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# Multi-Stage Construction of Pavements

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**Finnish National Road Administration**

Technical Development

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# MULTI-STAGE CONSTRUCTION OF PAVEMENTS

Summary of a Finnish report on planned stage construction
- what is the best schedule for highway pavement layers?

## 1 INTRODUCTION

It is an old practice in Finland to apply successive layers of asphalt concrete during a longer period of time, say, four to nine years or sometimes even more. Within these years, the road is formally still under construction. Every layer belongs to the original design thickness which is determined according to the traffic load.

The most important reason for Multi-Stage Construction of Pavements is due to the rutting caused by studded tires, but also settlement and capital gains are important. During the Multi-Stage Construction, the surfaces are always quite new and the riding quality is somewhat better than in the cases where all the bituminous layers were laid at the same time.

Here is a sample from the Finnish Road Administration (FinnRA) Design Manual. The layout plan below indicates the years in which Asphalt Concrete (AC) layers should be laid. The figures are general, and rapid rutting or distress may give reason to accelerate the schedule in individual cases.

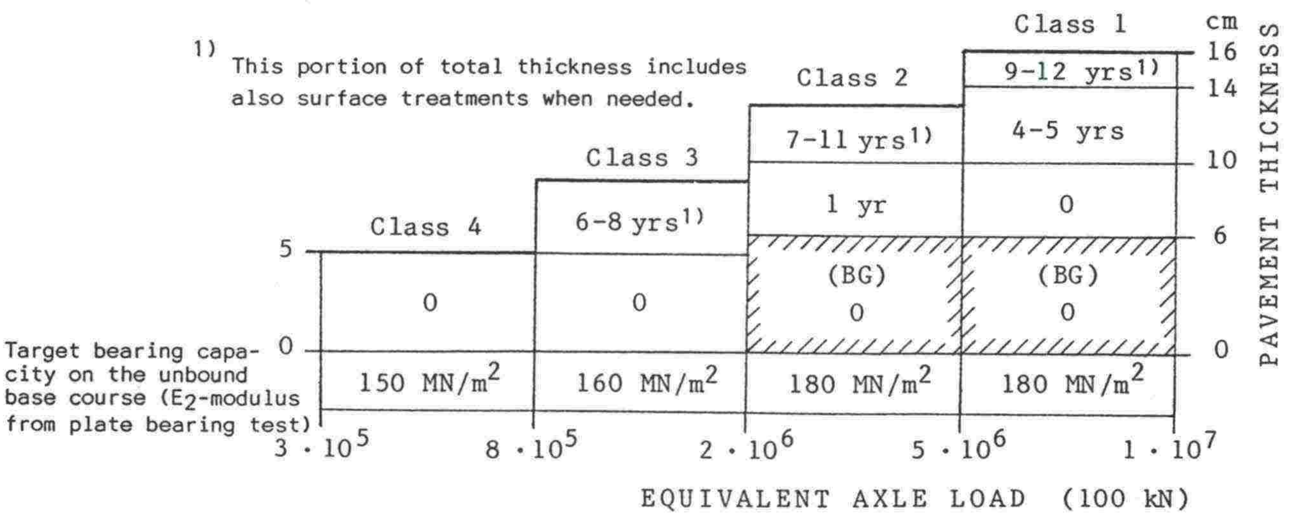



**Figure 1. Pavement layers and their scheduled laying years calculated from the opening of the road (numbers 0 to 12 in the box) for various design classes 1 to 4. The above line shows minimum thicknesses to achieve the bearing capacity as determined for 20 years' design life. BG = bituminous gravel; the other layers consist of asphalt concrete. - Finnish Road Administration 1985.**

The scheduled years in the layout plan above are based on the concept of the utilisation rate of the bearing capacity. Every new layer must be placed in due time, that is before the cumulative sum of loads of the lower layer does exceed 50 per cent (bituminous gravel) or 67 per cent (asphalt concrete) of the design life of that layer.

The advantages of stage construction come from the principle that every bituminous layer can perform dual tasks: it will add its share to the bearing capacity as a part of the design thickness, but it is also used as a wearing course for some years, receiving its share of the material abrasion, rutting and distress. The latter aspect will be lost if all pavement layers were laid at the same time or at least during the following year.

Thus, stage construction of the pavement layers will aim at two benefits:

(1) The roadkeeper may with every new layer be able to repair settlements, weak spots and incipient ruts (caused by studded tires), in a sense "free of charge".

(2) By postponing the second or upper layers, one saves money. At least the interest costs of the following investments are reduced, and sometimes also some measures of the road maintenance can be omitted by extending the construction period over several years.

## 2 NEED FOR EXPERIMENTAL AND ECONOMIC RESEARCH

In spite of long usage in Finland, multi-stage construction has only recently met certain criticism, arising from suspicions about insufficient bearing capacity. If the design thickness will only be reached after several years, doesn't there exist a risk of premature pavement damages? - There is a background in the fact that a remarkable share of the Finnish road network does not fulfill requirements for bearing capacity (in terms of deflection, or E-modulus in $MN/m^2$ = MPa), according to the standards for new roads. One may fear that even the new staged constructions would have defects in this respect.

Because no systematic data was readily available concerning possible relationships between stage constructions and pavement damages, a sample of 1- and 2-layer pavements were studied manually, complemented by some measurements and observations on multi-layer pavements. The purpose was to study whether those roads with slow-scheduled pavement layers have suffered more distresses than those completed within a shorter period. In the same time, all economic consequences must be considered. This comparison often emphasizes the advantages of the multi-staged principle.

Furthermore, some separate questions contributing to the success or failure of staged construction were studied. These questions include the wear resistance of hot-mix bases (bituminous gravel) as a temporary wearing course, and the influence of new traffic laws with raised axle loads (100 kN to 115 kN, and 160 kN tandem-axles to 180 kN), etc.

## 3 PAVEMENT DAMAGE STUDIES

The practical questions were put in the following forms:

(1) How many years new roads with just one bituminous layer can carry the traffic before a certain amount of damages will emerge?

(2) How many years roads with two bituminous layers can carry the traffic before the same amount of damages are observed? Does the time interval between the first and second layers have any effect on the behaviour of the pavement?

The recorded damages include alligator cracking and longitudinal cracks (no potholes, raveling, or wearing ruts), because the occurrence of these types of faults shows us the lack of bearing capacity which, in turn, may refer to a construction period stretched out too long.

The observation data, gathered in the autumn 1989, were limited. There were 16 roads with one bituminous layer and 14 with two but no roads with three or more bituminous layers were collected. The damages were described by so-called damage index which is obtained multiplying the damaged area by 0.1 (for longitudinal cracks) to 1.0 (alligator cracking) weighted factors.

Figures 2 and 3 (next pages) show the observation results: damage indexes are plotted against the age of surface on one-layer roads (Fig. 2) and two-layer roads (Fig. 3). In both pictures there are as a reference two curves describing the average growth of damages. The

Figure 2. Damage index versus pavement surface age on a sample of Finnish roads with one 40-50 mm thick AC-layer.

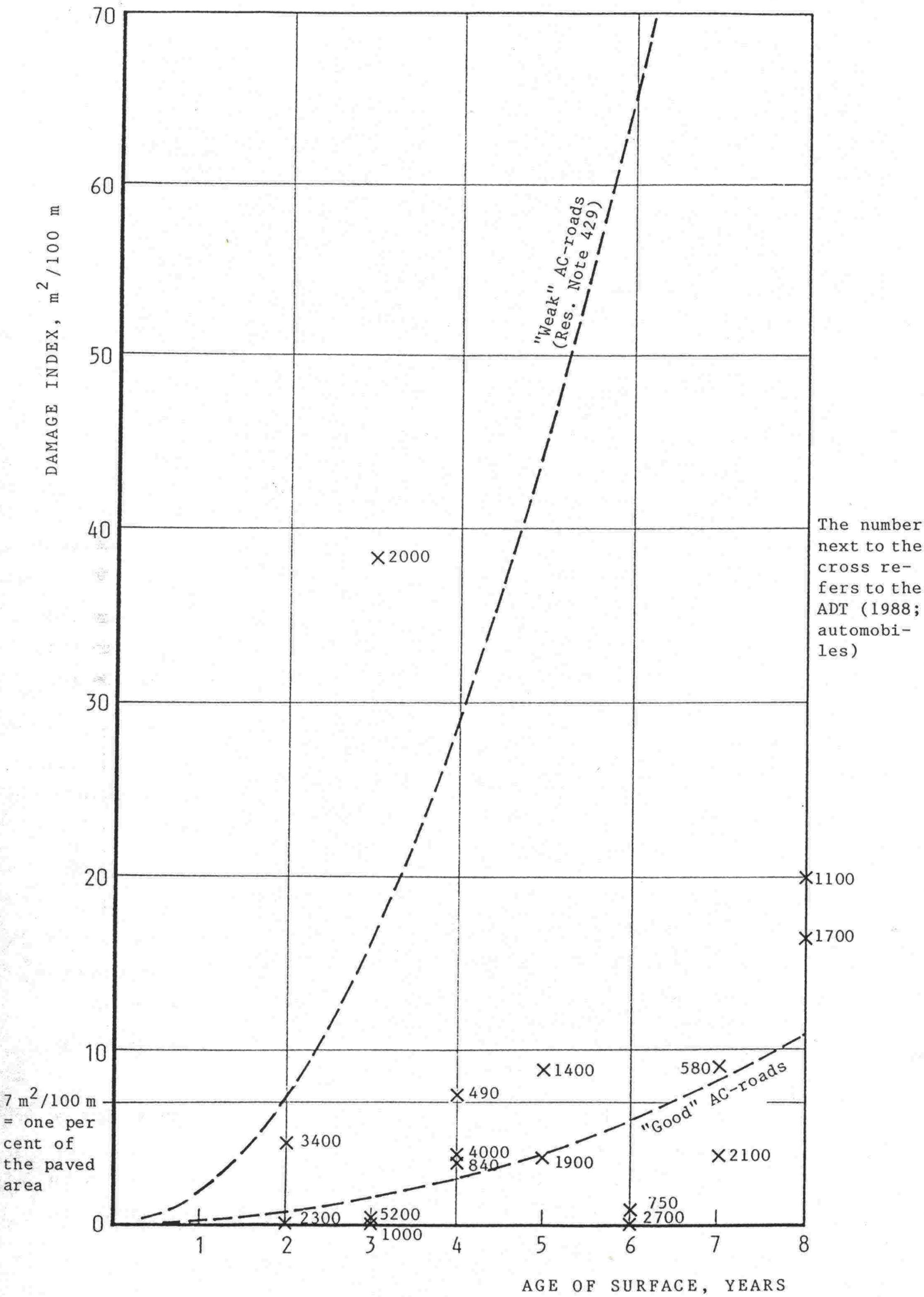
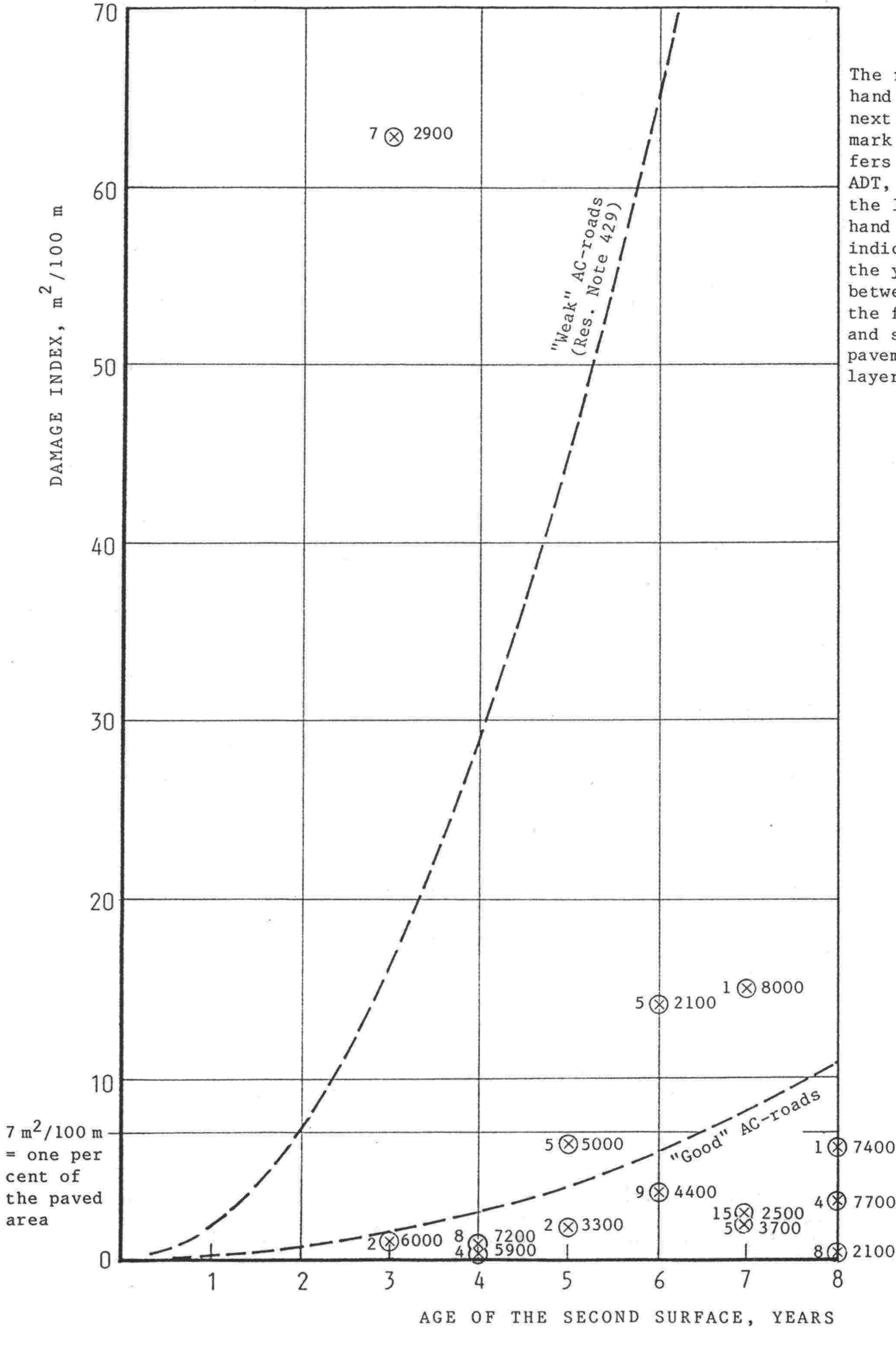


Figure 3. **Damage index versus pavement surface age on a sample of Finnish roads with two AC-layers.**




The right-hand number next to the mark ⊗ refers to the ADT, and the left-hand number indicates the years between the first and second pavement layers.

curves have been taken from another Finnish study[1]. "Weak" roads are old and not properly dimensioned, while "good" ones are newer and wider, and they meet the principal structural requirements.

The most marks in Figs. 2 and 3 show rather slow growth of pavement damages. The pavements in worst condition may have suffered some kind of failure when laid; aggregate segregation is one of the most common reasons for premature damages. The effect of traffic (ADT) seems to have only a minor significance.

In Fig. 3 with two-layer pavements, it does not give any clear indication of the effect of slow stage-construction on the surface condition. There are four cases out of eight where the surfaces with longer paving interval are in better condition than the others of the same age. So still more observations on this basic question in regard to stage construction must be obtained.

Let us assume that one per cent of the paved area (7 $m^2$/100 m of travelled way) were a suitable maximum before the next layer should be laid. Hence, some of the observed roads fall into the worse side of this limit. A general requirement cannot, however, be put so rigorously that no pavement section was permitted to exceed this limit, because the main reason for inferior condition seldom is too late repaving (or too slow stage construction) but rather some fault with materials or the construction itself.

It may be reasonable to interpret the results as follows: a new pavement layer should be laid not later than in a stage when one quarter of all observations show more damages than one per cent of the paved area. This criterion will lead to following schedules:

- the second layer is needed in the 5th year after the first one
- the third layer is needed in the 6th year after the second one.

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The small amount of observations can be complemented by several real examples of stage-constructed roads whose paving history, traffic load,

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[1] **Jämsä, Heikki & Saarinen, Harri: Teiden kunto ja palvelutaso. (English Abstract: Condition and serviceability of roads. Results from test sections in 1979-1983.) Technical Research Centre of Finland, Research Notes 429. Espoo, March 1985. 46 pp.**

and surface condition in some years are known. The analyses show that there are only very few cases where the upper layers are delayed in an injurious way; if so, this only concerns the hot-mix base (bituminous gravel) which is apt to rapid wearing due to its weak resistance against studded tires traffic. One of the conclusions is then that the BG-courses must not be exposed to traffic longer than one year before paving the next layer.

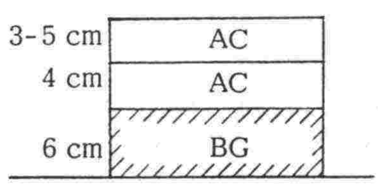
## 4 ECONOMIC ASPECTS

The studied examples referred above have revealed an uneconomic paving history in the cases where the traffic load was small and the roadkeeper had - to be on the safe side - resurfaced the road before any discernible defects. (The schedule in Fig. 1 gives only recommendations, and it is not obligatory to follow it exactly.) The interest costs will rise rather high, and one seldom gets them back in terms of reduced maintenance or driver costs.

On the other hand, successive layers are to be laid so soon that an excessive need of fine-graded levelling mix can be avoided, let alone a big consumption of patching materials. This would be both expensive and technically questionable as it would add to the susceptibility to deformations. So, an optimal timing is based on sound structures but according to so slow a schedule that every layer will also contribute as a temporary wearing course which will reduce the capital costs of the pavement.

Let us take an example of staged construction with two alternatives: a rapid schedule an a slow one, and compare the costs of each. The riding quality will be held as equal as possible. Hot-mix asphalt as levelling material will only be used for settlements after one year; later on the necessary levelling can be made by cold milling. - The interest rate is six per cent, as usual in Finland for investment calculations.

The design thickness corresponds to the Class 2 (Fig. 1 p. 1):



The unit costs for a 9.5 m wide road pavement are assumed as follows (ordinary prices 1989 in Finland):

| | | |
|---|---|---|
| - 6 cm bituminous gravel (BG) | 200 000 | FIM/km |
| - 4 cm asphalt concrete (AC), no levelling | 150 000 | " |
| - Hot-mix levelling or 2 cm cold milling + 4 cm AC | 190 000 | " |
| - " - + 5 cm AC | 210 000 | " |
| - 1 cm cold milling + 4 cm AC | 180 000 | " |
| - 2 cm cold milling only (whole pavement width) | 50 000 | " |
| - Repaving with heating method (travelled way only) | 80 000 | " |

Expected life:
(criterion: not too deep wearing ruts)

| | | |
|---|---|---|
| - Asphalt concrete layers | 6 | years |
| - Levelled surface by milling | 3 | " |
| - Repaving (heating method) | 3 | " |

Extra driver costs due to traffic delays:

- Any new AC-layer with previous levelling or milling: every vehicle has to wait presumably some 5 minutes during 10 days. If the ADT amounts 8000 automobiles including 800 commercial vehicles, and the road section is 10 km long, this will average a total of 600 hours/km for cars and 70 hours/km for trucks & buses. Further, time unit costs can be taken as 30 FIM/hour for cars and 100 FIM/hour for commercial vehicles. The sum will then result as follows: 25 000 FIM/km for one resurfacing operation.

- New AC-layer without levelling: delay will take place on 7 days instead of 10. This makes 17 000 FIM/km for one resurfacing.

- Cold milling (as the only measure), as well as repaving with the heating method: delay will take 3 minutes on 5 days which results in 7000 FIM/km for one measure.

Costs with alternative strategy A: rapid schedule of construction:

| | Year | Paving measure | Costs FIM/km (constr. + traffic) | Thickness at year's end |
|---|---|---|---|---|
| | 0 | BG 6 cm | 200 000 | |
| | 0 | AC 4 cm | 150 000 + 17 000 | 10 cm |
| | 1 | Hot-mix levelling + AC 4 cm | 190 000 + 25 000 | 14 cm |
| (Maintenance:) | 7 | Cold milling -2 cm + AC 4 cm | 190 000 + 25 000 | 16 cm |
| | 13 | Cold milling -2 cm | 50 000 + 7 000 | 14 cm |
| | 16 | Cold milling -1 cm + AC 4 cm | 180 000 + 25 000 | 17 cm |
| | (22 | Next paving measure) | | |

The present worth will be calculated discounting all costs to the year 0. The resulting sums are then:

| | |
|---|---|
| - Paving costs during 20 years: | 750 000 FIM/km |
| - Extra traffic costs (delays): | 70 000 " |
| Total: | 820 000 FIM/km |

Costs with alternative strategy B: slow schedule (stage construction):

| | Year | Paving measure | Costs FIM/km (constr. + traffic) | Thickness at year's end |
|---|---|---|---|---|
| | 0 | BG 6 cm | 200 000 | 6 cm |
| | 1 | Hot-mix levelling + AC 5 cm | 210 000 + 25 000 | 11 cm |
| | 7 | Cold milling -2 cm + AC 5 cm | 210 000 + 25 000 | 14 cm |
| (Maintenance:) | 13 | Cold milling -2 cm + AC 4 cm | 190 000 + 25 000 | 16 cm |
| | 19 | Repaving with heating method | 80 000 + 7 000 | 17 cm |
| | (22 | Next paving measure) | | |

After discounting to the year 0 (again at 6 per cent's interest) the results are:

- Paving costs during 20 years: 653 000 FIM/km
- Extra traffic costs (delays): 54 000 "

Total: 707 000 FIM/km

Summary results:

(1) Alternative A (rapid construction): paving costs during 20 years total 820 000 FIM/km. The latest measure, four years earlier, has been AC 4 cm. After 20 years, total pavement thickness is 17 cm.

(2) Alternative B (stage construction): paving costs during 20 years total 707 000 FIM/km which is 14 per cent less than in Alt. A (the roadkeeper's own costs are 13 per cent less than in Alt. A). The latest measure, one year earlier, has been repaving with heating method. The total thickness is 17 cm, or same as in Alt. A. In both alternatives, the next measure is expected to take place in the same year, 22, which means that no differences of residual values must be considered.

(3) The price level was in 1989 rather low, due to the cheap oil. If it is assumed that the price of bitumen would double from the second year of the period above, this would bring the alternatives closer together but Alt. B (stage construction) would still be 11 to 12 per cent cheaper than Alt. A.

(4) The riding quality of both alternatives may be on an average about equal. There are naturally also other alternatives as to the pavement types and their schedules, but the main result seems to favour the "stretching" of the construction period over a reasonable time.

## 5 MISCELLANEOUS QUESTIONS

Additional examinations of some detailed questions have given following results:

(1) Bituminous gravel: as mentioned, the pavement type most inclined to premature rutting and damages is bituminous gravel which is actually laid in hot-mix base courses. It is more useful to limit its use as wearing course to just some months or one year (exceptionally two years) than to improve its wearing resistance by more fine-graded aggregate, added binder content etc.

(2) Use of uncommon materials: if you consider other types of pavement structures, like grouted macadam, other bituminous mix-in-place pavements, or embankment of blasted rock boulders, most of them are in favour of the multi-staged construction principle. The structures have adequate bearing capacity (any premature fatigue is still farther away than with normal unbound layers) or, on the other hand, they are apt to unexpected settlements (blasted rock) which emphasizes the advantages of stage construction.

One important exception is soil cement which always needs a sufficient thickness of bituminous layers as a protection cover. That's why the soil cement, or cement stabilization is not well suited for stage construction, but needs appropriate bituminous layers as soon as the road will be released to traffic.

(3) Raised axle weights: in Finland the legal axle weights were raised from January 1, 1990 to about the same level as most EC-countries have them. Theoretically, this will add to the average Equivalent Axle Load (EAL) on the whole road network about 27 per cent. It was assumed that the transports move towards heavier and heavier vehicles and also the tire pressures are raising, and there are illegal overloads which are not brought under control. The last one makes the decisive point: it has been calculated that if just heavy overloads (> new weight limits + 10 per cent) could be reduced about to the legal weight maxima, this would reduce the whole EAL under that level the road network was exposed to before the new law with raised axle weights became effective.

Contrary to pessimistic expectations, the situation with overloads has in Finland turned into positive direction. Several factors are contributing to a more careful observation of the law. On the whole, the effect of the raised axle loads on the road network cannot yet be evaluated; it may also be quite negligible.

As to the stage construction, the axle weight raising, whether substantial or not, has only minor significance. If, for instance, the EAL of a certain new road will grow 20 per cent higher than when designed, even the risen EAL will most often fall into the same structural class (Fig. 1 p. 1). If not, the pavement behaviour deserves more attention regarding to any impending damages, but no drastic failures can be expected. Thus, only in seldom cases would some acceleration of the paving schedule be needed.

The most important damages due to very heavy axle loads are probably pavement deformations, because they closely depend on actual axle loads. Still, even there is open the primary question, whether or not will the heaviest overloads vanish from the highways. Anyway, it is better to make the pavements as well deformation-resistant as possible.

## 6 NEW RECOMMENDATIONS FOR MULTI-STAGE CONSTRUCTION

In spite of several aspects supporting the wide usage of stage construction, it seems as the timing schedule of 1985 (Fig. 1 p. 1) should to some extent be accelerated. The main reason is the need to be prepared for unexpected, unfavourable circumstances. They may be weak spots on the pavement base, poor materials, adverse weather conditions, or, for some reason, incompetent work.

At the same time, one must be warned not to speed up the paving schedule without some particular cause for it. To repave too early doesn't resemble a bank deposit; it is rather an erroneous investment, withdrawing the money from another road where the paving would be better needed.

Figure 4 (next page) shows a revised version of the paving schedules. The boundary lines between various classes 1 to 4 are numerically same as those in Fig. 1. It is presupposed, however, that the load equivalencies for different types of vehicles (cars to most heavy trucks) have been re-determined, according to the raised axle-loads (and improved obeyance of the law). - The total thicnesses are somewhat greater than the minimum thicknesses in Fig. 1 which allows reduced bearing capacities for the unbound base courses. (The bearing values in Fig. 1, especially that of 180 $MN/m^2$ are often quite hard to obtain.)

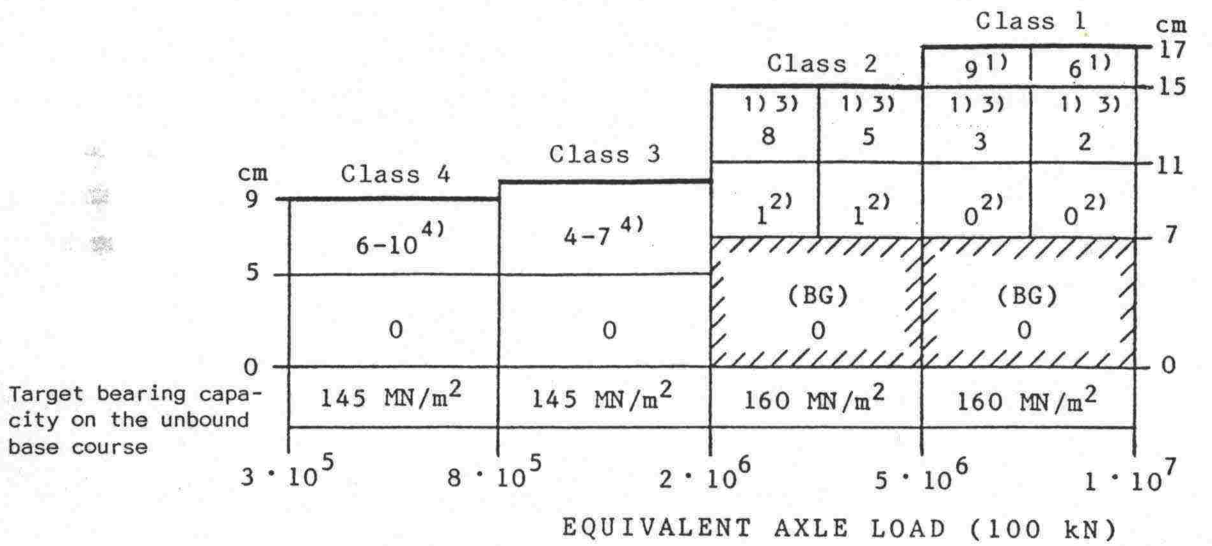



**Figure 4. A new outline for the paving schedule. Laying years calculated from the opening of the road (numbers 0 to 10) for various design classes 1 to 4. Remarks 1) to 4) are explained below.**

Remarks to Fig. 4:

1) From the third layer on upwards, the wearing ruts will be levelled by cold milling. The milling depth is usually 2 cm, and milling plus a new 4-cm layer will add only 2 cm to the total pavement thickness.

2) The second pavement layer may be postponed for another year (or less), if the surface condition is relatively good (less damages and ruts than usual).

3) The third layer may be postponed for 1 to 2 more years, if the surface condition is relatively good.

4) Within classes 3 and 4 the accurate timing of the second layer will depend on the progress of damages as well as on the type of the road project; road strengthening requires a rather rapid schedule while a new road permits a slower schedule.

Other aspects of Fig. 4:

(1) Fig. 4 shows normal paving schedules until the total thickness is enough to bring the bearing capacities in various classes to the required level. (Numerical target values in $MN/m^2$ on completed roads have not been put in Fig. 4.) From that on, the repaving and maintenance measures will be determined according to the Pavement Management System.

(2) A still more rapid timing than expressed in Fig. 4 should never be applied without some particular cause for it. If a quicker schedule is considered, the expected advantages must be proved by economic comparisons.

(3) The surface levelling of the first and second layers prior to the next one will be done by hot-mix asphalt. The levelling mix should be designed as much deformation-resistant as possible, and its excessive use must be avoided.

## 7 FURTHER COMMENTS ON STAGE CONSTRUCTION

What would it cost to put the new paving schedule into use? - The proposal in Fig. 4 is somewhat more rapid and more expensive than the old guide in Fig. 1 (p. 1). The net costs have been estimated at 5 to 10 million FIM/year, concerning annually some 400 km new roads.

In spite of these extra costs a moderate change might, however, be profitable. By means of the accelerated schedule, the risks of pavement damages are not entirely avoided but they will be limited in all cases. Second, the riding quality will on some road sections be a bit better than according to the old timing guide.

The comparisons above refer to Finland where stage construction is an old tradition. In many countries abroad the situation looks different: even a small move towards the principle of stage construction would mean positive gain; the interest savings from postponed pavement layers may be quite remarkable. Particularly this is true in the less developed, capital-lacking countries where also the traffic growth may be of incalculable size. Not only the maintenance but also the capital costs should be optimized as far as possible.

One national feature at the paving policy comes from the dominant role of studded tires in Finland. The wearing ruts appear far sooner and grow deeper than almost anywhere else. This means, for instance, that the pavements must be resurfaced more often for the sake of wearing and not of fatigue. As to the stage construction, the stud-free countries have the advantage of a longer life in their AC-layers which will make the pursuit of capital savings still more inviting.