Bearing capacity development on low volume roads (a 15-year case study)

J. R. Kristiansen
Carl Bro Pavement Consultants, Kokbjerg 5, 6000 Kolding, Denmark

ABSTRACT: This paper presents a 15-year study (1989-2004) of the actual bearing capacity development on a number of low volume road sections in Denmark. The project was started up in 1989 as part of the implementation of a PMS project and, apart from various deterioration technical aspects; the purpose was to study and uncover the actual bearing capacity development and to develop deterioration models for the bearing capacity of low volume roads in Denmark.

The basis on which the mentioned test sections were selected will be mentioned in the paper as well as how they were divided into sections of 10x10 metres, how current and comprehensive analyses were made of materials and soil conditions. Furthermore, it will be discussed, how daily measurements and registrations were made of meteorological data, sounding of the groundwater level (which is high on some sections) and how an artificial lowering of the groundwater level influenced both negatively and positively on the road deterioration.

Finally, results will be presented from selected sections where the bearing capacity has developed as expected, but in some cases also in a rather surprising way.

KEY WORDS: bearing capacity, PMS (Pavement Management System), FWD (Falling Weight deflectometer), design, deterioration, distress, models, groundwater, condition; GPR (Ground Penetration Radar), RoSy (RoSy Road Systems), residual life (based on Danish design criteria).

1 INTRODUCTION

In Denmark the municipal road network consists of approx. 65,000 km roads or approx. 85% of the total road network. The main part of the road network has surfaces consisting of asphalt or asphaltic pavements. At the same time a large part of the municipal roads are so-called low volume roads that origin from old wheel tracks or, as it holds for newer roads, they have been designed for their purposes.

This paper describes how an agreement was made with a road authority in 1989, in connection with the implementation of a PMS, to select a number of test sections that could secure the basis of the development of individual deterioration models (including models for the bearing capacity development) for low volume roads.

2 BACKGROUND

In 1988 a very large part of the road network in Ulfborg-Vemb Municipality had reached a point, where the service level of the 180 km road network was considered as one of the worst off in Denmark at that time. The municipality lacked documentation for its assertion that it would bee too expensive not to maintain the road network immediately. For this purpose Ulfborg-Vemb Municipality decided to implement the entire RoSy® PMS concept [3] including deterioration models for low volume roads [1]. These models were to be adjusted later according to the results from the test project running parallel to the PMS project.

3 A BRIEF DESCRIPTION OF THE PMS PROJECT

The purpose of the PMS project was to establish, collect and record the data needed for the calculation of maintenance strategies [5, 6]. The criterion for these strategies was that the future maintenance was to be carried out in the most economical way. Furthermore, solutions and consequences would be calculated on the basis of various constrained budget levels to allow comparison.

3.1 Monitoring and condition survey

The following registrations and registration methods were selected:

- Inventory: Geometric data (length, width, shoulders, ditches, kerbs, etc.)
- Condition survey: Visual, 10 condition objects were selected.
- Thickness measurements on all sections using ground penetrating radar (GPR)
- Bearing capacity measurements (with falling weight deflectometer - FWD)
- Traffic census (annual average daily traffic - AADT, estimated standard axle load - ESAL)

3.1.1 Inventory

The geometric data was collected by means of the fully electronic CamSurvey method. Figure 1 gives an example of how geometric data can be presented in the database.

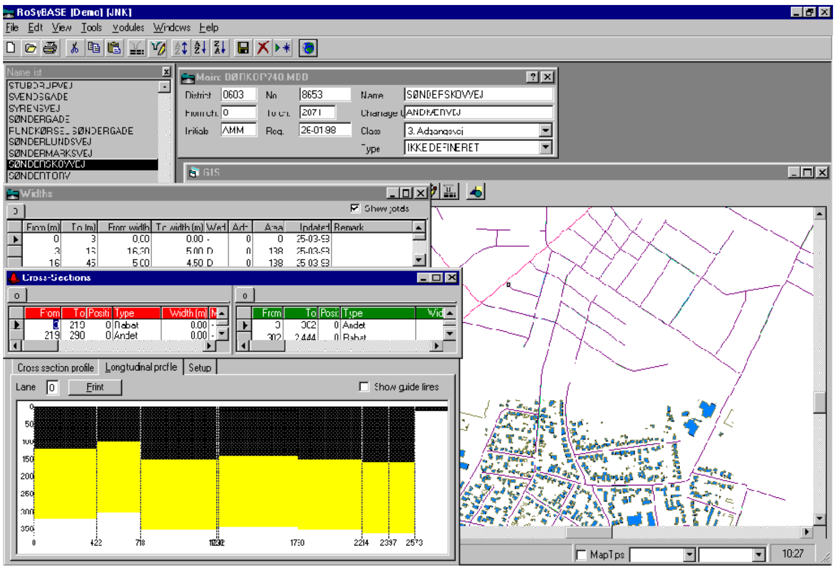

Figure 1: Example of geometric data presentation

3.1.2 Condition survey

For this project a maximum of 10 condition objects were selected as being representative of the functional condition of the road network. 9 objects were to form part of the deterioration parameters to be applied for the maintenance calculations.

3.1.3 Thickness measurements (GPR) and bearing capacity measurements (FWD)

All roads were measured by means of GPR, recorded in the database and at the same time divided into homogeneous sections with similar pavement structures. Furthermore, the bearing capacity of all road sections was measured with FWD equipment twice a year. Applying the data on pavement layer thickness, the expected future traffic load and the measured deflection data, RoSy DESIGN (non-linear elasticity back-calculation and design program for FWD) calculated the present remaining service life and necessary reinforcement based on Danish criteria [8,9 with later updates]. Figure 2 gives an example of the results of the GPR and FWD measurements.

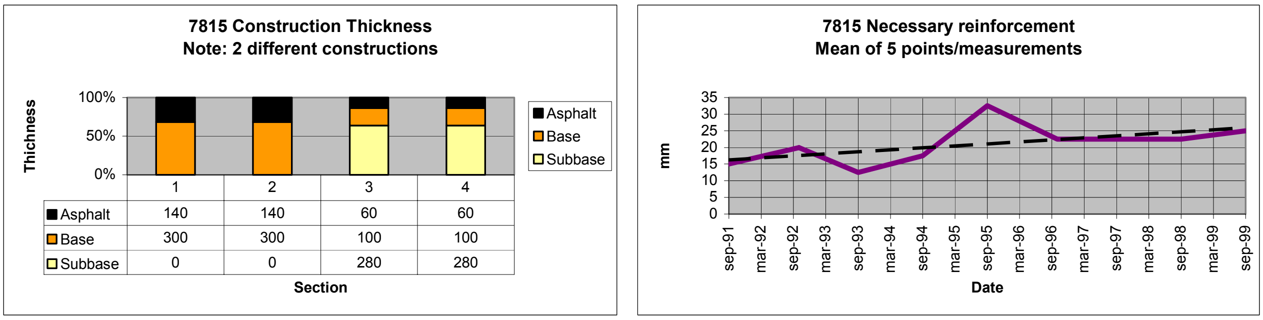

Figure 2. Result of GPR and FWD measurements

3.1.4 Traffic and axle load registration

Traffic census and recording of axle loads were performed on selected sites. The measurements were performed as AADT and also the vehicle lengths were measured. On this basis ESAL was calculated in relation to the European Vehicle Classification.

4 THE PARALLEL TEST PROJECT

As mentioned earlier, a test project was running parallel to the PMS project. The purpose of this project was to follow the actual deterioration and maintenance needs of the roads in order to compare this data to the needs calculated by the PM system. At the end of 1989 the municipality and the PMS supplier entered into a five-year cooperation agreement. This agreement was later extended to a 15-year agreement.

4.1 Project scope

The following project scope was defined:

a. Selection and current monitoring of eleven 100-meter test sections being representative of the entire network. Initial ages of the pavements on the individual sections were between 0 and 8 years.
b. Definition and creation of a calculation model for the functional service life.
c. Selection of repair and maintenance methods and products
d. Test and suggestions as to future software development and definition of needs.

Below criteria were applied for the selection of the eleven test sections:

a. The sections were to be located near local wastewater cleaning plants out of consideration for the daily registration of local climatic conditions.
b. The sections were to be under and not under the influence of the groundwater level
c. The sections were to be grouped in accordance with four traffic load types.
d. A grouping in accordance with various pavement structure types
e. A grouping in accordance with the actual condition (structural and functional)
f. A grouping in accordance with the functioning of drainage conditions (ditches/shoulders)
g. The sections could under no circumstances (regardless of current and future condition) be repaired. This turned out to be a very important contractual condition, as the condition of some of the roads grew so bad that complaints were sent to the politicians of the municipality. These were rejected with reference to the agreement.

The individual 100-meter sections were then divided into ten 10-meter sections. On each 100-meter section the below items were investigated:

a. Core taking/excavations and detailed material analyses (once). However, due to the fact that the agreement was extended, further asphalt analyses were made.
b. Bearing capacity measurements by means of FWD in the same measuring points twice a year (May and September).
c. Daily recording of air temperature and precipitation.
d. Recording of traffic density (as required)
e. Visual condition surveys of 10 condition objects once a year
f. Photos (bird's eye view) at 10-meter intervals once a year (September out of consideration of the light intensity etc.) as a supplement to point e.
g. Insertion of measuring rods and weekly reading of the actual groundwater level.

Figure 3 gives an example of 3 selected photos of the same ten meters on one of the test sections. The initial condition in 1989 (7 years old AC), after 5 years and after ten years.

Figure 3. Example of visual condition of 10 metres of a test section in 1989, 1994 and 1999

5 RESULTS

A characteristic factor for all test sections was that the deterioration cycle on the individual sections over the first 5-6 years was somewhat slower than the PMS calculations predicted. This also appears from the PhD study made at The Danish Technical University carried out over 5 years of the project [2]. On the contrary, at the end of the 10-year period something drastic began to happen on several of the sections [4]. Figure 4 gives an example of this development.

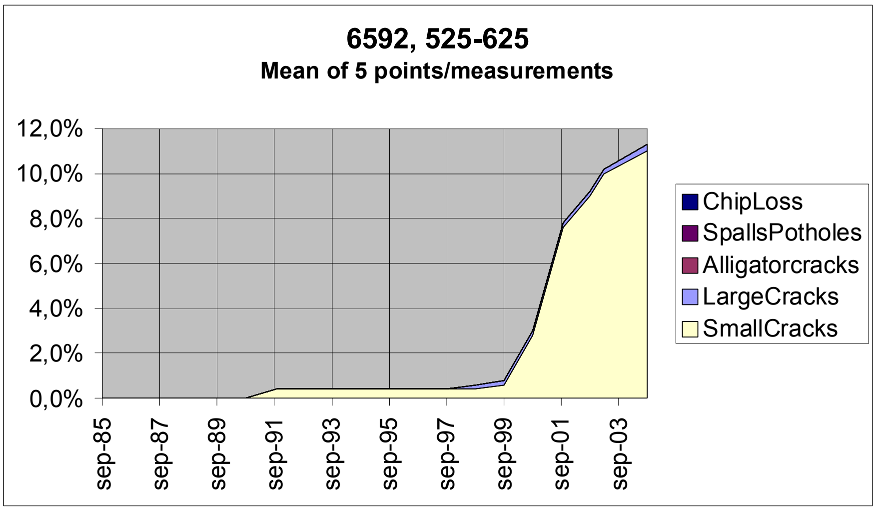

Figure 4. Distress development on test section 6592. New asphalt in 1985

Other sections show more regular and logical distress developments as illustrated in figure 5.

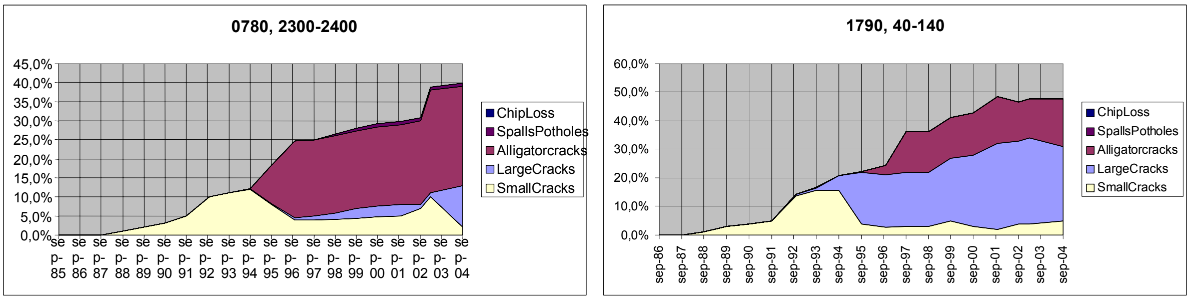

Figure 5. Distress development on selected test sections (Note: Age variations)

As it appears, the functional condition development varies from test section to test section. Also, as described in the following, the structural condition development has in some cases differed from the initial expectations.

5.1 Results related to bearing capacity

As appears from the above, all 11 test sections differ from each other as regards pavement structure and traffic load. Furthermore, the asphalt top layers were between 0 and 8 years old when the project started.

Figure 6a illustrates the ages of the upper asphalt layers in 2004. Figure 6b illustrates the differences in the pavement structures of the individual sections expressed in traffic load (ESA/day) divided by the asphalt thickness (mm). It appears e.g. that sections no. 1460 with ESA/day= 9, no. 7895 with ESA/day= 70 and no. 7895.1 with ESA/day= 31 have considerably larger traffic loads per mm asphalt pavement than the other sections. The traffic loads on the other 8 sections vary from 1 to 29 ESA/day.

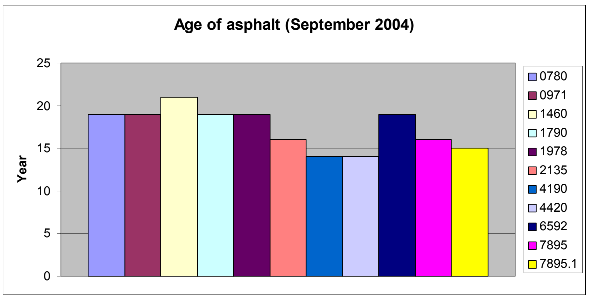

Figure 6a. Age of asphalt on each section

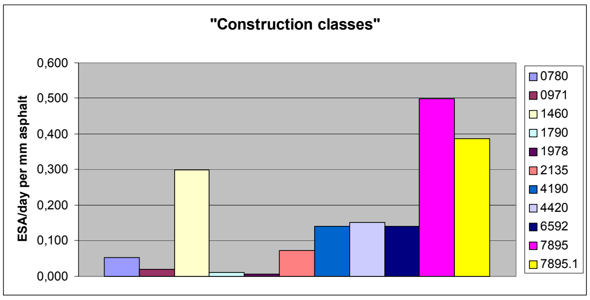

Figure 6b. Construction classes

It is not possible to give a detailed presentation of the results of each individual part section in this paper. The following is a closer study of the results from a number of selected test sections.

5.1.1 Section 0780, 2300-2400

Table 1 – Groundwater level lowered with 20 cm at the beginning of the nineties

ESA per day	7
Age of asphalt in 1990	5 years
FWD measuring points	5
Thickness of asphalt	3 points with 50 mm, 2 points with 30 mm
Thickness of unbound material	3 points with 300 mm, 2 points with 250 mm
Design period	15 years

This section (table 1) is characteristic in that it is situated in an area where it was at the beginning of the nineties decided to lower the groundwater level permanently with 20 cm. Figure 7 (upper figure) shows that since 1995, a permanent lowering of the groundwater level has actually taken place. Furthermore, the figure (lower figure) illustrates that the groundwater lowering, maybe a little surprisingly, seems to have had a negative effect on the bearing capacity of the test section, as the residual life (five measuring points), after having increased year after year, suddenly seems to decrease drastically in 1995 and then again increase over the entire time span. This happens parallel to the clear and drastic deterioration of the asphalt, see figure 5 (left figure).

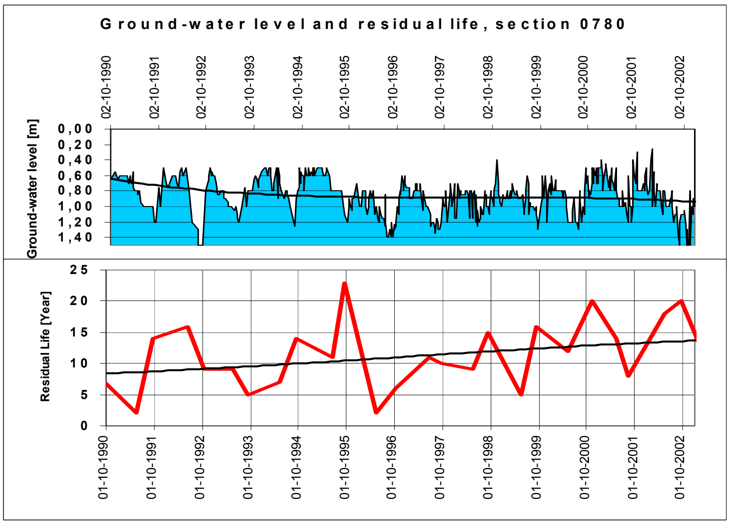

Figure 7. Influence of a permanent lowering of the groundwater level

5.1.2 Section 2135, 405-505

Table 2 – A section with a constantly varying groundwater level

ESA per day	11
Age of asphalt in 1990	2 years
FWD measuring points	5
Thickness of asphalt	5 points with 150 mm
Thickness of unbound material	5 points with 150 mm
Design period	15 years

This section (table 2) is particularly interesting, as it is situated in an area where the groundwater level varies considerably. In periods the groundwater level is only 25 cm below the pavement surface. From Figure 8 appears that the groundwater level on this section is generally increasing, but, as it was the case for section 0780 in 1995, a reduction was also found here. This also happened at a time with a low groundwater level. A characteristic fact about this section is, however, that there is a connection between the groundwater level variations and the residual life variations. When the groundwater level is high the residual life is short and visa versa. It is, however, also in this case remarkable that generally the residual life is increasing over the years, while the asphalt (see figure 9) seems to show structural weaknesses over the last five years.

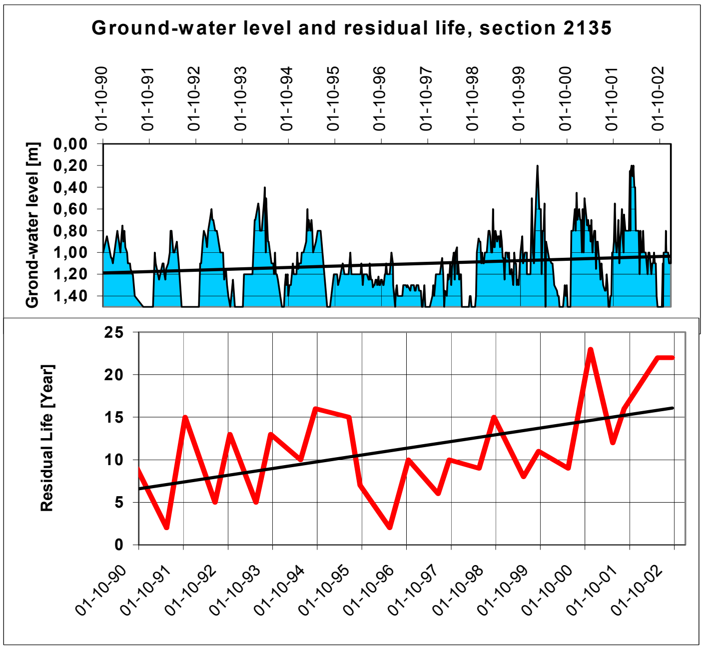

Figure 8. Influence of a permanent groundwater level lowering.

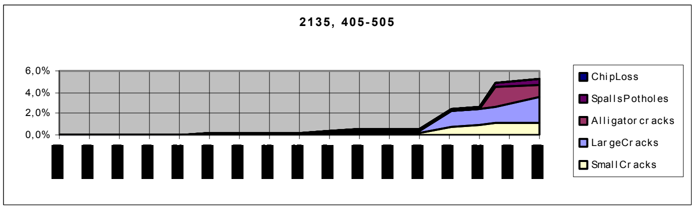

Figure 9. Distress development on section 2135

5.1.3 Section 7895, 20-120

Table 3: Groundwater level is constant and has no influence

ESA per day	70
Age of asphalt in 1990	2 years
FWD measuring points	5
Thickness of asphalt	2 points with 140 mm, 3 points with 60 mm
Thickness of unbound material	2 points with 300 mm, 3 points with 100 mm
Design period	15 years

This section (table 3) is subjected to the highest traffic load of all 11 test sections. In return the groundwater level of this section is constant at a depth of 1 metre or more all year. The section has a traffic load and a pavement structure that makes one reflect on, whether we are really talking about a low volume road in the original sense of the word. Irrespective of this reflection, this section also offers surprising observations.

Figure 10a shows that the residual life only develops very slowly in negative direction. This is surprising, as, cf. Figure 10b, the section has already in the mid-nineties started to show more and more structural distress. A reinforcement of 60-70 mm would, according to calculations, have corresponded to a residual life of 5-7 years and given the section a residual life of 15 years. However, reality shows that in spite of "an early warning", a postponement of the reinforcement until the pavement starts to deteriorate is an even as good solution, instead of making any efforts at the time where measurements show that it is required,. Question: Are sublayers also consolidating in this case?

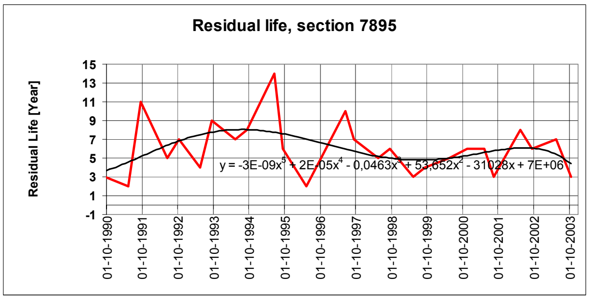

Figure 10a. Residual development on 7895

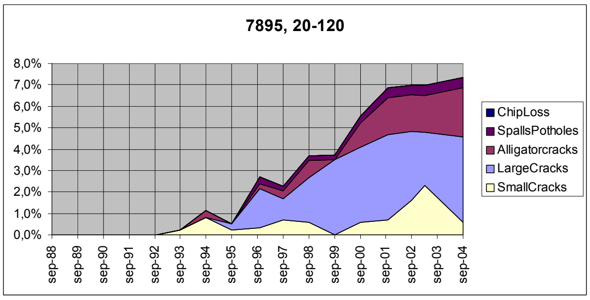

Figure 10b. Distress development

5.1.4 Section 7895.1, 320-420

Table 4. The groundwater level has no influence

ESA per day	31
Age of asphalt in 1990	1 year
FWD measuring points	5
Thickness of asphalt	5 points with 80 mm
Thickness of unbound material	5 points with 150 mm
Design period	15 years

Like the previous one, this section (table 4) is not influenced by the groundwater level. It should, however, be noticed that the measurements of the first year were performed on a newly paved asphalt layer, which may also be the reason for the somewhat noticeable residual life development over the years (see figure 11a). Apart from the first two years, the residual life seems to be slowly decreasing over the years and from 1992 to 2003 (11 years) the residual life was in principle reduced by approx. 9 years. Though, the residual life development turns out to vary from year to year in practice. Since 2000, as it appears from figure 11b, the structural distress development was considerable (concurrently with a drastic reduction of the residual life). This section must be considered as the section that corresponds best to an ”ideal situation” if we only look at the bearing capacity development.

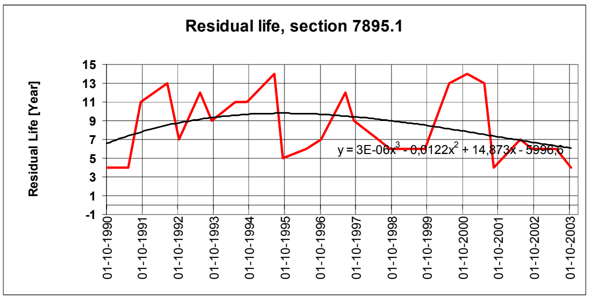

Figure 11a. Residual development on 7895.1

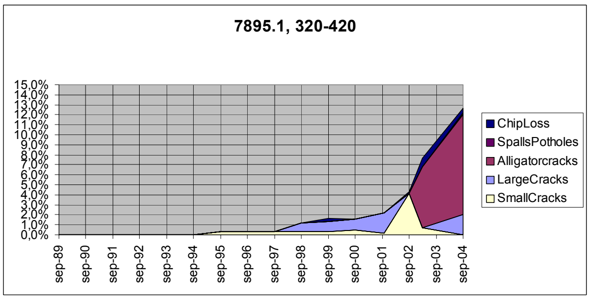

Figure 11b. Distress development

5.1.5 The other test sections

The other seven test sections are also interesting seen in a bearing capacity perspective and FWD measurements were also carried out on these sections. A common fact for the sections is that they all show minor changes in the bearing capacity based on a 15-year design period. All these sections are within a variation range (still a long residual life) as regards bearing capacity, which means that the surface condition of the existing pavement will need new overlay long before the bearing capacity conditions call for this. It should, however, be mentioned that five of the sections have demonstrated a decreasing residual life, while two have shown an increasing residual life.

6 CONCLUSION AND RECOMMENDATIONS

A general lowering of the groundwater level in an area resulted in a poorer bearing capacity on the roads in this area. The reason may be rebedding of the materials of the road structure. The condition did not become permanent.

Sections with a high groundwater level show considerable sensitivity to changes of the groundwater level as regards bearing capacity.

The bearing capacity development on low volume roads seems to be atypical compared to what could be expected. The residual life seems to have increased concurrently with the deterioration of the asphalt pavement. The reason may be that along with the deterioration of the asphalt layer, the unbound layers have consolidated. Previous studies [7] seem to confirm that mild winters without frost heaves may have a corresponding effect on the bearing capacity.

The fact that the pavement temperature may have a certain influence on the bearing capacity is common knowledge. In this project corrections have been made for the temperature influence. However, new studies show that it is very important that the obtained pulse time on the performed bearing capacity measurements is as identical as possible from time to time. Especially at the beginning of the nineties, no special attention was paid to this and at that time the pulse time lengths of the measurements were not automatically saved in the measuring files, as they are today. This fact may have a certain influence on the comparison of the measurements from before 1995.

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