed sections, for the objective to create degradation models (20-m step of measurement at observed traffic lanes),
- measurements of sections (projects), proposed for pavement rehabilitation - for the determination of the permanent life of pavement and the design of pavement strengthening (measurement step 40 m, using a checkerboard system – 50 % skipping in opposite direction),
- investigative measurements, in order to obtain basic overall information about the pavement condition at the larger extent of road network. (200-m step, checkerboard system),
- measurements, serving research projects and projects of technical development (measurements at the circular testing track of the company "VUIS-cesty" Ltd.),

measurements at the cement-concrete runways of airports (different loads, and different approach to the selection of measuring points and load sequence, compared to flexible and semi-rigid pavements)

PROFILOGRAPH GE

The device provides the acquisition of data about pavement longitudinal and cross unevenness. It is mainly used for:

- measurements of long term observed sections, for the creation of degradation models,
- continual measurements of whole road routes at motorways, 1st class roads and 2nd class roads (the projects (sections), proposed for pavement rehabilitation are included here), 2nd class roads are measured every other year,
- measurements of already completed construction for the purpose of acceptance tests,
- measurements for research projects and projects of technical development,
- determination of geometric alignment of road communication,
- survey of traffic engineering characteristics,

Picture 2 - The diagnostic device KUAB 2m-150

Picture 3 The diagnostic device PROFILOGRAPH GE

SKIDDOMETER BV 11

Within the framework of pavement diagnostics, the longitudinal skid friction of pavement is measured by the device Skiddometer. The following measurements are performed:

- measurements of long term observed sections, for the creation of degradation models,
- survey at selected black spots (sections selected based on statistical elaboration of accident register, i.e. the sections with high accident rate, caused by slippery road),
- determination of the overall condition of pavements as of longitudinal skid friction at longer contiguous road sections,
- comparative measurements – comparison of results with other devices, or technical equipment, for the determination of surface roughness on behalf of the criteria enhancement for the evaluation of results.

Picture 4 The diagnostic device SKIDDOMETER BV11

VIDEOCAR

The device Videocar provides rapid visual inspections of pavement. Specifically it is used for:

- survey of pavement failures at contiguous sections (including the projects (sections), proposed for pavement rehabilitation, hereby is performed the check test for the quality of the visual condition surveys performed by road administrators),
- survey for the actualisation of selected inventory data in the Road Data Bank,
- digital-optical record of the situation at a particular road communication.

Picture 5 The diagnostic device VIDEOCAR

These diagnostic devices, regarding their qualitative level enable the objectively determine the serviceability and operation capacity of pavements on roads and motorways. The applied methodology of measurement must conform with the specific purpose of data.

The results of measurements and pavement diagnostics are being used for the following purposes:

- ***Acquisition of the review on an overall condition of pavement for roads and motorways***

The efficiency of these devices enables repeated annual diagnostics of pavements throughout the voluminous road network in the Slovak republic. By these means obtained data give an objective and overall review about the condition of road network, e.g. as for cross unevenness (depth of rutting), longitudinal unevenness (IRI index), or the other parameters of pavement. This data can be used for the network level of Pavement Management System, for preparing budget for the forthcoming period or as an information support for decision makers in the distribution of finances (ministry, parliament, government)

- ***Obtaining of essential inputs into the Pavement Management System, for the preparation of the plan for pavement rehabilitation on roads and motorways.***

By means of pavement diagnostics the data about pavement condition is acquired in such detail, accuracy and quality, which would be practically impossible to be obtained through any other alternative method. This data is used in the algorithms of the PMS prioritisation model, by means of which the priority list of sections for pavement rehabilitation is prepared. The priority list supports the selection of projects for rehabilitation or in the past is was used also when required by foreign banks for the purpose of providing loans for financing pavement rehabilitation.

- ***Data acquisition for the determination of degradation functions and models for different types of road structure.***

Processing the time series of data, obtained by frequent pavement structure diagnostics at some selected sections of road communications, the information on alterations of pavement technical characteristics (degradation) during its operation. The alterations are expressed by degradation functions for particular technical parameters. The degradation functions can be incorporated into the optimisation model for the PMS. It will enable the optimisation of pavement rehabilitation, i.e. determine the optimal time for a specific repair applied on a particular road section. This optimisation also represent a very efficient tool for preparing different scenarios of pavement rehabilitation for different budgetary scenarios for pavement rehabilitation.

- ***Gaining data on the condition of new road and motorway sections for an acceptation process***

Data gained by means of pavement diagnostics at new-built sections, being passed to operation, became an important supporting information in an acceptation process. The observance of defined criteria for pavement parameters, by the contractor, is being tested. The additional measurements are performed during warranty period, or before its expiration. The execution of pavement diagnostics is done in a close co-operation with a central laboratory, regional laboratories and a particular investment organisation or management and maintenance centre.

- ***Gathering or necessary data for scientific and technical development projects.***

The diagnostic technology enables also the data acquisition, that was not done by now, or gathering some special data, that can be used for research projects. E.g. the devices Profilograph and Videocar are used for acquisition of data that were not collected and stored in the Road Data Bank before (e.g. road equipment). The device Profilograph can be also used for completion of geometrical alignment of roads or gaining data traffic-engineering characteristics. The extensive possibilities of these diagnostic devices provide the increase of scientific and technical standard in the road management sector in Slovakia.

The technical regulations, for the evaluation of pavement condition, based on the results of measurements by means of diagnostic technology, were developed. Each parameter of pavement condition has its own evaluation criteria developed. Pavement condition is classified by this five-grade scale of evaluation:

Grade 1 – excellent pavement condition,

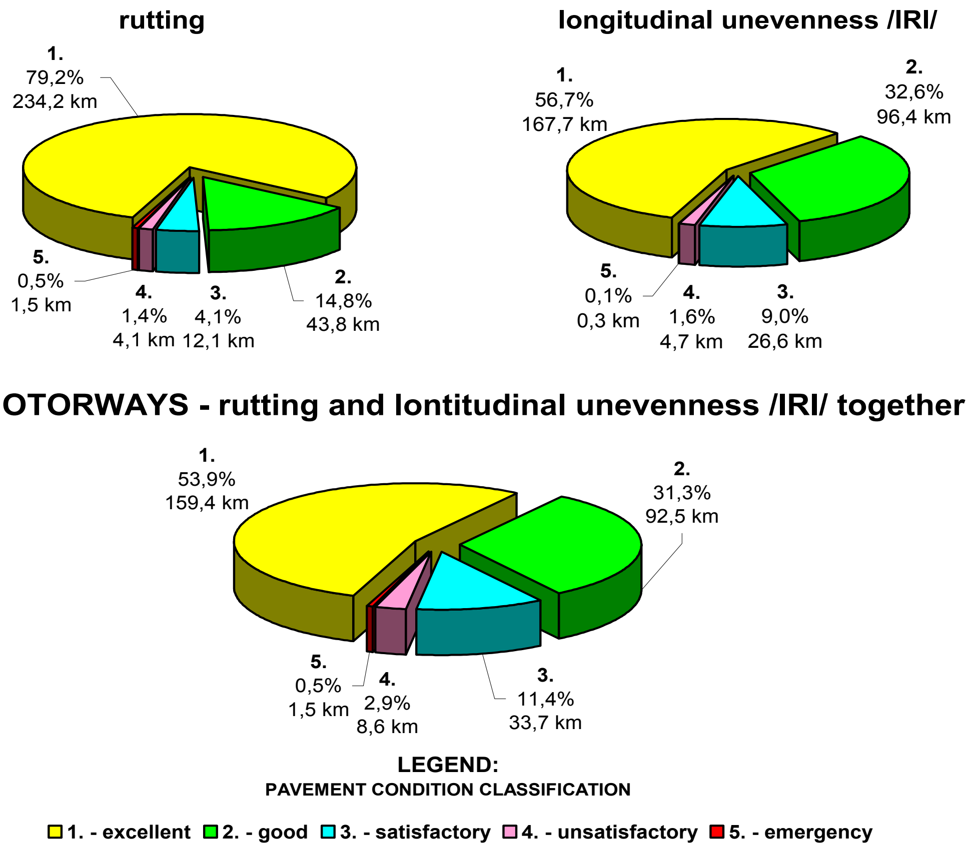
Grade 2 – good pavement condition – pavement fully meets conditions for safe, continuous and economical drive of motor vehicles, and requires an routine maintenance only,

Grade 3 – satisfactory pavement condition – pavement fully meets conditions for safe, continuous and economical drive of motor vehicles, and requires routine and continuous maintenance,

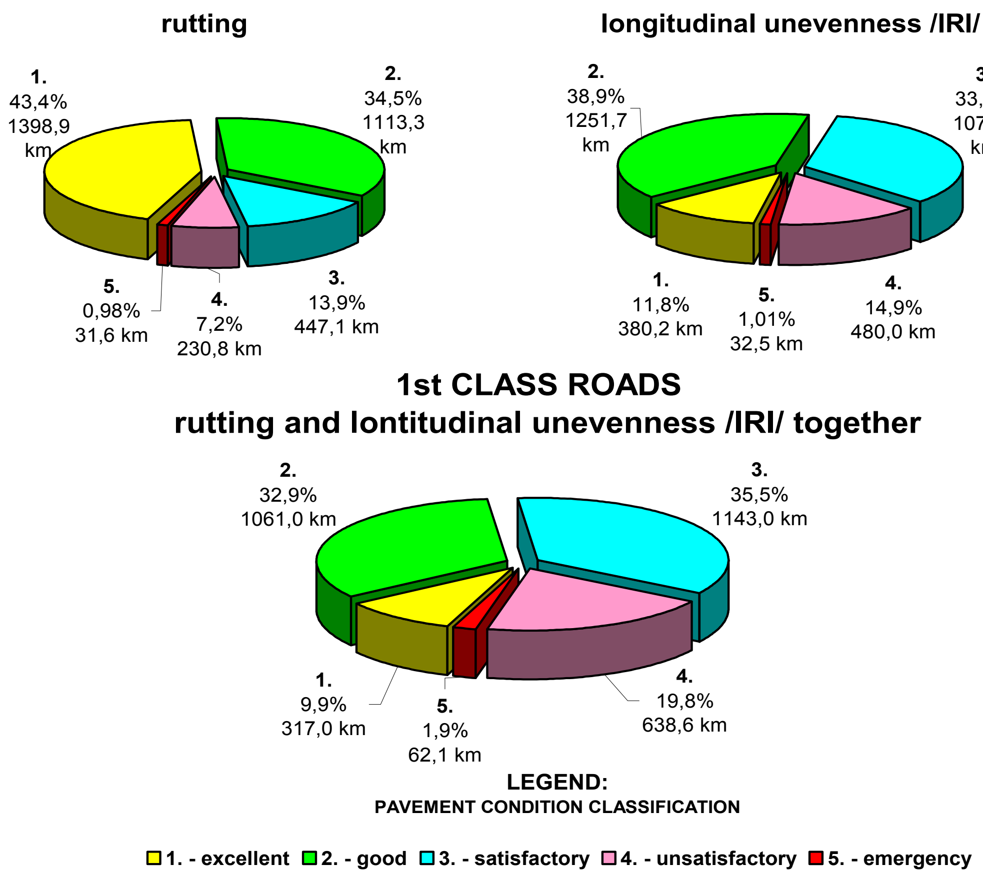
Grade 4 – unsatisfactory pavement condition – pavement fails to meet conditions for safe, continuous and economical drive of motor vehicles, and requires repair,

Grade 5 – emergency pavement condition – pavement does not meet conditions for safe, continuous and economical drive of motor vehicles. Such condition of pavement requires an urgent signing of road by traffic signs (warning and prohibitory signs) and an immediate repair.

The evaluation results, for the asphalt pavements on motorways and 1st class roads in the Slovak republic, are shown by a summary charts in the attached Pictures 6 and 7:



Picture 6 – Condition of motorways as for rutting and longitudinal unevenness (IRI), measured in 2001



Picture 7 – Condtion of 1st class roads as for rutting and longitudinal unevenness (IRI), measured in 2001

B SURFACE DEFORMATION – RUT DEPTHS

An innovated design methodology for asphalt pavements contains rules, requirements and criteria, that are essential to be applied in calculations and examination of pavement structures. It is an analytical, theoretical-empirical design method, that represent an integrated system. At the design of an asphalt pavement structure and consequently at its examination, the standard loading by vehicles and standard condition of its use is considered, i.e. the conditions of sub-grade and climatic conditions. At the examination of a particular design though it is also possible to take non-standard loading and non-standard conditions for the road operation. Or their combination can be applied.

Basic criteria, by means of which is the design of asphalt pavement structure examined are:

A. Protection of pavement against frost penetration
B. Strength and fatigue of bounded materials
C. Stability of unbounded materials
D. Stability of subgrade

The additional criteria for the examination of asphalt pavements is a permanent deformation. An anticipated rut depth is derived from permanent deformations.

Deformation characteristics of different asphalt pavements and their response to the standard and non-standard loading are such, that for the calculation of permanent deformation (and a trace of rut depth) it is necessary to distinguish:

a) flexible asphalt pavement (NT)

b) semi-rigid asphalt pavement (PT)

along with a loading pattern:

Z_1) standard loading, represented by the trucks having an average speed 60 $km.h^{-1}$

Z_2) standard and non-standard loading, represented by vehicles that are decelerating, standing, accelerating, or vehicles with a total weight and axle-load exceeding permitted values

The composition of pavement layers in the structure of asphalt pavement, distinguished, as for its mechanics, as semi-rigid and flexible, have applied different calculations of permanent deformations is shown in the following schemes.

SEMI-RIGID PAVEMENT

Surfacing	1	asphalt mixtures (asphalt concrete)
	2	asphalt mixtures (asphalt concrete)
Base courses	3	asphalt mixtures
	4	mixtures bounded with hydraulic binder (cement stabilisation)
Protective courses	5	unbounded material (aggregate, macadam)
Subgrade		

FLEXIBLE PAVEMENT

Surfacing	1	asphalt mixtures (asphalt concrete)
	2	asphalt mixtures (asphalt concrete)
Base courses	3	asphalt mixtures
	4	unbounded material (aggregate, macadam)
Protective courses	5	unbounded material (aggregate)
Subgrade		

Picture 8 Pavement structure composition – semi-rigid and flexible pavements

B1 Calculation of the Permanent Deformation of Flexible Pavement

The permanent deformation of the asphalt pavement with a flexible structure is calculated using a model, whereat a summary of permanent deformations of particular layers (and sub-grade) is done. The summary is generally expressed by this equation.

$$Y_{trv,NT} = K_p.y_p + \sum_{i=1}^{i=n} K_i\,(y_{pr,i} - y_{pr,i+1}) \qquad (1)$$

where y_p - elastic deflexion at a top of sub-grade, calculated through a model of pavement,

$y_{pr,i}$ - elastic deflexion at the bottom of a layer i,

$y_{pr,i+1}$ - elastic deflexion at the bottom of a layer i + 1 (top course),

K_p, K_i - deformation coefficients, expressing the ratio of elastic and permanent deformations of soil in a sub-grade and different materials used in pavement layers. They also depend on a number of repeated load N,

Elastic deflexions are calculated from a loading by a design axle with a weight 10 t (2P = 100 kN).

In the calculation of permanent deformations, caused by moving vehicles, for a flexible asphalt pavement, the traffic load that accrue to a particular season (spring, autumn and summer) is considered.

Considering the intensity of load and conditions, the equation (1) would be itemised as follows:

$$Y_{trv,NT} = K_p\,.\,y_p + \sum_{i=1}^{n} K_{i,l}\,(y_{pr,i,l} - y_{pr,i-1,l}) + \sum_{i=1}^{n} K_{i,j}\,(y_{pr,i,j} - y_{pr,i-1,j}) \qquad (2)$$

where $K_{i,l}$ is a deformation coefficient for a material of layer *i*, that is calculated from the following equation:

$$K_{i,l} = m\,.\,N_l^n \qquad (3)$$

when $N_l = 0,3\,N_c$ and a coefficient *m*, alternatively an exponent *n* for different materials are shown in the Table 6.

$K_{i,j}$ - coefficient of deformation for a material of layer *i*, when $N_j = 0,5\,N_c$,

K_p - coefficient of deformation for soil in sub-grade, that is shown in the Table 7.

when $N_{def} = 0,5\,N_c + 0,3\,N_c$

where N_c is a design traffic load (for a whole design period) expressed as a number of desing axles.

Table 6 - Coefficient *m* and exponent *n* for the calculation of deformation coefficient K

Material	Slovak Standard's Nomenclature	*m*	*n*
Asphalt mixtures	AB, AKD, AKO	4,5	0,23
	AB-M, AKM, AKT	3,5	0,22
	LA	4,5	0,21
	OK I	4,5	0,25
	OK-M	4,4	0,24
Unbounded aggregate	ŠP	2,0	0,30
	ŠD, ŠV	2,0	0,25
	MSK	2,5	0,22
Macadam	VA, PM	4,0	0,25

Table 7 - Deformation coefficient for soil in sub-grade K_p gets its values according to a bearing capacity of sub-grade

$E_{p,n}$. ≤ 45 MPa	$K_p = 1{,}3 + 0{,}70 \log N_{def}$
$E_{p,n}$ 45 to 60 MPa	$K_p = 1{,}3 + 0{,}65 \log N_{def}$
$E_{p.n}$ > 60 MPa	$K_p = 1{,}3 + 0{,}60 \log N_{def}$

In the calculation of permanent deformation, caused by a standard and non-standard load from vehicles, that brake, stand and accelerate (cause b), it is necessary to define a portion, representing non-standard load, as a part of a total number of design axles - N_{def}. Provided, that this was not defined by an investor, it would be considered, that the portion of vehicles, with negative effects, represents 60% (N_{def}). From the vehicles, impact of which is regarded under average conditions (spring and autumn) their proportion is:

$$0{,}6 \times 0{,}5\ N_c = 0{,}30\ N_c \qquad (4)$$

and during summer conditions

$$0{,}6 \times 0{,}3\ N_c = 0{,}18\ N_c \qquad (5)$$

At the calculation of permanent deformations, caused by these vehicles, the input data as well as the parameters of pavement model, must be adapted so, that the deformation parameters (E, μ) of course materials are considered for the duration of applied load t = 60 s.

The number of design axles with a standard impact, considered by its 40 %, is for a calculation of deformation coefficient:

- $K_{i,j}$ (for average conditions) $0{,}4 \times 0{,}5\ N_c = 0{,}20\ N_c$
- $K_{i,l}$ (for summer conditions) $0{,}4 \times 0{,}3\ N_c = 0{,}12\ N_c$.

B2 Calculation of the Permanent Deformation of Semi-Rigid Pavement

The permanent deformation of the asphalt pavement with a semi-rigid structure is calculated using a model, whereat a summary of permanent deformations of asphalt layers in semi-rigid or rigid base courses is done. The summary is expressed by the equation

$$Y_{trv,PT} = \sum_{i=l} K_i\,(y_{pr,i} - y_{pr,i+1}) \qquad (6)$$

where $y_{pr,i}$ - elastic deflexion at the bottom of a layer i,

$y_{pr,i+1}$ - elastic deflexion at the bottom of a layer i + 1 (top course, or for the layer i=1 at the pavement surface)

K_i - deformation coefficient of course material *i*, depending on a frequency of loading N_{def}.

Elastic deflexions are calculated from a loading by a design axle for the spring and autumn conditions and for summer conditions. Considering the intensity of load (cycle of loading) and conditions, the equation (6) would be itemised as follows:

$$Y_{trv.PT} = \sum_{i=1}^{n} K_{i,l} \left(y_{pr,i,l} - y_{pr,i+1} \right) + \sum_{i=1}^{n} K_{i,j} \left(y_{pr,i,j+l,j} \right) \qquad (7)$$

where $K_{i,l}$ - deformation coefficient for a material of layer *i*, that is calculated from the equation (3)

$K_{i,j}$ - deformation coefficient for a material of layer *i*, when $N_j = 0{,}5\ N_c$.

In the calculation of permanent deformation, caused by a standard and non-standard load from vehicles, it is considered that just 40% of vehicles (design axles) is moving continuously and have a standard impact, but 60 % of vehicles have a non-standard impact, as vehicles brake, stand and accelerate. From the vehicles, impact of which is regarded under average conditions (spring and autumn) their proportion is:

$$0{,}6 \times 0{,}5\ N_c = 0{,}30\ N_c$$

and during summer conditions

$$0{,}6 \times 0{,}3\ N_c = 0{,}18\ N_{c.}$$

The criteria for the depth of ruts

The rut depth at the surface of a flexible pavement is calculated through an empirical correlation:

$$H_K = 1{,}40\ .\ Y_{trv,NT} \qquad (8)$$

The rut depth at the surface of a semi-rigid pavement is calculated through an empirical correlation:

$$H_K = 1{,}2\ .\ Y_{trv.,PT}. \qquad (9)$$

The design of structure for an asphalt pavement in terms of wheel tracking, where rut depth H_K would be less, than the allowable values:

- for pavements on motorways and expressways 20,0 mm,
- for pavements on 1st and 2nd class roads 25,0 mm,
- for pavements on 3rd class roads 30,0 mm.

Note: The investor of a particular road can modify the additional criteria for rut depth.