Influencing factors on the visibility of surface distresses

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Abstract. A systematic and future-oriented maintenance management requires quality-assured data regarding the condition of the roadway. An important characteristic for assessing the condition of the road surface are cracks [1]. Experience has proven that the road surface temperature and residual humidity can influence the visibility of cracks. To investigate and quantify these influencing factors in more detail, the Federal Ministry of Transport and Digital Infrastructure has implemented a comprehensive research project [2], during which several measurement campaigns were carried out at different seasons and at different temperatures and humidity degrees of the road surface. The visibility of the cracks was assessed using the German approach ZTV ZEB-StB [3]. After evaluating the cracks, the data was synchronized and the network allocation of the geo-referenced raw data was realized. The relevant condition performance indicators were calculated subsequently. For each evaluation section of 100 meters length, the mean road surface temperature was calculated and, if available, the type and year of construction of the surface course was determined. The evaluated data was visualized to establish correlations between the data and the influencing factors. For the statistical analysis of the results, a total of six comparative scenarios were defined in which the influencing factors of road surface temperature and residual humidity were assessed. This paper documents the results of the research project. In order to obtain a uniform and comparable picture of the condition of the road surface over the years and thus to be able to observe the aging process of the road surface, the measurement campaigns are to be carried out under defined conditions. The research project included proposals for defining and further specifying the measurement conditions.

1. Research needs and scope
The aim of the pavement condition survey and assessment (ZEB) on federal highways is to provide quality-assured data for maintenance management. The acquisition and evaluation rules for this data are described in the ZTV ZEB-StB [3]. Cracks, including accumulation of cracks, individual cracks as well as longitudinal and transverse cracks, on the road surface are an important characteristic for assessing the condition of both the structure and the surface of the pavement [1], [4]. In the ZTV ZEB-StB [3], there are currently no restrictions regarding the permissible temperature ranges for the condition survey. However, it is prescribed that measurements of evenness within the ZEB should be carried out on a dry and clean road surface. Yet, previous projects showed that residual humidity on the road surface can improve the visibility of fine cracks [5], [6]. This and the influence of the road surface temperature on the visibility of cracks were studied and quantified within this research project.
2. State of research
More than 25 years ago, a federal initiative launched the pavement condition survey and its assessment (ZEB). The condition data are combined into a usage condition index and a substance condition index [3]. Within the ZEB, the damage on the road surface is recorded in the so-called subproject 3 by measuring vehicles using imaging methods and evaluated manually on-screen (state of the art). Rules for the survey and evaluation of surface damage are defined in the regulations ZTV ZEB StB [3]. Weather conditions are not addressed, but the measurements of evenness indirectly indicate that the measurements must be carried out on clean and dry road surfaces.

The Working Group 4.3.1 [7] of the Road and Transport Research Association is currently working on the technical test specifications for acquiring surface images using high-speed imaging systems. According to this, measurements should only be performed on surfaces that appear to be dry and clean. Specific temperature ranges are not required. However, the US non-profit NORTHWEST PAVEMENT MANAGEMENT ASSOCIATION recommends that the road condition survey and assessment should always be carried out at the same time of the year [8].

In the years 2012 to 2014, HELLER Ingenieurgesellschaft mbH conducted a research project on the influence of temperature on the visibility of cracks, in which surface distresses were evaluated in detail. The final report of the project [5], [6] states that the visibility of cracks can be dependent on temperature and humidity.

LEHMANN + PARTNER [9] carried out measuring campaigns with high-resolution surface cameras on dry and drying roads (after wetting the lanes artificially). While fine cracks could not be detected in the dry state, they became visible when wetted. However, the road surface dried at different speeds due to weather conditions, which affected the results.

As VOS and BOUMAN [10] report, the illumination of the road surface and the observation angle are crucial for determining the type and extent of damage correctly. The quality of the data collected depends directly on the quality of the underlying surface images. Weather conditions can significantly influence the image quality and output data when the lighting is unfavorable [11]. Xu [12] used artificial lighting in the condition survey to eliminate all shadows in the image and thus improve the uniformity of the data regardless of the weather conditions. Artificial lighting allowed consistent crack detection results under different natural lighting conditions (at night, daytime with shadows and daytime without shadows).

3. Planning and execution of the experiment
3.1. Measurement campaigns
To investigate whether the road surface temperature and residual humidity influence the visibility of cracks, a total of nine measurement campaigns were carried out on selected asphalt and concrete roads under different conditions.

- Campaign 1 – Fall 2015 [H15]. Survey of four test sections (3 asphalt, 1 concrete), dry and clean roadway, road surface temperatures 10-20 °C.
- Campaign 2 – Winter 2016 [W16]. Survey of four test sections (3 asphalt, 1 concrete), dry and clean roadway, road surface temperatures < 0 °C.
- Campaign 3 – Spring 2016 [F16]. Survey of four test sections (3 asphalt, 1 concrete), dry and clean roadway, road surface temperatures 10-20 °C.
- Campaign 4 – Summer 2016 [S16]. Survey of four test sections (3 asphalt, 1 concrete), dry and clean roadway, road surface temperatures 30-40 °C.
- Campaign 5 – Fall 2016 [H16]. Survey of four test sections (3 asphalt, 1 concrete), dry and clean roadway, road surface temperatures 10-20 °C.
- Campaign 6 – Winter 2017 [W17]. Survey of four test sections (3 asphalt, 1 concrete), dry and clean roadway, road surface temperatures < 0 °C.
- Campaign 7 – Wet roadway [N16]. Survey of four continuously wet test sections (3 asphalt, 1 concrete), road surface temperatures 10-20 °C.
• Campaign 8 – Diurnal curve I (Spring 2016) [TGL1]. Multiple (at least four times each) survey of two test sections (1 asphalt, 1 concrete) throughout the day, dry and clean roadway, road surface temperatures approx. 10-30 °C.

• Campaign 9 – Diurnal curve II (Summer 2016) [TGL2]. Multiple (at least four times each) survey of two test sections (1 asphalt, 1 concrete) throughout the day, dry and clean roadway, road surface temperatures approx. 20-40 °C.

The campaigns 1 to 6 were designed to collect measurement data on the visibility of cracks at different road surface temperatures. With the diurnal curves (campaigns 8 and 9) it was investigated to what extent the natural variations of the road surface temperature during the day influence the detectability of cracks. In addition, the degree of residual humidity, if any, was also evaluated during the day.

3.2. Selection of the test sections
The test sections were selected by using existing condition data from previous years and by a virtual inspection [13].

All test sections had to show cracks but not to an extent that would have made the comparison of the distresses impossible. Furthermore, comparable traffic densities without obstructions should prevail so that traffic could also be examined as a possible influencing factor. Other influencing factors had to be minimized. Therefore, the construction data was analyzed in an engineering manner when selecting the test sections. Moreover, no maintenance treatments should be carried out during the research project.

Three asphalt sections and one in concrete construction, i.e. a total of four test sections of 25 km each, were selected that met these criteria.

3.3. Measuring vehicle
The acquisition was carried out with a high-speed (80 km/h) measuring system equipped with an area scan camera system. Both front and surface images were taken to capture the surface distresses. The surface camera system at the back of the measuring vehicle can capture a total width of up to 4.50 m and uses stroboscopes to illuminate the road surface. With a second, the so-called secondary front camera, additional road images were taken. As the camera is attached to the beam to detect transverse evenness, it captures the road from a different, significantly flatter angle than the (primary) front camera. In addition, the measuring vehicle was equipped with an infrared industrial thermometer to measure the road surface temperature.

It had the time-limited operating approval of the Federal Highway Research Institute, a license required to guarantee high measuring quality and conformity with the standards. Laser-based systems for the automatic identification of surface distresses could not be used for acquiring the data in this research project, as there are currently no vehicles in Germany that fulfil the conditions for the license required.

3.4. Evaluation of the measurement data
The evaluation of the surface images was carried out only by experienced inspectors with at least three years of experience in detecting surface distresses who had been additionally trained at the beginning of the project. Each measurement campaign was assessed twice by two independent inspectors. Both results were compared, possible differences discussed and, if necessary, the data was changed accordingly. To see how often the inspectors agreed upon the visibility of cracks, contingency tables were assembled. Those tables show the frequencies of different results assigned by two inspectors. The picture-based assessment is a highly repeatable way of quantifying the visibility of cracks. The agreement rate between experienced inspectors is on average 95% [5].

Since no suitable method is known to date to reliably quantify the degree of humidity on a road surface, the following classification was determined for this research project: dry surface, drying surface (residual humidity is only visible in the area of cracks) and wet surface (the road surface is continu-
ously wet). In order to determine which degree of humidity prevailed on a certain section, the test sections were divided into segments of 100 meters each and visually examined by inspectors.

To compare the results of the assessment, it is necessary to compare the data of two or more measurement campaigns which requires a very accurate position of each picture. The GPS position and the odometer length collected during the data acquisition, however, are not accurate enough [5], [14]. Therefore, the measurement data was finely synchronized based on the chainage, the front and secondary camera images and suitable unique features (e.g. peaks in the longitudinal profile).

After that, the raw data was converted into condition values and compiled as a result table. Afterwards, the condition parameters for cracking were evaluated and the overall condition indexes were calculated. The evaluation sections with maintenance treatments between the first and last measurement were marked and excluded from further analyses. For each evaluation section, the mean road surface temperature was calculated, the degree of residual humidity defined and, if available, the type and year of construction of the surface course was determined.

All data was compiled in a project database, which provided the basis for further visualizations and analyses.

3.5. Visualization of measurement data

The evaluated data was visualized in multiple ways to allow for engineering analyses and for establishing correlations between the data and the road surface temperature or humidity, provided that identical conditions existed when comparing two locations.

Firstly, the linear profiles and the results from the crack assessment were compared with each other. The linear profile with the raw data can be used for the object-specific analysis of changes in cracks on the raw data level. The cracks were coded with respect to grid fields of 1 m x 1/3 of the lane width for asphalt roads or per concrete slab. Grid fields with observed distresses are marked accordingly on the profile.

Secondly, the aggregated crack performance indicators were compared to each other. The linear profile with the aggregated condition data (Figure 1) allows the changes of the relevant condition performance indicators to be displayed. However, not only the condition performance indicators can be read off, but also the total length of a crack within an evaluation section, which results from the sum of the crack lengths in the individual grid fields or concrete slabs.

![Figure 1. Example of a linear profile with aggregated crack performance indicators.](image-url)
Finally, the cracks were analyzed visually and their development was illustrated [2]. Within this research project, several measurements were carried out in a relatively short period of time. Due to this frequency, the development of specific cracks could be observed and documented based on road and surface images. However, this image-based method cannot be compared with in situ crack monitoring which allows to look at the damage from different angles and to investigate the environment for possible causes. An online visualization information system was therefore used. The database was searched for relevant examples of cracks and the matches were provided with further information such as date and time of the measurement, air temperature and temperature of the road surface.

4. Results and evaluation

4.1. Statistical and scientific evaluation

To be able to differentiate between the influences of the road surface temperature and the degree of residual humidity, a total of six comparative analysis scenarios were developed iteratively for the statistical and scientific analyses of the results.

4.1.1. Scenario 1: Comparison of the results of all seven seasonal measurements. In the first comparative scenario, seven measurement campaigns (H15, W16, F16, S16, H16, N16 and W17) and all degrees of road surface humidity were taken into account. This scenario thus represents the broadest spectrum of measuring conditions in terms of temperature and humidity.

For the statistical analysis, the condition values ZGRISS (area affected by cracks on asphalt) and ZGLQRP (slab area affected by longitudinal and transverse cracks) were calculated for the sum of all common comparable evaluation sections of a construction method (585 asphalt and 137 concrete sections). Figure 2 shows the affected areas in percent and the average road surface temperatures $T_{FO,\text{asphalt}}$ and $T_{FO,\text{concrete}}$ for the respective measurement campaigns.

Figure 2 clearly shows that in the campaign W16, significantly more cracks were detected on the asphalt sections than in H15. The campaign W17 also revealed considerably more cracks than all other seasonal measurements that did not take place in winter. Such considerable differences cannot be observed for the concrete section, except for the campaign F16. This suggests that the lower road surface temperatures in winter and the evaluation sections with drying road surfaces are responsible for the higher areas affected. However, Figure 3 shows that more cracks were detected in the measurement campaign W16, which in contrast to W17 had higher road surface temperatures and a lower proportion of drying evaluation sections. A differentiation of the influences of road surface temperature and humidity can therefore not be deduced.

Figure 2. ZGRISS and ZGLQRP, plus mean values of the road surface temperatures per measurement campaign in scenario 1.

Figure 3. Degree of humidity of the road surface in scenario 1.
The transition diagrams, which refer to the condition indexes of the individual evaluation sections, confirm the previous results. The campaign W16, which was carried out mostly on a drying road surface, shows the largest proportion of evaluation sections in poor condition (condition index greater than 4.5).

As shown in the transition diagram W16 to S16 (Figure 4) for the asphalt sections, the evaluation sections change predominantly from a poor to a better condition. In other measurement campaigns on the asphalt test tracks, there were only minor changes in the condition indexes. Both from H15 to H16 and from F16 to H16, however, a significant decrease in evaluation sections with condition indexes better than 1.5 could be observed. The transition diagrams of the concrete section reveal a deterioration in condition from W16 to S16. This development was not expected.

4.1.2. Scenario 2: Comparison of the results of measurements on dry roadways. To determine the influence of road surface temperature on the visibility of cracks in asphalt and concrete sections, an analysis of all dry evaluation sections of the measurement campaigns H15, F16, S16 and H16 was carried out. The campaigns N16, W16 and W17 were not taken into account, as there were no or too few dry evaluation sections.

Results:
- Comparing the campaign S16 with the two measurements H15 and H16 conducted in fall, it becomes apparent that the ZGRISS of S16 (3.5 %) lies between the ZGRISS of H15 and H16 (3.2 % and 4.0 %). The range ZWLQRP of the campaigns H15, S16 and H16 is 0.6 %, with the campaign S16 having the lowest ZWLQRP (2.2 %) of the three measurement campaigns. This suggests that medium (>15.0 °C) and high (>35 °C) road surface temperatures have no direct influence on the detectability of cracks. The evaluation of the crack lengths of all common comparable evaluation sections of the test sections in asphalt supports this conclusion.
- The same is valid for longitudinal and transverse cracks on the concrete section. The mean total length of the cracks remains constant at 1.2 m during all four measurement campaigns, while the proportion of slabs affected varies between 0.8 % (F16) and 2.9 % (H15). This again indicates that there is no direct influence of medium and high road surface temperatures on the visibility of cracks.
- Both the mean indexes ZWRISS and ZWLQRP are almost constant during all measurement campaigns and do not indicate a direct influence of medium (>15.0 °C) and high (>35 °C) road surface temperatures on the detectability of cracks.
4.1.3. Scenario 3: Comparison of the results on drying roadways. In this scenario, the effects of a drying road surface on the results of the condition survey were investigated. For this purpose, only evaluation sections of the campaigns W16 and W17 were evaluated which were marked as drying. No comparable data were available for the concrete section, as all evaluation sections were classified as dry.

Results:
- Due to the higher percentage of ZGRISS in the measurement campaigns W16 and W17, compared to scenario 1, it can be assumed that the degree of humidity has a considerable influence on the visibility of cracks on asphalt pavements.
- Comparing the condition indexes ZGRISS and ZGLQRP with the sums of the crack lengths shows that the indexes in the campaign W16 are approximately twice as high as in W17. A possible explanation could be variations in the degree of humidity "drying", which can have a positive or negative effect on the detectability of cracks.
- The transition diagrams show that almost 23% of the evaluation sections that were above the threshold level (condition value greater than 4.5) in campaign W16 transitioned into a better condition area. The relatively big change of the condition indexes leads to the assumption that the road surface was humid to varying degrees, although the examined evaluation sections were uniformly classified as drying.

4.1.4. Scenario 4: Comparison of the results on dry roadways at different road surface temperatures. In this comparative scenario, the effects of different road surface temperatures on the visibility of cracks at identical degrees of humidity of the road (here: dry) were examined in more detail. The campaign S16, which had the highest road surface temperatures, and the campaign W16 with the lowest road surface temperatures were used for this purpose.

Results:
- There were significant differences in the ZGRISS for the sum of the common comparable evaluation sections of the asphalt track between the campaigns S16 (0.9 %) and W16 (9.3 %).
- There is an opposite trend in the concrete section. The range of the ZGLQRP for the sum of all common comparable evaluation sections between the campaigns S16 and W16 is 0.5 % and is thus relatively small compared to the range for the asphalt sections (8.4 %). The low value in campaign S16 suggests that at high road surface temperatures the crack lengths decrease or are less visible than at low road surface temperatures.
- The examination of longitudinal and transverse cracks on the concrete section also shows that slightly more slabs were affected in summer at high road surface temperatures than in winter. The mean total length of all cracks, on the other hand, remains largely the same.
- In contrast to scenario 2, there was a considerable difference in this scenario between low (< 10 °C) and high (> 35 °C) road surface temperatures. It can be assumed that the difference is due to differences in assessing the degree of humidity of the road surface.

4.1.5. Scenario 5 and 6: Comparison of the results on a dry roadway for the examination of the diurnal curve in spring and summer. For scenarios 5 and 6, two of the four test tracks, the motorway A7 (concrete construction) and the federal highway B217 (asphalt construction), were surveyed five times during the day. The TGL1 measurement campaign took place in spring 2016 and the TGL2 in summer 2016. Both campaigns should take place on dry roads. The TGL1 was carried out at road surface temperatures of 17.1 °C to 31.7 °C. The TGL2 was conducted at slightly higher road surface temperatures (21.9 °C to 33.9 °C).

Results:
- The ZGRISS of the asphalt section showed ranges of 0.8 % (TGL1) and 0.6 % (TGL2). The condition index ZGLQRP for the test track in concrete construction resulted in ranges of 0.5% for the TGL1 and 0.7% for the TGL2.
• No correlation between the varying road surface temperatures and the visibility of cracks could be observed during the day, neither in the asphalt nor in the concrete section.
• Since all evaluation sections had a dry surface, it could be excluded in this scenario that residual humidity had an influence on the results.
• Both the mean values ZWLQRP and ZWRISS remain at an almost constant level throughout the day and show no influence due to the road surface temperature.

4.2. Conclusions

The evaluations reveal that the temperature and humidity degree of the road surface actually affect the visibility of cracks. In the campaigns W16 and W17, where the average temperatures were the lowest and the number of drying sections was highest, the cracks were generally more visible than in any other campaign.

Residual humidity as an influencing factor was investigated in more detail by analyzing only drying sections from the two winter measurements. The results clearly show that on average more cracks were visible on these drying sections than in scenarios where also sections with other humidity degrees were considered. However, it is not possible to establish a fundamental correlation between the degree of residual humidity and the improved visibility of the cracks from this data. In the measurement campaign W17, significantly fewer cracks were detected than in the measurement campaign W16, although only the drying sections were considered in each case. This suggests that in the sections defined as "drying", the road surface was humid to varying degrees and thus the visibility of the cracks was promoted differently. When analyzing the acquired data and especially when evaluating the raw data, it has become clear that the degree of humidity of a road surface is difficult to define since it is based on purely subjective estimations.

In order to analyze the extent to which different road surface temperatures affect the detectability of cracks, the dry evaluation sections of the measurement campaigns H15, F16, S16 and H16 were first compared with each other. It became obvious that mean (> 15.0 °C) and high (> 35 °C) road surface temperatures have no direct influence on the visibility of cracks. However, when comparing the measurement campaigns W16 and S16 with a temperature variance of 31.7 K, differences were found. Cracks in asphalt roads were more visible at lower road surface temperatures. This influence could not be proven on the test section in concrete construction. The improved visibility of the cracks on asphalt roads is probably due to differences in the determination of the residual humidity degree. Although the evaluation sections were classified as dry during the measurement campaign W16, a certain percentage of residual humidity in the crack areas could not be excluded, which improved the detection of cracks.

As a result, the temperature does influence the visibility of cracks indirectly, as residual humidity in crack areas is favored by low temperatures. The visibility of cracks on concrete roads decreased slightly during the measurement campaign W16 compared to the measurement campaign S16. The campaigns W16 and W17 were carried out in winter conditions and with apparently dry road surfaces at the beginning of the measurement. Nevertheless, evaluation sections with residual humidity were detected which will always be the case during the winter months.

5. Summary and outlook

The objectives of the research project were to further specify the acquisition method, to determine and quantify the influence of temperature and humidity on the visibility of cracks and to formulate technical requirements for the acquisition as a supplement to the regulations.

5.1. Influence of residual humidity

The evaluations have confirmed that the degree of residual humidity on the road surface has an influence on the visibility of cracks. However, this could not be quantified within the research project. Compared to dry road surfaces, cracks become more visible when the road surface is drying off and residual humidity remains in the cracks. Since residual humidity on the road surface cannot be con-
trolled and is difficult to quantify, however, surveys on drying roadways cannot be recommended. Measurements in rain as well as in case of closed and large water films on the road surface are also to be avoided, as this greatly reduces the visibility of cracks.

5.2. Influence of road surface temperature

The extent to which the temperature affects the detectability of cracks could not be determined with certainty. Although cracks were increasingly detected during winter measurements, it was not possible to differentiate precisely whether the visibility of the cracks could be attributed exclusively to low road surface temperatures. Due to the low air temperatures in winter, there is a high probability that sections identified as dry still contain residual humidity that cannot be seen visually (mainly in the crack area). Consequently, the measurement results can lead to different conclusions. At higher air and road surface temperatures, areas with residual humidity quickly dry off and thus comparable conditions are more frequent. Therefore, measurements to investigate the surface distresses should not be carried out in winter. However, it was not possible to determine an exact lower temperature limit for measurements based on the measurement campaigns analyzed in this research project.

A significant influence of mean and high road surface temperatures on the visibility of cracks could not be proven for the test sections in asphalt construction. On the test section in concrete construction, cracks became more visible at higher road surface temperatures and less visible at lower temperatures. A possible explanation for the unexpected behavior of the test track in concrete construction may be the different temperature at the top and bottom of the concrete slabs at different seasons. At high air temperatures and direct sunlight, the concrete slabs heat up faster than the underside of the concrete slab. This temperature gradient has the consequence that at the top of the road a positive strain and at the bottom a negative strain (compression) takes place. As a result, the concrete slab arches upwards. Cracks can thus be better visible, for example in summer. On the contrary, the concrete slab may behave in cold temperatures. If the temperature of the road surface is lower than the temperature at the bottom of the concrete slab due to low air temperatures, the top will have a negative (compression) and the bottom will have a positive strain, causing the concrete slab to bulge down. Since this research project investigated only one concrete test section, no general conclusions can be drawn from this.

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