Clogging of porous pavements
- The cleaning experiment

Danish Road Institute
Technical note 60
2007
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Preface

The DRI-DWW Noise Abatement Programme was started in the beginning of 2004. It is a joint cooperation between the Road and Hydraulic Engineering Institute (DWW) in the Netherlands and the Danish Road Institute (DRI) for research and development in issues related to abatement of road traffic noise. The cooperation is carried out within the framework of the Dutch Noise Innovation Programme (the IPG programme). The research on clogging of porous pavements is one of the seven themes included in the cooperation [1].

During a study tour to Japan new and more effective cleaning strategies using improved equipment were observed [2]. The development and testing of image analyses procedures for analysing the ravelling and clogging phenomenon on CT-scan images and thin and plane sections made from drilling cores is reported in [3]. The analysis and assessment of clogging from drilling cores from highways A28 and A17 in the Netherlands and an urban street (Øster Søgade) in Copenhagen is reported in [4].

The present report addresses the analysis and assessment of drilling cores from A28 at Staphorst by CT-scanning before and after cleaning.
Forord

Centre for Transport and Navigation (DVS) i Holland og Vejdirektoratet, Vejtechnisk Institut samarbejder under det Hollandske Noise Innovation Programme (IPG) i en række projekter relateret til støjbekæmpelse. Målet er at udføre forskning og udvikling indenfor vejtrafikstøj.


Denne rapport beskriver CT-scanning og analyse af borekerner fra A28 ved Staphorst i Holland før og efter rensning.
Summary and conclusions

The DRI-DWW Noise Abatement Programme is a joint cooperation between the Road and Hydraulic Engineering Institute (DWW) in the Netherlands and the Danish Road Institute (DRI) within the framework of the Dutch Noise Innovation Programme (the IPG programme).

The present report addresses the effect of cleaning a porous pavement on A28 at Staphorst. Cleaning was performed by three different contractors:

- Dura Vermeer, Steamcleaner (10 cores before and 10 cores after cleaning)
- BAM Wegen Regio West (5 cores before cleaning, no cores after cleaning)
- Heijmans (7 cores before cleaning, 8 after cleaning).

All cores are scanned in a CT-scanner at Delft University of Technology. Data analysis is performed by DRI.

From the assumption that cleaning reduces the amount of mastic and increases the voids content the effect of cleaning has been assessed by CT-scanning of drill cores. Differences between pairs of drill cores before and after cleaning are assessed from the vertical profiles of voids or mastic content and CT-scan images. The criterion for the cleaning to have an effect is that the difference before and after cleaning is larger than the variations with depth.

From all profiles of voids and mastic contents it is noted that in general cleaning has very limited or almost no effect on clogging. Only in specific positions differences between voids or mastic content before and after cleaning are observed. Though, this might be due to differences in voids or mastic content between the two positions in the pavement before cleaning. Only if differences in voids content are confirmed by similar differences in mastic content the differences is attributed to the effect of cleaning.

The following detailed observations were noted:

- **Dura Vermeer.** A positive effect of cleaning is found in the lower part of the bottom layer in the right wheel track in the right lane but also a slight negative effect is found in the same position. In all other positions no detectable effect of cleaning is observed.

- **BAM.** Since no cores were drilled after cleaning it is not possible to assess the effect of cleaning. Specifically in the boundary between top and bottom layer the voids content is low. This could be due to the intrusion of fine mix into the bottom layer.
• **Heijmans.** A negative effect of cleaning is found in the lower part of the bottom layer in both wheel tracks in the right lane. In all other positions no detectable effect of cleaning is observed.
1. Experimental procedures

Drill cores from three locations on A28 at Staphorst have been investigated as outlined in figures 2, 8 and 12. No data on the original voids and mastic content or other mix data was obtained. It is therefore not known, if there are any differences between the sections indicated in the drill core location plans as received from DWW. Cleaning was performed by three different contractors:

- Dura Vermeer, Steamcleaner (10 cores before and 10 cores after cleaning).
- BAM Wegen Regio West (5 cores before cleaning, no cores after cleaning).
- Heijmans (7 cores before cleaning, 8 after cleaning).

All cores are scanned in a CT-scanner at Delft University of Technology. Data analysis is performed by DRI. CT-scanning provides non-destructive three-dimensional visualization and characterization of drill cores and creates a series of two-dimensional images (slices) of x-ray images that are taken in a horizontal cross section of the drill cores. Each slice, or section, is the taken of a few millimetres thickness at a few millimetres distance.

Contrast in an X-ray CT image is generated by differences in X-ray absorption which relates closely to density differences within the object. A series of x-rays are emitted simultaneously from different angles and after they have passed through the core the strength of the rays are measured which depends on how dense the material they have passed through is. A computer can subsequently calculate the relative density of the materials in the scanned cross section and draw a two-dimensional image of this. For each cross section a two-dimensional image is taken and these are then joined to form a three-dimensional image that can be viewed from all angles. The Dutch CT-scanner used in this study is a medical scanner located at Delft University of Technology.

The heights of all layers are measured on CT-scan images and given in figures 3, 9 and 13. In the CT-scan images voids (and exterior areas) are black, the mastic including clogging is grey and the aggregate is light grey. To be able to quantify the amount of clogging it is necessary to segment the images in voids, mastic and aggregate. On CT-scan images from the CT-scanner used in this study clogging is included in the mastic volume and it is not possible to distinguish between mastic and clogging. Therefore the amount of clogging and the effect of cleaning are assessed from the voids and mastic content and possibly changes in these contents by cleaning.
Since the original voids and mastic content are not known it is not possible to calibrate the volumes obtained from the CT-scan analysis. Therefore, the grey level values for segmentation of the CT-scan images are selected from the values reported in [3]. The average value for all road sections in this report is

- Voids [-1023; 630]
- Mastic [631; 1421]
- Aggregate [1422; 3071]

From this the best estimate of segmentation values are selected. Since the segmentation values determine the amount of voids, mastic and aggregate and hereby influence the assessment of cleaning, three different sets of segmentation values have been investigated to illustrate the sensitivity of the analysis. The three sets are given in table 1. The sets are selected to illustrate the extremes of mastic content, which is used as an indicator for the level of clogging. If the cleaning has an effect on clogging it is assumed that after cleaning the amount of mastic decreases and the voids content increases.

The vertical profiles of voids and mastic volume content is calculated for each core for the three sets of segmentation values. The results are illustrated in figures 4-7, 10-11 and 14-17. In each graph the voids or mastic content for cores drilled before and after cleaning is given. For each core the best estimate is given as a bold line and the high and low voids or mastic contents as dim lines. It should be noted that the cores scanned before and after cleaning are not the same; they have been drilled in the same section but voids and mastic content may not have been the same before cleaning.

Table 1. Three sets of segmentation values for CT-scan analysis to illustrate the sensitivity of the analysis.

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<th>Mastic / Aggregate</th>
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<td>a. High voids content Low mastic content</td>
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<td>1300</td>
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<td>b. Best estimate</td>
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<td>1400</td>
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<tr>
<td>c. Low voids content High mastic content</td>
<td>500</td>
<td>1500</td>
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In appendices 1-3 detailed CT-scan images and graphs are given for each set of cores before and after cleaning. On the vertical cross section on the top of each page, thin lines indicate the horizontal planes identified as the boundaries for the surface, the fine top layer, the coarse bottom layer and the bottom of the drill core. Below the vertical cross section are images of the horizontal cross sections 10 mm from the surface (in the top layer) and 50 mm from the surface (in the bottom layer) given. This is illustrated in figure 1.
Figure 1. The CT-scan images given in appendices 1-3 for each drill core. 1) Vertical cross section, 2) Horizontal cross section 10 mm from the surface (top layer), 3) Horizontal cross sections 50 mm from the surface.
## 2. The effect of cleaning

### 2.1 Steamcleaner Dura Vermeer

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*Figure 2. Location of drill cores in two-layer porous pavements on A28 at Staphorst before (bold) and after cleaning by Dura Vermeer.*

*Figure 3. Thicknesses of 4/8 mm mix (upper layer) and 11/16 mm mix (lower layer) measured on CT-scan images of cores drilled by Dura Vermeer.*
Figure 4. Vertical voids profiles in drill cores before cleaning (red) and after cleaning (blue) by Dura Vermeer in the right lane. Location of drill cores and reference numbers as given in figure 2.
Figure 5. Vertical voids profiles in drill cores before cleaning (red) and after cleaning (blue) by Dura Vermeer in the emergency lane. Location of drill cores and reference numbers as given in figure 2.
Figure 6. Vertical mastic profiles in drill cores before cleaning (red) and after cleaning (blue) by Dura Vermeer in the right lane. Location of drill cores and reference numbers as given in figure 2.
Figure 7. Vertical mastic profiles in drill cores before cleaning (red) and after cleaning (blue) by Dura Vermeer in the emergency lane. Location of drill cores and reference numbers as given in figure 2.
2.2 BAM Wegen Regio West

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<td>km 108.825</td>
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<td>km 108.900</td>
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Figure 8. Location of drill cores in two-layer porous pavements on A28 at Staphorst before cleaning by BAM. No cores were drilled after cleaning.

Figure 9. Thicknesses of 4/8 mm mix (upper layer) and 11/16 mm mix (lower layer) measured on CT-scan images of cores drilled by BAM.
Figure 10. Vertical voids profiles in drill cores before cleaning (red) by BAM in the right lane. No cores were drilled after cleaning. Location of drill cores and reference numbers as given in figure 8.
Figure 11. Vertical mastic profiles in drill cores before cleaning (red) by BAM in the right lane. No cores were drilled after cleaning. Location of drill cores and reference numbers as given in figure 8.
### 2.3 Heijmans

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<td>12</td>
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Figure 12. Location of drill cores in two-layer porous pavements on A28 at Staphorst before (bold) and after cleaning by Heijmans.

Figure 13. Thicknesses of 4/8 mm mix (upper layer) and 11/16 mm mix (lower layer) measured on CT-scan images of cores drilled by Heijmans.
Figure 14. Vertical voids profiles in drill cores before cleaning (red) and after cleaning (blue) by Heijmans in the right lane. Location of drill cores and reference numbers as given in figure 12.
Figure 15. Vertical voids profiles in drill cores before cleaning (red) and after cleaning (blue) by Heijmans in the emergency lane. Location of drill cores and reference numbers as given in figure 12.
Figure 16. Vertical mastic profiles in drill cores before cleaning (red) and after cleaning (blue) by Heijmans in the right lane. Location of drill cores and reference numbers as given in figure 12.
Figure 17. Vertical mastic profiles in drill cores before cleaning (red) and after cleaning (blue) by Heijmans in the emergency lane. Location of drill cores and reference numbers as given in figure 12.
3. Assessment of cleaning

Since no data on the original voids and mastic content or other mix data was obtained it is not known, if there are any differences or similarities between the sections indicated in the drill core location plans. Also, it is not possible to calibrate the volumes obtained from the CT-scan analysis. Therefore, the basis for making any assumptions on voids or mastic contents is not present. In the assessment of the cleaning effect it is therefore decided not to present any averages values of voids or mastic contents between sections since they give no useful information on the cleaning effect. Instead, only differences between pairs of drill cores are assessed from the vertical profiles of voids or mastic content and the CT-scan images.

It should be noted that the cores scanned before and after cleaning are not the same; they have been drilled in the same section but voids and mastic content may not have been the same before cleaning. Also, it should be noted that on CT-scan images from the CT-scanner used in this study clogging is included in the mastic volume and it is not possible to distinguish between mastic and clogging. Therefore, the amount of clogging and the effect of cleaning are assessed from the voids and mastic content and possibly changes in these contents by cleaning and not directly from the amount of clogging.

Three different sets of segmentation values have been investigated to illustrate the sensitivity of the analysis. The sets are selected to illustrate the extremes of mastic content, which is used as an indicator for the level of clogging. In general it is noted that the variations in voids content between the three sets are limited (1-2 %) whereas variations in mastic content is larger (3-5 %). The reason for this is the way the sets of segmentation values are selected. Set a) causes high voids content and at the same time low mastic content, which will result in very low mastic content. Set c) causes low voids content and at the same time high mastic content, which will result in very high mastic content.

Though, the most important result is that profiles are almost identical, they are only shifted to a lower or higher level. This means that the difference between profiles before and after cleaning is not affected by the segmentations values in the range studied. This indicates that the best estimate (set b) could be used to assess the effect of cleaning.

If cleaning has an effect on clogging it is assumed that after cleaning the amount of mastic decreases and the voids content increases. With this assumption looking at all profiles of voids and mastic contents it is noted that in general cleaning has very limited or almost no effect on clogging. Only in specific spots differences between voids or mastic content before and after cleaning are observed. Even in some cases the voids content decreases after cleaning. Though, as mentioned above this might be due to differences in voids content between the two spots in the pavement before cleaning.
In a more detailed assessment the **criterion for the cleaning to have an effect** could be that the profiles of voids or mastic content should be separated at least over a depth of 10 mm. This means that the difference before and after cleaning is larger than the variations with depth. With this criterion the cleaning by Dura Vermeer and by Heijmans is assessed. The cleaning by BAM could not be assessed since no cores were drilled after cleaning.

### 3.1 Steamcleaner Dura Vermeer

In the following positions an effect of cleaning according to the criterion mentioned above is observed (figures 4-7):

**Right lane**
- Between wheel tracks
  - No effect observed
- In right wheel track
  1. Voids content decreases by 10 % in the top layer from a high level (30 %)
      - No similar effect on mastic content (core 19 & 9)
  2. Voids content increases by 5 % in the lowest part of the bottom layer
      - Similar effect on mastic content (core 19 & 9)
  3. Voids content increases by 3 % in the top layer
      - No clear similar effect on mastic content (core 15 & 5)
  4. Voids content increases by 5 % in the lower part of the bottom layer
      - Similar effect on mastic content (core 15 & 5)
  5. Voids content decreases by 5 % in the lower part of the bottom layer
      - Slight similar effect on mastic content (core 12 & 2)

**Emergency lane**
- Voids content decreases by 2 % in the top layer
  - No similar effect on mastic content (core 20 & 10)
- Voids content decreases by 3 % in the top layer
  - No similar effect on mastic content (core 13 & 3)

The observations are marked with these numbers in figures 4 and 5 and appendix 1 on the relevant profiles. The observations above is in red when the effect of cleaning is negative (more clogging) and in green when the effect is positive. Since the effect of cleaning should be observed on both voids and mastic contents the observations 1, 3, 6 and 7 is assumed to be due to differences between the two drill cores before cleaning. Observations 2, 4 and partly 5 are confirmed for both voids and mastic contents and are therefore assumed to be due to the effect of cleaning.

The positive effect of cleaning is therefore found in the lower part of the bottom layer in the right wheel track in the right lane for two sections (section 2 and 3). A slight negative effect of cleaning is observed in the third section in the same position (section 1). In all other positions no detectable effect of cleaning is observed.
3.2 BAM

Since no cores were drilled after cleaning it is not possible to assess the effect of cleaning. The voids and mastic profiles does not give any overall reason why it should not be possible to clean the pavement compared to the pavements cleaned by Dura Vermeer and Heijmans since the levels of voids and mastic is comparable. Though, it seems that specifically in the boundary between the top and the bottom layer the voids content is low. The mastic content is not unusually high which means that the boundary is partly blocked by the aggregate from the fine mix in the top layer. This is illustrated in figure 18 with three slices in the boundary between the top and bottom layer. The lowest voids content (13.4 %) is found 25 mm from the surface.

Figure 18. BAM drill core 4. Boundary layers (23 mm, 25 mm, 27 mm from surface) including top and bottom mix (voids contents 17.2 %, 13.4 %, 15.0 %).

3.3 Heijmans

In the following positions an effect of cleaning according to the criterion mentioned above is observed (figures 14-16):

Right lane
- In left wheel track
  1. Voids content decreases by 5 % in the lower part of the bottom layer
     Slight similar effect on mastic content (core 15 & 13).
- In right wheel track
  2. Voids content decreases by 5 % in the lowest part of the bottom layer
     Similar effect on mastic content (core 14 & 12).
  3. Voids content decreases by 5 % in the lowest part of the bottom layer
     Slight similar effect on mastic content (core 10 & 9).

Emergency lane
- No effect observed

The observations are marked with these numbers in figure 14 and appendix 3 on the relevant profiles. The three observations above are confirmed for both voids and mastic contents and are therefore assumed to be due to the effect of cleaning. It is seen that the effect of cleaning is negative for all three observations. The negative effect of cleaning is found in the lower part of the bottom layer in both wheel tracks in the right lane for two sections (section 4 and 5). In all other positions no detectable effect of cleaning is observed.
The present report addresses the effect of cleaning a porous pavement on A28 at Sta- phorst. From the assumption that cleaning reduces the amount of mastic and increases the voids content the effect of cleaning has been assessed by CT-scanning of drill cores. Differences between pairs of drill cores before and after cleaning are assessed from the vertical profiles of voids or mastic content and CT-scan images.

It is suggested that the **criterion for the cleaning to have an effect** is that the profiles of voids or mastic content is clearly separated at least over a depth of 10 mm. This means that the difference before and after cleaning is larger than the variations with depth.

From all profiles of voids and mastic contents it is noted that in general cleaning has very limited or almost no effect on clogging. Only in specific positions differences between voids or mastic content before and after cleaning are observed. Though, this might be due to differences in voids or mastic content between the two positions in the pavement before cleaning. Only if differences in voids content are confirmed by similar differences in mastic content the differences is attributed to the effect of cleaning.

The following detailed observations were noted:

- **Dura Vermeer.** A positive effect of cleaning is found in the lower part of the bottom layer in the right wheel track in the right lane but also a slight negative effect is found in the same position. In all other positions no detectable effect of cleaning is observed.

- **BAM.** Since no cores were drilled after cleaning it is not possible to assess the effect of cleaning. Specifically in the boundary between top and bottom layer the voids content is low. This could be due to the intrusion of fine mix into the bottom layer.

- **Heijmans.** A negative effect of cleaning is found in the lower part of the bottom layer in both wheel tracks in the right lane. In all other positions no detectable effect of cleaning is observed.

It is recommended to compare these observations with the acoustic performance of the pavements before and after cleaning. No data on the original voids and mastic content or other mix data was obtained. It is therefore not known, if there are any differences between the sections indicated in the drill core location plans. It is recommended to use the original mix design and quality data as basis for future evaluations of cleaning effects.
5. References


Appendix 1: Cleaning by Dura Vermeer
Figure A1-1. Dura Vermeer, core 18 before cleaning (left) and core 8 after cleaning (right).
Figure A1-2. Dura Vermeer core 18 and 8, voids and mastic profiles before and after cleaning.
Figure A1-3. Dura Vermeer, core 19 before cleaning (left) and core 9 after cleaning (right).
Figure A1-4. Dura Vermeer core 19 and 9, voids and mastic profiles before and after cleaning.
Figure A1-5. Dura Vermeer, core 14 before cleaning (left) and core 4 after cleaning (right).
Figure A1-6. Dura Vermeer core 14 and 4, voids and mastic profiles before and after cleaning.
Figure A1-7. Dura Vermeer, core 15 before cleaning (left) and core 5 after cleaning (right).
Figure A1-8. Dura Vermeer core 15 and 5, voids and mastic profiles before and after cleaning.
Figure A1-9. Dura Vermeer, core 11 before cleaning (left) and core 1 after cleaning (right).
Figure A1-10. Dura Vermeer core 11 and 1, voids and mastic profiles before and after cleaning.
Figure A1-11. Dura Vermeer, core 12 before cleaning (left) and core 2 after cleaning (right).
Figure A1-12. Dura Vermeer core 12 and 2, voids and mastic profiles before and after cleaning.
Figure A1-13. Dura Vermeer, core 20 before cleaning (left) and core 10 after cleaning (right).
Figure A1-14. Dura Vermeer core 20 and 10, voids and mastic profiles before and after cleaning.
Figure A1-15. Dura Vermeer, core 16 before cleaning (left) and core 6 after cleaning (right).
Figure A1-16. Dura Vermeer core 16 and 6, voids and mastic profiles before and after cleaning.
Figure A1-17. Dura Vermeer, core 17 before cleaning (left) and core 7 after cleaning (right).
Figure A1-18. Dura Vermeer core 17 and 7, voids and mastic profiles before and after cleaning.
Figure A1-19. Dura Vermeer, core 13 before cleaning (left) and core 3 after cleaning (right).
Figure A1-20. Dura Vermeer core 13 and 3, voids and mastic profiles before and after cleaning.
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Figure A2-2. BAM, core 2, voids and mastic profiles before cleaning.
Figure A2-3. BAM, core 5 before cleaning.
Figure A2-4. BAM, core 5, voids and mastic profiles before cleaning.
Figure A2-5. BAM, core 4 before cleaning.
Figure A2-6. BAM, core 4, voids and mastic profiles before cleaning.
Figure A2-7. BAM, core 3 before cleaning.
Figure A2-8. BAM, core 3, voids and mastic profiles before cleaning.
Figure A2-9. BAM, core 1 before cleaning.
Figure A2-10. BAM, core 1, voids and mastic profiles before cleaning.
Appendix 3: Cleaning by Heijmans
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Figure A3-2. Heijmans, core 15 and 13, voids and mastic profiles before and after cleaning.
Figure A3-3. Heijmans, core 14 before cleaning (left) and core 12 after cleaning (right).
Figure A3-4. Heijmans, core 14 and 12, voids and mastic profiles before and after cleaning.
Figure A3-5. Heijmans, core 11 after cleaning.
Figure A3-6. Heijmans, core 11, voids and mastic profiles after cleaning.
Figure A3-7. Heijmans, core 9 before cleaning (left) and core 10 after cleaning (right).
Figure A3-8. Heijmans, core 9 and 10, voids and mastic profiles before and after cleaning.
Figure A3-9. Heijmans, core 3 before cleaning (left) and core 4 after cleaning (right).
Figure A3-10. Heijmans, core 3 and 4, voids and mastic profiles before and after cleaning.
Figure A3-11. Heijmans, core 2 before cleaning (left) and core 1 after cleaning (right).
Figure A3-12. Heijmans, core 2 and 1, voids and mastic profiles before and after cleaning.
Figure A3-13. Heijmans, core 5 before cleaning (left) and core 6 after cleaning (right).
Figure A3-14. Heijmans, core 5 and 6, voids and mastic profiles before and after cleaning.
Figure A3-15. Heijmans, core 7 before cleaning (left) and core 8 after cleaning (right).
Figure A3-16. Heijmans, core 7 and 8, voids and mastic profiles before and after cleaning.
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