FINNISH ROAD ADMINISTRATION

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THE EFFECT OF BASE COURSE MATERIAL AND OTHER PROPERTIES OF PAVEMENT ON THE DURABILITY OF ROADS

Background

This is a summary of four studies:
1. Deficiency models for the guidelines to the design of road structure
2. The effect of unbound base course on the deterioration of roads.
3. Permanent deformation of unbound base course
4. Suction and deformation properties of base course aggregates

The first of the studies is based on the data base of the Finnish Road Administration which includes information on 78 000 km of roads, including the pavement history, deflection measurements and observations concerning cracking, rutting and roughness covering 15 years.

The aim of the study was to find basic models to predict the rate of
- the distress propagation
- rutting
- roughness (IRI).

In order to be able to compare pavements with different ages it was necessary to find the shape of the distress versus time relation. For this type of a study it is necessary to have road sections with at least three observations (including an assumption: no cracks in new pavements). The following results were found:

Distress

Distress is described with the Sum of Defect (m^2/100m). It includes alligator cracks with a high weighing factor (1.0) and other types of cracks with lower weighting factors. The Sum of Defect can be estimated by using the following formula:

The Sum of Defect = a * age^b + c.

c, the initial Sum of Defect was assumed to be 0 m^2. Then a and b were computed for each 100 m long paved road sections for which at least three sequential distress observations were available. The mean value for b was 1.8…2.5 and the median 1.3…1.9 depending on the type of the pavement. That means that the annual increase of the Sum of Defect becomes higher every year. For further studies 1.4 was chosen for b.

After choosing value 1.4 for b it became possible to compute factor a from the database for different types of roads, when there is at least one observation for each road section where the Sum of Defect and the age of the wearing course is known.

According to the results, factor a (the rate of distress propagation) depends on the type of the layers below the wearing course (unbound, or bound which means in most cases the previous wearing course), type of the wearing course (AC, soft AC or very soft AC), the width of the road, the traffic volume (commercial vehicles in both directions), the area (North or South) and the history of the road (properly designed and build, or developed from a gravel road by a simple strengthening.

The rate of distress propagation [$m^2/a^{1.4}$] =

$$\left(\frac{D0}{1mm}\right) * \left[\begin{pmatrix} Layer\_below \\ wearing\_course \\ unbound = 0{,}3 \\ bound. = 0 \end{pmatrix} + \begin{pmatrix} Wearing\_course \\ AC = 1{,}32 \\ softAC = 1{,}97 \\ v.softAC = 2{,}22 \end{pmatrix} + \begin{pmatrix} Width \\ 11{,}9m = 0 \\ 8{,}0m = 0{,}24 \\ 6{,}4m? = 0{,}73 \end{pmatrix} + \begin{pmatrix} ADTheavy \\ 25veh/d = 0 \\ 105veh/d = -0{,}08 \\ 355veh/d = 0{,}58 \end{pmatrix} + \begin{pmatrix} Area \\ S. = -0{,}08 \\ N. = 0 \end{pmatrix} \right]$$

$$+ \begin{pmatrix} Construction\_type \\ normally\_build = -0{,}01 \\ from\_gravel\_road = 0{,}6 \end{pmatrix}$$

The rate of the distress propagation after a rehabilitation can also be estimated by using the rate observed before the rehabilitation (= a_1).

The rate of distress propagation [$m^2/a^{1.4}$] = $a_2 = f * (a_1 + c)$,
where
c = 3 $m^2/a^{1.4}$ for roads with a normal AC and 5 $m^2/a^{1.4}$ for ones with a soft AC

Table 1. Factor f = efficiency factor of the type of the rehabilitation:

Type of rehabilitation	on normal AC	on soft AC
50 mm AC	0.24	0.16
40 mm AC	0.36	0.28
Remix and 30 mm additional AC	0.34	
150 mm bit. stabilisation, 40 mm AC	0.22	
40 mm soft AC		0.30
40 mm very soft AC		0.37
Remix and 30 mm additional soft AC		0.40
150 mm bit. stabilisation, 40 mm soft AC		0.16

The factor for stabilisation is based on minor studies concerning stabilisations.

Rutting

The rut depth = a * age^b + c

c is the initial rut depth, which is normally 2 mm.

For roads paved with normal AC and ADT normally higher than 800 veh/d the mean value for b is 0.6…1.2 and the median 0.5…0.8. In these cases the rutting is caused by studded tyres. For roads with soft AC and normally less traffic the mean value for b is 0…0.3 and the median 0.1…0.5. On these roads the rutting is caused mainly by heavy vehicles. For further studies 0.2 was chosen. Studies made with the Heavy Vehicle Simulator give a bit higher b values, 0.25 or 0.4 for the number of loads.

The rate of rutting depends on the same things as the distress propagation does.

Roughness

The initial roughness varies a lot between different roads. That is why the following form of formula was chosen:

The roughness IRI_2 = a * (age_2 – age_3) + IRI_1

IRI_1 is the roughness at age_1 and IRI_2 is the roughness at age_2 Factor a is the annual increase of roughness. It depends on the same things as the distress propagation does.

The effect of unbound base

In study The Effect of Unbound Base Course on the Deterioration of Roads a separate sample of roads was chosen for the study concerning the unbound base, since the general data base does not include the quality of unbound layers.

The sample consisted of 59 locations on 25 roads. At least 10 of the roads had to be severely damaged when the wearing course was not older than 10 years, and at least 10 roads had to be in a good condition when the age of the wearing course was c. 8 years old. The ADT was to be c. 600 veh./day. The sample had to include crushed rock and crushed gravel from different part of Finland. Locations with damage caused by frost heave were not accepted. The age of the wearing course and the amount and type of cracking was taken from the data base, but it was checked on the place as well. Deflection, moisture content and density were measured on the site in spring and in summer, and base material samples were taken for the laboratory.

On roads with a traffic volume 600 veh. per day or less the performance of the pavement can be evaluated by using the rate of distress propagation (factor a defined above).

The effect of different characteristics of the base course material on the rate of distress propagation is described in figures 1…6.

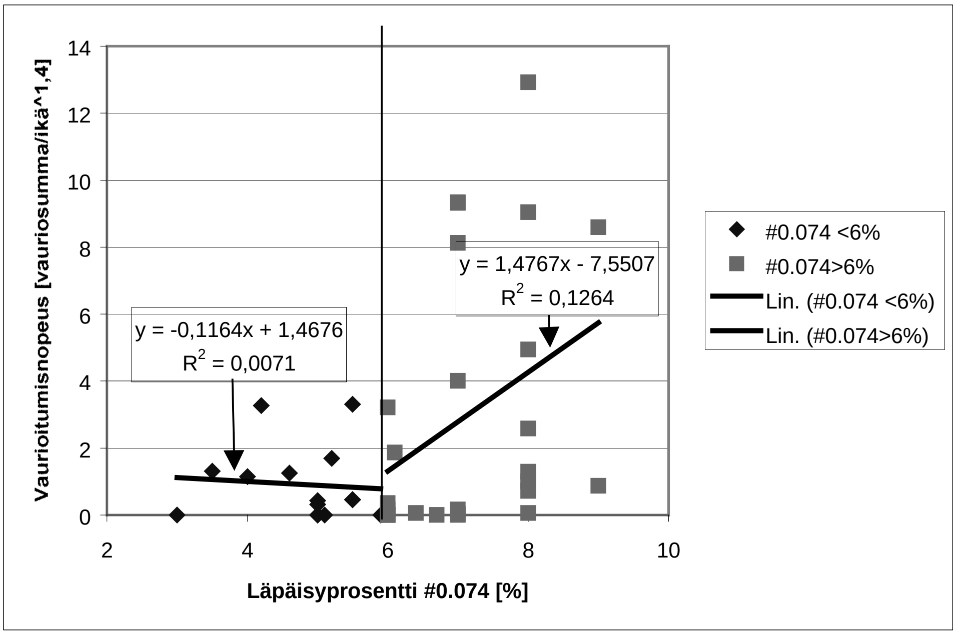

Figure 1. Fines content (Läpäisyprosentti #0.074) of crushed rock base course and the rate of distress propagation (vaurioitumisnopeus) $m^2/a^{1.4}$. The examined 59 locations were divided into two groups (≤ 6 % and < 6 %). A high fines content has a clear effect on durability.

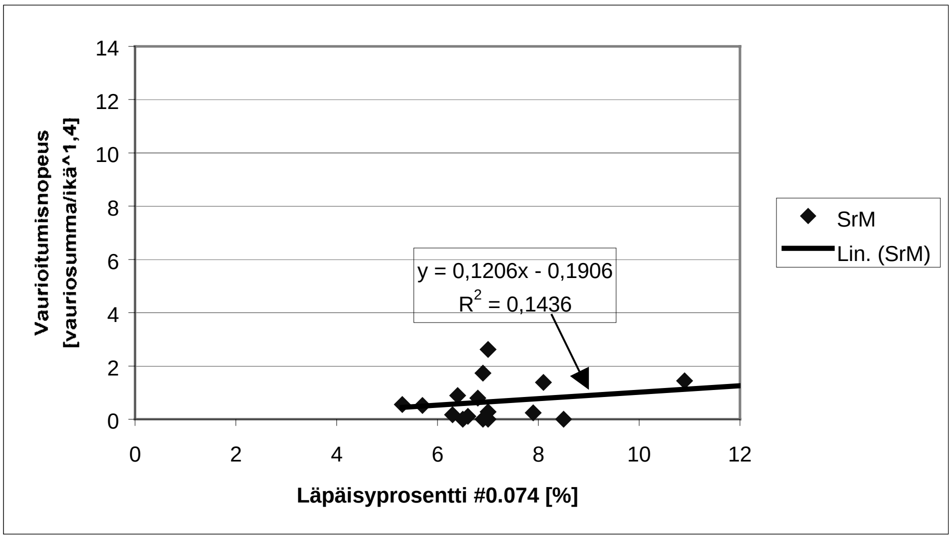

Figure 2. Fines content (Läpäisyprosentti #0.074) of crushed gravel base course and the rate of distress propagation (vaurioitumisnopeus) $m^2/a^{1.4}$. The durability is better than for roads with crushed rock base courses, and the fines content has almost no effect on durability.

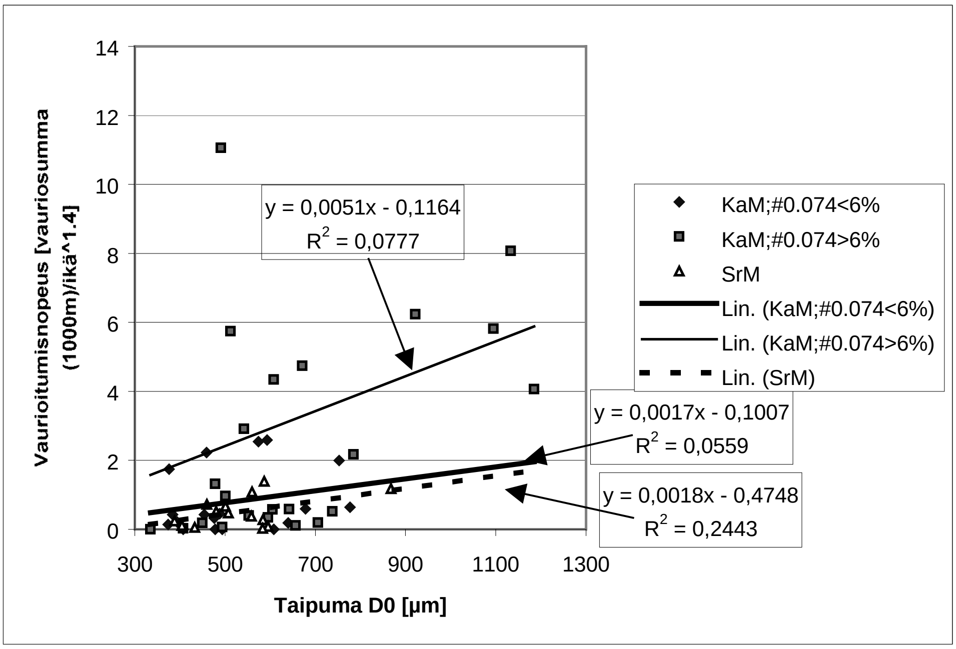

Figure 3. Deflection (Taipuma D0) in summer and the rate of distress propagation (vaurioitumisnopeus) $m^2/a^{1.4}$ for roads with different base course aggregates: crushed rock with different fines content (KaM; #0.074 < 6 % and KaM; #0.074 > 6 %) and crushed gravel (SrM).

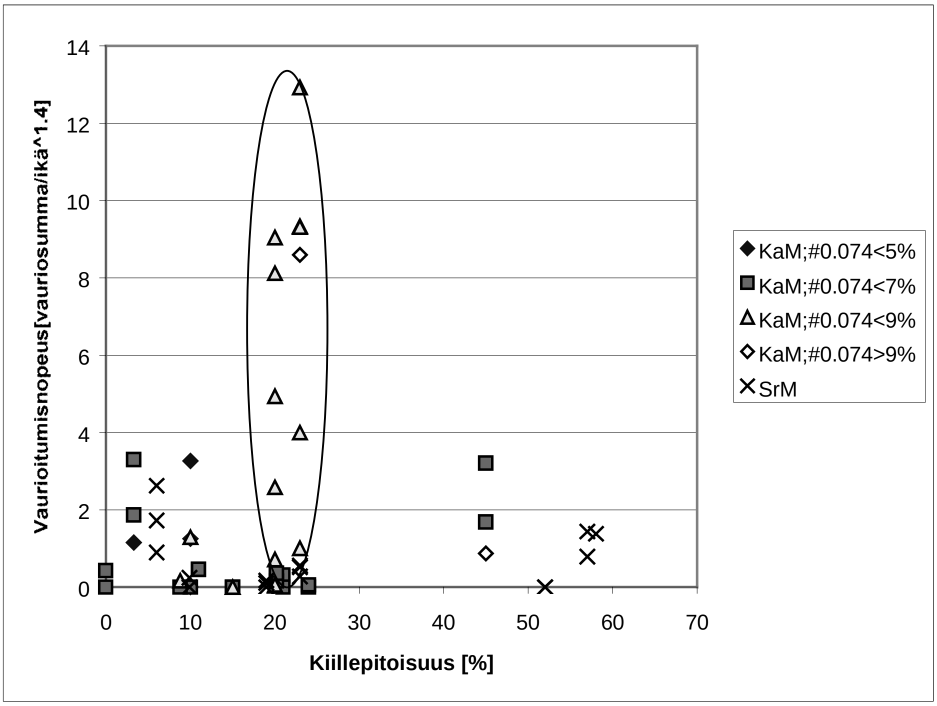

Figure 4. Mica content (Kiillepitoisuus) and fines content (Läpäisyprosentti #0.074) of crushed gravel base course, and the rate of distress propagation (vaurioitumisnopeus) $m^2/a^{1.4}$. A high mica content does not always result into poor durability. The highest distress is found in pavements with a combination of a moderate mica content (20 %) and a high fines content (above 7 %) in crushed rock base (KaM; 0.074 < 9 % and >9 %), which is common for aggregates from Vaasa area.

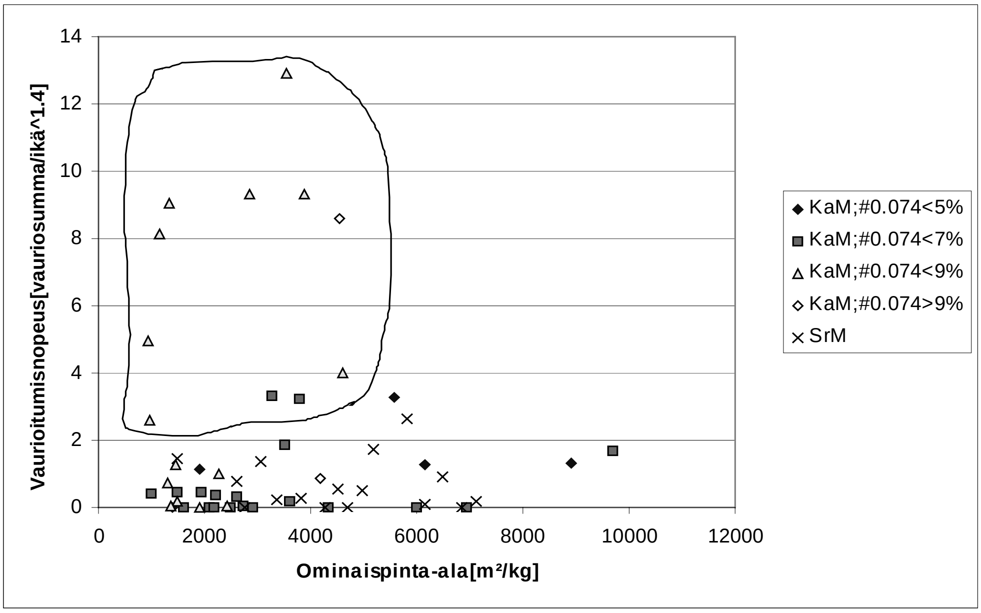

Figure 5. The specific surface (Ominaispinta-ala) area and fines content (Läpäisyprosentti #0.074) of crushed gravel base course, and the rate of distress propagation (vaurioitumisnopeus) $m^2/a^{1.4}$. A high specific surface area does not always result into poor durability. The highest distress is found in pavements with a combination of a moderate specific surface area (20 %) and a high fines content (above 7 %) in crushed rock base (KaM; 0.074 < 9 % and >9 %), which is common for aggregates from Vaasa area.

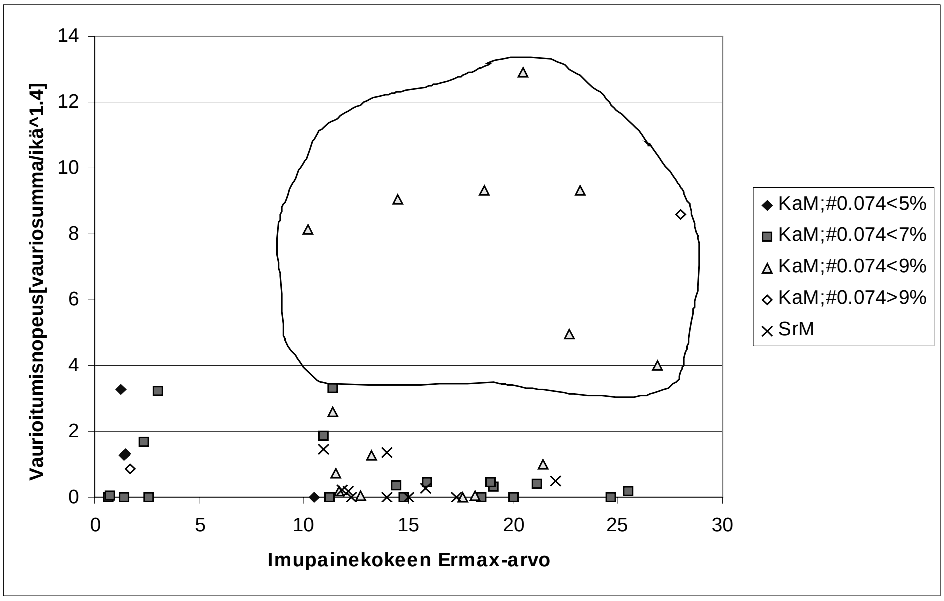

Figure 6. The $E_{r\,max}$ value from suction test (Imupainekokeen $E_{r\,max}$ arvo) and fines content (Läpäisyprosentti #0.074) of crushed gravel base course, and the rate of distress propagation (vaurioitumisnopeus) $m^2/a^{1.4}$. A high $E_{r\,max}$ value does not always result in poor durability. The highest distress is found in pavements with a combination of a high $E_{r\,max}$ value (> 10 %) and a high fines content (above 7 %) in crushed rock base (KaM; 0.074 < 9 % and >9 %), which is common for aggregates from Vaasa area.

Similar results as in figures 4, 5 and 6 were got with 0.02 mm fines content, the mineral size of the rock and the Water Adsorption. The Methylene blue tests and the Sand Equivalent tests were performed as well, but they did not have a good correlation with durability of roads.

It was possible to find the initial fines content (0.074) of the compacted base in one road only (3 locations of 59). It was 0.5 % lower than one observed in this study about 10 years later. The difference may be caused by traffic loading or by a difference in the exact location of the sample.

Most of the locations examined represent roads with a thin (normally 40 mm) open graded soft or very soft AC as bound layers. For roads with a thick or dense AC layers the effect of fines content on the durability is assumed to be much smaller than given in figures 1 to 3. It was not possible to examine if there were major differences in the quality of the wearing course. Is it possible that roads with a poor base material also have a wearing course made of poor aggregate? Then the quality of the wearing course may have caused the cracks? The aggregate often comes from the same quarry, but on the other hand, the grain sizes of bound layers are controlled better than for unbound layers.

The effect of the base course quality on the rate of rutting was not measured in this study, but it has been studied in an other study called 'Permanent Deformation of Unbound Base Course'. Spring and summer conditions and dynamic wheel load was simulated with a pavement test facility in laboratory. In wet spring conditions the rate of rutting is about 100 % higher for a crushed rock base with fines content (0.063 mm) 6.4 % than one with 4.5 %. Also the shape of the sieving curve and the mineralogical composition had an effect on rutting, especially in wet conditions.

Further laboratory tests were done in the study 'Suction and Deformation Properties of Base Course Aggregates'. The test results show that a moderate frost heave is possible with aggregates with fines content exceeding 5 %. High fines content in crushed rock may result in a high resilient modulus when dry but quite low when wet. Tube suction test results show that the dielectric value of crushed rock may be as high as 20, but it lies below 15 with all crushed gravel, with fines content 4…9 %, and crushed rock, with a low fines content. The high dielectric value shows that the material can absorb more water than other aggregates and is sensitive for deformation.

Conclusions (made by the Finnish Road Administration)

A practical way to compare durability of roads with wearing courses of different ages is to use factor a, the rate of distress propagation, of formula: The Sum of Defect = a * age$^{1.4}$.

According to studies mentioned above generally the most practical way to evaluate the quality of base course material is the fines content (0.074 or 0.063 mm). The fines content should not exceed 6 % in crushed igneous rock or 9 % in crushed gravel when they have been compacted in base course. A slightly higher value may be accepted if the contractor compensates the additional rehabilitation costs caused by the accelerated rate of distress propagation in the prise. Los Angeles value is used to evaluate the strength of the aggregate. It should not exceed 30, the absolute maximum is 40.

Previous numbers:

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