Skid resistance evaluation of Austrian tunnels

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ABSTRACT

Within the scope of periodical road condition monitoring the skid resistance and other road surface parameters of the Austrian motorways, expressways and federal roads are measured by the Road Surface Tester of arsenal research (RoadSTAR). Since 2005 also acceptance tests of skid resistance on new constructed pavements are mandatory on the motorway and expressway network. Due to the fire in the Tauern Tunnel in the year 1999 with 12 fatalities and 42 injured the Austrian regulations and standards have been changed. Now it is mandatory to use concrete road pavements (the standard construction method of concrete pavements in Austria is exposed aggregate concrete) in tunnels which have a length over 1000 m. But there also exist a lot of tunnels with asphalt pavements, especially tunnels with a length lower than 1000 m or older tunnels.

The data evaluation of the measurements pointed out, that the values of skid resistance in tunnels are often noticeable lower than those of the other sections of the road network. Because of this problem a national research project has been started to analyse these friction data in detail and to find some indications for the skid resistance problems in tunnels.

This paper describes the results of this research project as well as the RoadSTAR and the friction device of the RoadSTAR in detail.

KEY WORDS

SKID RESISTANCE / TUNNEL / ROADSTAR / ROAD MONITORING

1. SKID RESISTANCE MEASUREMENTS

In Austria skid resistance measurements are carried out periodically with the high performance measuring vehicle RoadSTAR (Road Surface Tester of arsenal research, see Figure 1). The motorway network (ASFINAG-Network) has already been measured in three campaigns (1991 - 1994, 1999 and 2004 - 2005) and the trunk roads network in two campaigns (1991 – 1996 and 2001 - 2002).

In addition, skid resistance acceptance tests and tests at the end of the guarantee-period are mandatory on new road pavements of the motorway network of Austria since 2005.

The RoadSTAR was developed by arsenal research's experts in close cooperation with the Stuttgart Research Institute of Automotive Engineering and Vehicle Engines. The RoadSTAR measures the most important surface properties and road geometry parameters under normal traffic conditions at measuring speeds between 40 km/h and 120 km/h (standard speed 60 km/h). The RoadSTAR's measuring devices are mounted on an ÖAF 2-axle truck. Engine power is sufficient to allow the RoadSTAR to measure a road with a skid resistance of $\mu = 1.0$ and a gradient of 8 % at a speed of 80 km/h with a full water tank holding 6000 litres.

The RoadSTAR enables measuring the following important surface properties and road geometry parameters under normal traffic conditions (Gruber & Maurer, 2004).

Skid Resistance:

- 18 % slip (standard)
- Blocked wheel
- ABS (Automatic Breaking System)
- Temperature of the road surface

Macro-Texture:

- MPD (Mean Profile Depth)
- ETD (Estimated Texture Depth)

Transverse Evenness

- Rut depth (left, right)
- Profile depth (left, right)
- Theoretical waterfilm thickness

Roughness

- IRI (International Roughness Index)
- RN (Ride Number)
- FFT-Analysis
- Longitudinal profile

Road Geometry

- Curvature
- Crossfall
- Gradient
- Height profile
- dGPS-coordinates

The skid resistance measurements were carried out using the "modified Stuttgart skiddometer"

(STURM, see Figure 2). The new friction testing device of the RoadSTAR includes completely newly designed units which show huge improvements compared to the "original Stuttgart skiddometer" (SRM). The new design of the loading unit - a pneumatic cylinder keeping the tyre contact pressure of the measuring wheel constant - and the additional acquisition of current wheel loads have resulted in a significant increase in the measuring accuracy of friction coefficients (Maurer, 2004).

① Measuring wheel including braking torque measurement	⑤ Gearbox for producing 18 % slip
② Pneumatic cylinder	⑥ Water tank
③ Wetting unit	⑦ Device storage
④ Prewetting system	⑧ Drivers cabin - digital data acquisition

Figure 1: RoadSTAR (Road Surface Tester of arsenal research)

2. SKID RESISTANCE IN AUSTRIAN ROAD TUNNELS

The Austrian road network consists of approximately 2000 km motorways (with separate carriageways except for some tunnel sections with only one tube), 10.000 km trunk roads, 24.000 km federal roads and 70.000 km rural roads. Because of the mountains of the Alps there are a lot of tunnels in Austria, especially in the western regions of Austria.

On the motorways there are approximately 320 km tunnel-lanes (8 %) and on the trunk roads there are 60 km tunnel-lanes (0.6 %).

Due to the fire in the Tauern Tunnel in the year 1999 with 12 fatalities and 42 injured the Austrian regulations and standards have been changed. Now it is mandatory to use concrete road pavements in tunnels which have a length over 1000 m.

The data evaluation of the friction measurements, especially the measurements of the acceptance tests pointed out, that the values of skid resistance in tunnels are noticeable lower than those of the other sections of the road network.

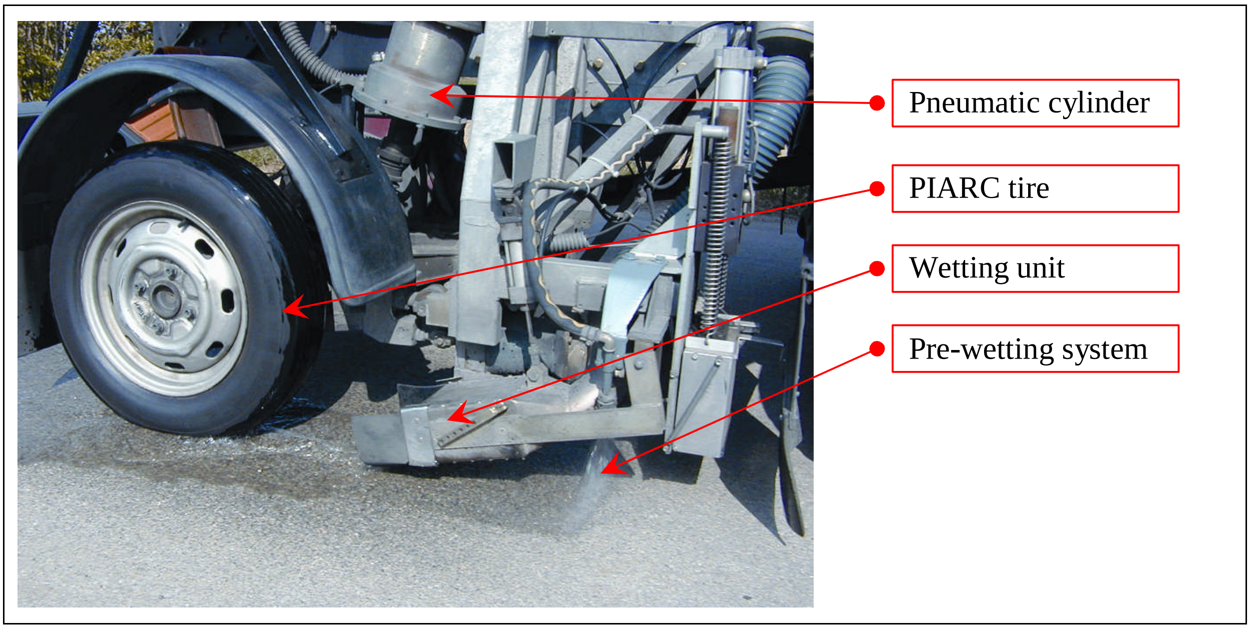

Figure 2: Skid resistance device of the RoadSTAR

In Figure 3 and Figure 4 two examples of skid resistance problems in tunnels are illustrated. The skid resistance measurements, whose results are presented in Figure 3 were performed immediately after completion of the road surface and were repeated after approx. one year. The data evaluation pointed out, that the skid resistance problems are not a result of early life skid resistance problems, because the level of the skid resistance is nearly constant.

In Figure 4 it is shown, that the level of skid resistance is significant lower in the tunnel, although there is the same surface outside and inside the tunnel. This road surface consists of the same material (inside and outside the tunnel) and was built by the same contractor. Figure 4 also shows a typical behaviour of the skid resistance, because the level of the skid resistance is gradually decreasing with the length of the tunnel.

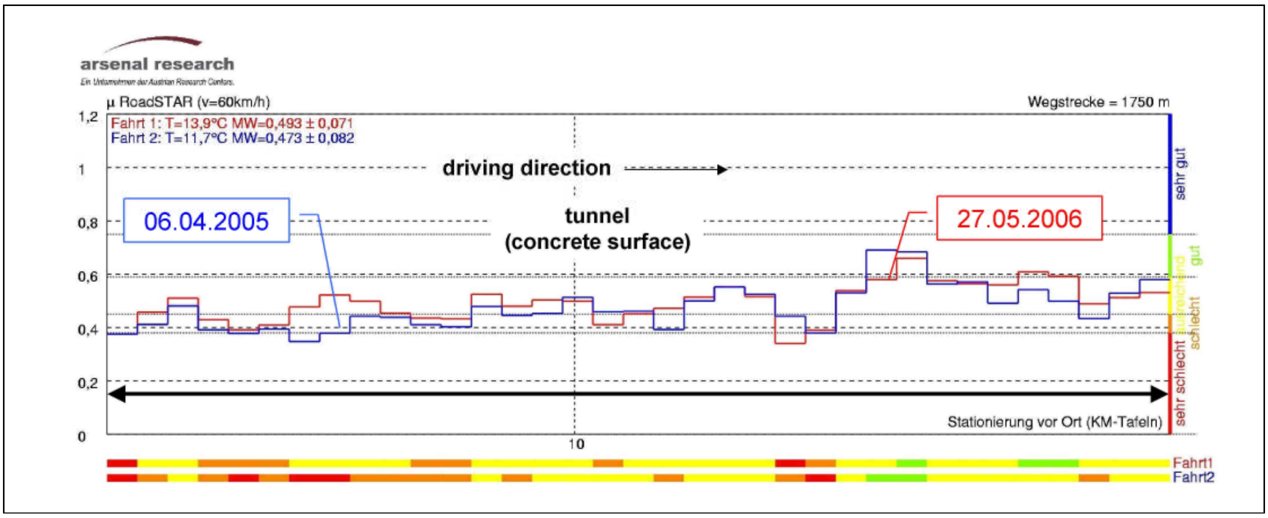

Figure 3: Skid resist. of a tunnel section, results of acceptance test and results after one year

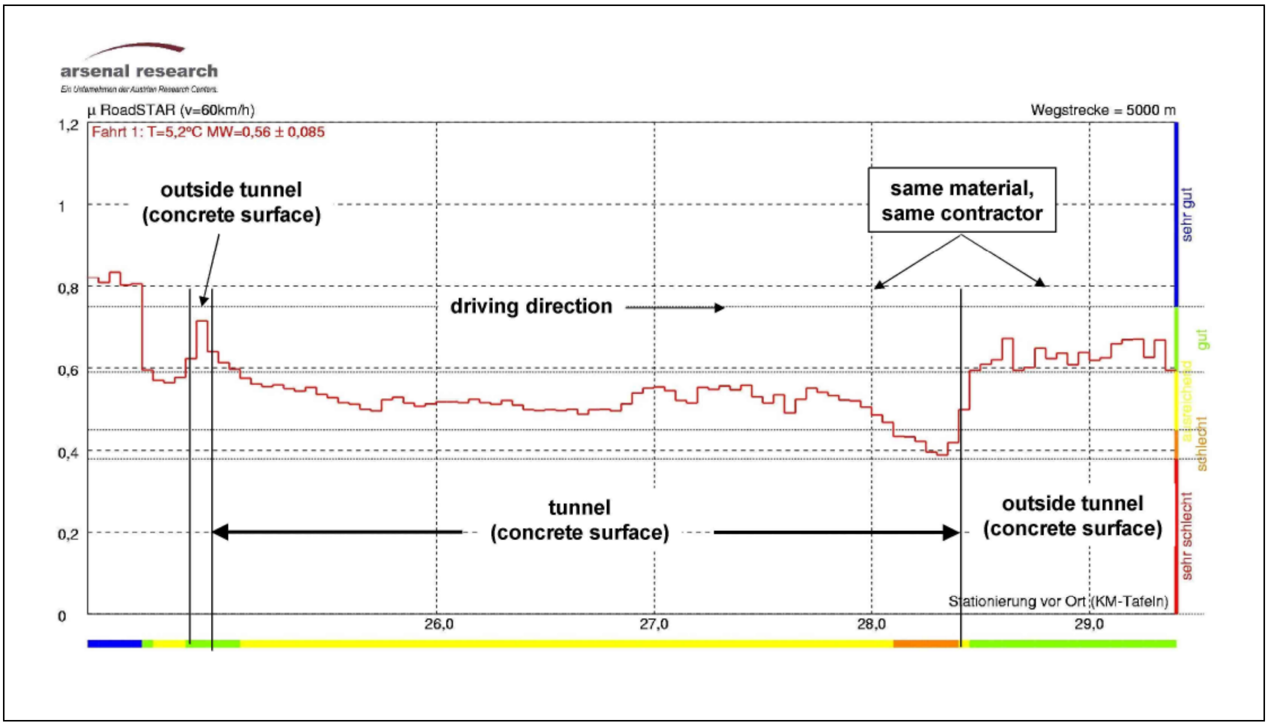

Figure 4: Skid resistance inside and outside of a tunnel (same contractor and material)

Because of this problem a national research project (Maurer et al., 2006) has been started to analyse these friction data in detail and to find some indications for the skid resistance problems in tunnels.

This research project has been defined in 3 steps:

1st step: anamnesis and diagnosis

2nd step: "therapy" – skid resistance improvements

3rd step: monitoring

In the first step a statistical analysis of friction data and interviews with clients and constructors should be arranged. In the second step different measures for road friction improvements in tunnels should be tested and evaluated and in the third step the long-term behaviour of these road friction improvements should be monitored.

In this paper the results of the first step of this research project are presented. It is already well defined now, that further research on this topic is needed, because these first results produced a lot of open questions on the topic "skid resistance in Austrian tunnels". So the first step of this research project will be enlarged for in-depth analysis of the used road surface.

2.1. STRUCTURE AND RESULTS OF THE RESEARCH PROJECT

In the first step of the project, existing skid resistance data of surfaces in tunnels were analysed in detail. On the basis of this evaluation 5 to 10 tunnel objects with low skid resistance values were selected for advanced analysis. The clients and the construction companies of these selected tunnels were interviewed and technical parameters of the road surface were analysed in detail.

2.1.1. Statistical Analysis of existing skid resistance data

2.1.1.1. Base data

In the first step of the evaluation the level of the skid resistance in tunnels in comparison to sections outside has been analysed. This analysis has been performed for a large part of the network of the Austrian motorways and the whole trunk roads network (Gruber & Maurer, 2004). The following data were used as basis (see also Table 1):

- approximately 10000 km skid resistance data of the near side lane of the trunk roads
- approximately 3075 km skid resistance data of the near side lane of the Austrian motorways and skid resistance data of the acceptance tests

2.1.1.2. Number of evaluated tunnels

A tunnel is defined as an object with one or two tubes. A total of 250 tunnels (with 369 tunnel-sections and 395 km of tunnel-lanes) has been the basis for the evaluation. The skid resistance data of these tunnel sections have been compared with the data of the sections outside. In Table 1 the length of the evaluated network and the number of the tunnels are illustrated. The tunnel sections of the motorways are distinguished between asphalt surfaces and concrete surfaces.

Table 1: Length of the evaluated network and tunnel sections

	evaluated network	evaluated tunnel sections	
	carriageway-km	number	carriageway-km
trunk roads (134 tunnel objects)	9856	134	61
motorways (approx. 118 tunnel)	3075	235 asphalt: 165	334 asphalt: 136

		concrete: 70	concrete: 198

The analysis of the skid resistance data of the trunk roads showed no interesting output, so in this paper only the results of the data analysis of the Austrian motorways are presented.

2.1.1.3. Analysis of the skid resistance data of the motorways network

Figure 5 shows the distribution of the cumulative frequency of the skid resistance on the motorways network (red line) and in comparison the distribution of the cumulative frequency in the evaluated tunnel sections (blue line). At first glance the poor level of the skid resistance in tunnels is apparent. By using the virtual threshold of µRoadSTAR=0.56 it is below the target in 37 %. In addition, the warning value and the threshold value are presented in Figure 5. According to this, the warning value is below the target in 10 % and the threshold value is below the target in 4 % of all tunnel sections of the Austrian motorway network.

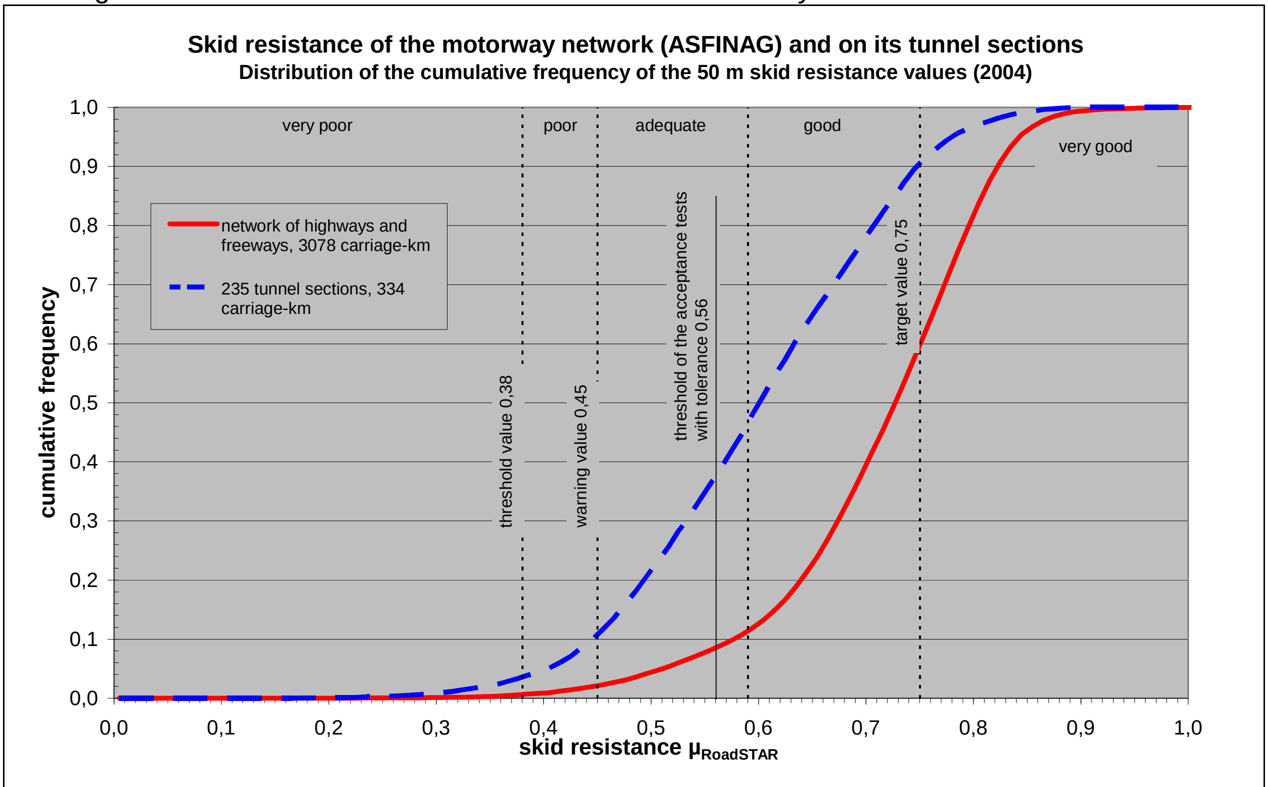

Figure 5: Skid resistance of the motorway network and in tunnel sections

In the follow up analysis the tunnel sections were separated in sections with asphalt and concrete surfaces. Figure 6 illustrates, that tunnel sections with concrete surfaces (white line) show minor skid resistance values than sections with asphalt surfaces (black line). By using the virtual threshold of µRoadSTAR = 0.56 it is below the target in 42 % in sections with concrete roads and in 30 % in sections with asphalt roads.

In the next step it has been analysed if "new" surfaces in tunnels show a different behaviour than "old" surfaces. "New" surfaces have been defined as "new", if the year of construction was 2003 or younger.

The analysis of the distribution of the cumulative frequency (Figure 7) shows no differences for "old" (yellow line) or "new" (white line) concrete roads up to values of µRoadSTAR = 0.57. Clearly visible is the difference between "old" or "new" surfaces from skid resistance values µRoadSTAR > 0.57.

The awareness, that there is no difference between „old" or „new" concrete surfaces is a conflict to operating experiences in the context of the acceptance tests on the motorway network. A detailed analysis of the acceptance tests showed, that the threshold was not reachable for nearly all concrete surfaces.

For this reason further analyses were arranged to document these operating experiences also in graphical form.

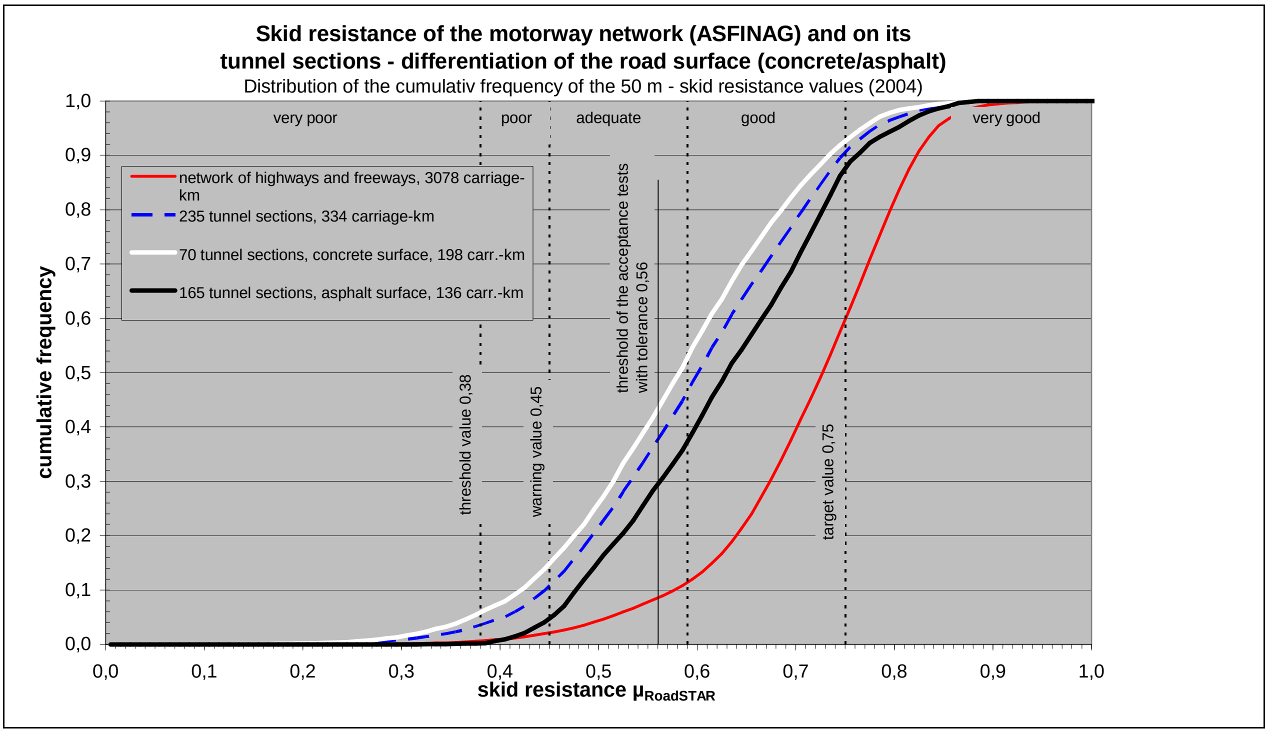

Figure 6: Skid resistance of the motorway network and in tunnel sections, differentiation on road surface

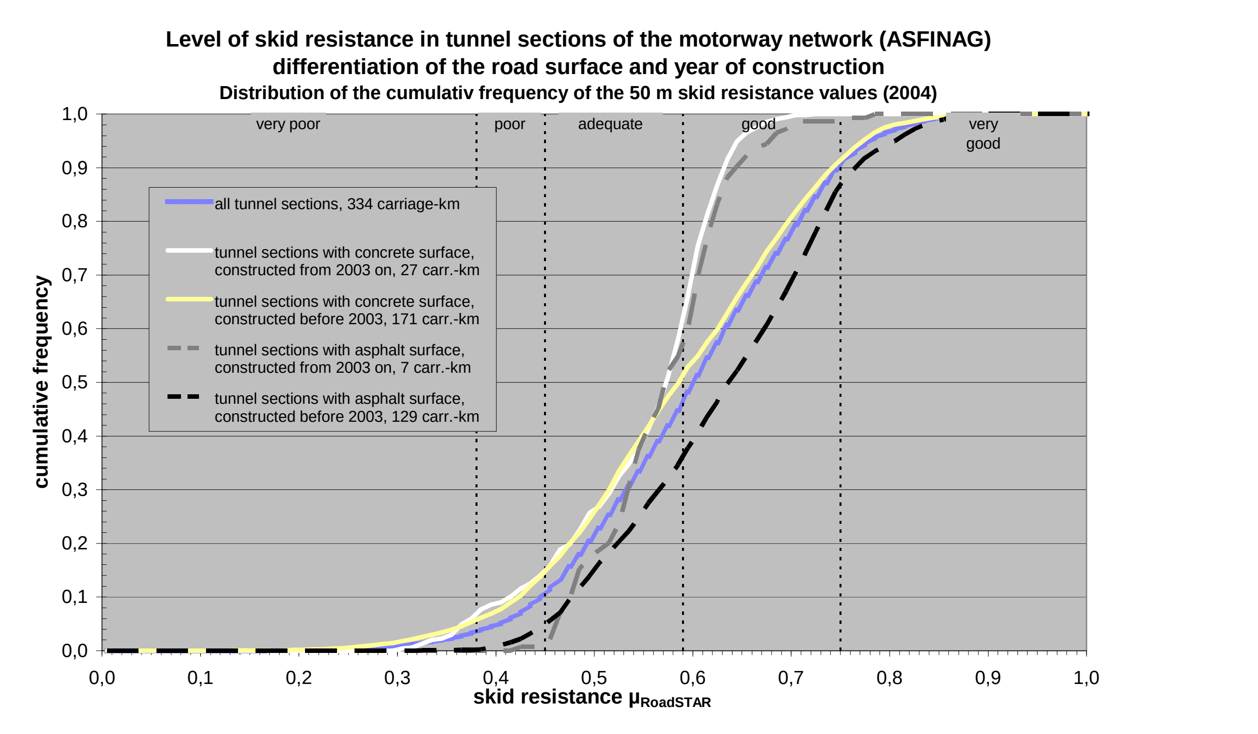

Figure 7: Skid resistance in tunnel sections of the motorway network – differentiation on road surface and year of construction

In Figure 8 a comparison of the skid resistance values of the different tunnel sections of the motorway network is illustrated. The skid resistance value for each tunnel section was defined as the mean value of all skid resistance values of this tunnel section minus the double standard deviation. The concrete and asphalt surfaces are presented in Figure 8 with different colours and also a coloured differentiation of the construction year has been done.

In addition, a classification of the tunnel length has been performed; the tunnel sections were grouped in 500 m-sections. The following consolidated findings can be derived from Figure 8:

- with the exception of one tunnel section all skid resistance values of „new“ tunnels with asphalt surfaces (white points) are below the virtual target of µRoadSTAR = 0.56
- also with the exception of one tunnel section all skid resistance values of „new“ tunnels with concrete surfaces (white rectangles) are below the virtual target of µRoadSTAR = 0.56
- it is visible, that older concrete roads in tunnels (orange rectangles) tend to result in lower skid resistance values than older tunnels with asphalt surfaces (grey points)
- the mean values of the different 500 m classes (black triangles) show a drift to lower skid resistance values with increasing tunnel length

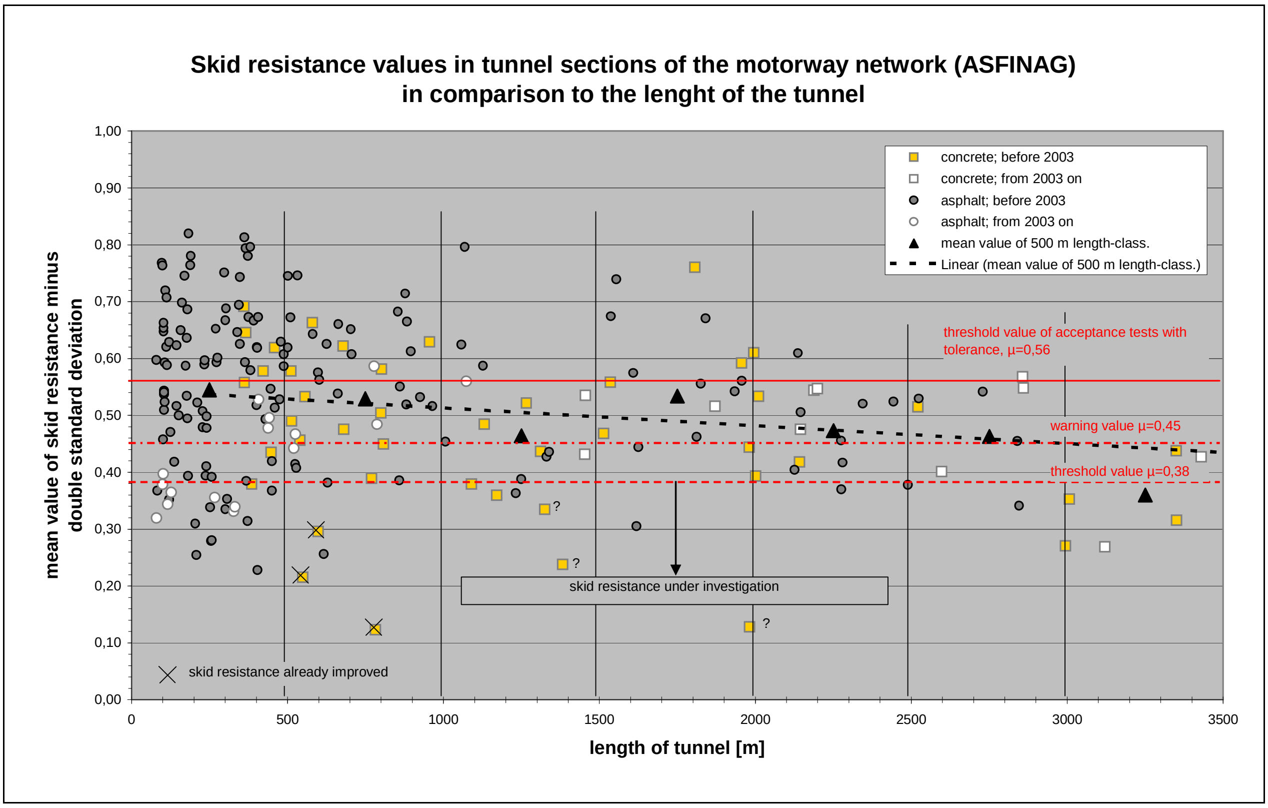

Figure 8: Skid resistance values in tunnel sections of the motorway network in comparison to the length of the tunnel

Figure 8 also illustrates that pavement with asphalt surfaces, especially the “new” surfaces, which were constructed in the year 2003 or later, show the same skid resistance problems like concrete surfaces. But it has to be stated, that only a small number of tunnel sections are below the threshold value of µ=0,38 and the skid resistance of some of this tunnels has been already improved in the meanwhile. Anyway, if tunnel objects with low skid resistance are not improved yet, they are under investigation.

2.1.2. Advanced analysis of 6 tunnel objects

The goal of the advanced analysis of 6 tunnel objects was to find an answer of the question, if the low skid resistance of the finished surface is a matter of

- inadequate construction materials
- inadequate concrete finishing method or
- inadequate maintenance procedure.

Of further interest was the clearance of the reasons for the low initial skid resistance values of new tunnels, especially of concrete pavement surfaces with an exposed aggregate technique. The exposed aggregate technique is used in Austria now since more than 10 years and the surface usually is well known as a surface with a high level skid resistance.

Further open questions were:

- the differences between outdoor and indoor measured values,
- the decreasing skid resistance values with the increasing tunnel length,
- the decreasing skid resistance with the entry into the tunnel, the increasing skid resistance with the exit out of the tunnel.

In order to find the answers to the above mentioned questions, a special questionnaire was developed. The clients and the construction companies of the selected tunnels were interviewed and technical parameters of the road surfaces were analysed in detail. The construction parameters of the Austrian Standards and Regulations for concrete road construction (RVS 8S.06.32) were controlled, special attention was given to:

- concrete composition of the top concrete, specially type and origin of the coarse aggregates
- PSV - (polished stone value) and LA – value (Los Angeles value) according to the used aggregates
- concrete consistency, casting method and type of concrete surface finishing (burlap structure, broom finish, exposed aggregate surface with a maximum grain size of 8 mm or 11 mm)
- type of the curing compound, amount per m² and time of application
- differences in the curing methods of outdoor / indoor curing compounds
- cleaning method for the removal of the fine mortar and the slurry of the joint cutting
- the detailed construction process with initial tests, conformity control parameters (texture depth, number of profile tips per 25 cm²), etc.
- special features (temperature, cleaning, …)
- etc.

The investigations of the first part of the research project were closed with the evaluation of the questionnaires and the site inspections.

The main results of the advanced analysis of the first part are:

- The reasons for the low skid resistance level in road tunnels could not be attributed in general to relations between the above mentioned material parameters, differences in the construction methods or special features and low skid resistance values.
- Locally, these parameters influence the skid resistance single values very strong.
- The relations seem to be more complex than expected. The influence of the different climatic conditions (weathering conditions, exposure conditions, acid rain, etc.) seems to be of higher importance than expected.
- If the exposure conditions are a fact, different methods to improve the skid resistance and their long-time behaviour should be the next steps in the research programme.

- The investigations were executed for concrete pavements, but as a result of this first part of the project, the low skid resistance values do not refer to a white (concrete) or black (asphalt) surface. In both cases – the skid resistance in tunnels is generally lower than outside the tunnel.
- The further investigations should be extended to asphalt pavements, too.

3. SUMMARY AND FURTHER ACTIVITIES

The reasons for the low skid resistance level in road tunnels, build since 2003 could not be solved sufficiently. Further investigations are necessary, especially the extension to tunnels with asphalt pavements as well. The exposure conditions seem to influence the skid resistance more than construction / material parameters in comparison of indoor / outdoor behaviour of the tunnels.

Based on the results of this first part of the investigations the further investigations should be executed in a second part with different methods to improve the skid resistance:

- the selection of appropriate methods like cleaning with water, high-pressure water – jetting, sand-blasting, bullet – blasting, suction of the removed brushed fine surface mortar, suction of the joint cutting slurry, etc.
- measurements before and immediately after the treatment with a special method
- application of selected methods to existing road tunnels
- long – time behaviour of the executed methods
- evaluation, description of the mode of operation and documentation
- recommendation of appropriate “skid resistance improvement methods” of the future

In the third and final part of the research activities the long-time behaviour of the improvement methods should be investigated with additional measurements in defined intervals with the RoadSTAR in order to elaborate a “code of practice” for the construction of road tunnels.

It has to be noted, that only a small number of tunnel sections are below the threshold value of μ=0,38 and the skid resistance of some of this tunnels has been already improved in the meanwhile. Anyway, if tunnel objects with low skid resistance are not improved yet, they are under investigation.

Due to safety reasons the speed limit in Austrian tunnels is generally 100 m/h and in tunnels with two-way traffic it is generally 80 m/h. So even if the skid resistance in tunnels is a little lower than outside the tunnels, the risk of accident is lowered because of these reduced speed limits.

The results which are presented in this paper produced a lot of open questions on the topic “skid resistance in tunnels”, so all skid resistance experts are welcome to contribute their expertise.

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