PERFORMANCE OF CONCRETE PAVEMENTS IN SWITZERLAND
A CHECK OF THE VALIDITY OF THE AASHTO INTERIM GUIDE DESIGN METHOD

Ivan F. Scazziga, Federal Institute of Technology, Zurich, Switzerland

The design method for concrete pavements in force at the moment in Switzerland has been published in 1971 and is based on the results of the AASHO-Road-Test. A previously started research program with the initial purpose of finding a new design method was then transformed into an instrument for the verification of the method which had already been adopted. This program of field observation of the behaviour of selected concrete pavements is now running since 15 years. The paper gives the construction details of the observed pavements and a description of the measurements of present serviceability and traffic. The comparison of actual pavement performance to theoretical values to be expected by calculations with the AASHO-Road-Test equations shows up to now a good, sometimes "conservative" agreement of both curves. Present performance values indicate a service life expectancy higher than originally designed for. This first verification recognises the method as valid without urgent need of modification.

The design methods for rigid and flexible pavements actually recommended in Switzerland have been published in 1971 after 5 years of work in a special committee of experts. The method corresponds technically to the AASHTO Interim Guide for Design of Pavement Structures 1972 (1), although the well-known nomographs have been transformed into another type of graphical presentation. A thickness/bearing capacity diagram with lines for different traffic values is used for concrete pavements (2), as only one concrete strength is specified.

At the same time as work for the swiss formulation of a design method was started, research work also began with a large field observation program of the performance of selected pavements, in order to find a new design method from the results. As the method was then published only few years later based on the results of the AASHO-Road-Test, the purpose of the cited research work was obsolete. It also became very soon quite evident, that it would have taken much longer time, far more than 10 years, to get really useful informations out of such a long-term observation of performance, unless the pavements had shown a nearly catastrophical behaviour due to poor quality of materials and construction work or to insufficient design thickness, and therefore reached the end of their design life in less than 10 years.

In order to continue the work and utilize profitably the results, the purpose of the research work was changed. The accent was placed both on the general accumulation of experiences in form of a small road data bank for selected pavement sections as well as on the verification of the validity of the design method which now had been chosen.

This work has actually (last serviceability measurements: december 1980) reached a state which already enables to draw first, partial conclusions. The answer to the question whether or not the design method based on the AASHTO Interim Guide has so far been successfully used in Switzerland will be answered here for concrete pavements only.

Test Pavements

Common values for all observed pavements are a standard length of 300 m and the requirements of flexural strength (4.9 MPa in the average for upper and lower concrete layer). Use of thick granular subbases in Switzerland is intended to avoid frost demage. A lower layer thickness would however be used today in new construction.

Pavements Nr. 1 and Nr. 2

Location. The first two pavements (3) are located on National Highway N3 near Basel, pavement Nr. 1 in the right traffic lane towards Basel, pavement Nr. 2 at the same site, but in the opposite direction.

Structure. The pavement structure is in both cases a two-layer (fresh in fresh) doweled and reinforced concrete slab, 150 + 50 mm, placed over a granular subbase with a thickness of 600 mm (frost protection).

Concrete Slab. The slab size is 0.4 by 8.0 m, with 22 mm Ø dowels in the transversal joints (with a spacing of 0.5 m) and tie bars (Ø 14 mm, spacing 1.0 m) in the keyed (tongue and groove) longitudinal joints. Reinforcement bars (Ø 12 mm) are placed along the slab edges 40 mm above the bottom and a light reinforcement ($\sim$2.0 kg/m^2) is placed between the two concrete layers.

Concrete Quality. Cement content in the upper layer is 330 to 350 kg/m^3 and 250 to 300 kg/m^3 in the lower layer. The air entrainment provides 4 to 6 % air in the concrete.

Subbase and Subgrade. The subbase of 600 mm thickness is of class I granular material according to swiss specifications. Control of the bearing capacity of the compacted subbase is done by means of the swiss plate loading test (first loading, plate Ø 300 mm, pressure 0.25 MPa). The corresponding value of the modulus of subgrade reaction is above 140 MPa$\cdot$m^{-1} (>500 pci). The subgrade is a clayey, gravelley silt with a modulus of about 40 MPa$\cdot$m^{-1}.

Pavements Nr. 3 and Nr. 4

Location. Pavements Nr. 3 and Nr. 4 (3) are located on National Highway N1 near Aarau, between Bern and Zurich. Pavement Nr. 3 is on the right traffic lane towards Zurich, pavement Nr. 4 on the left traffic lane (overtaking lane) towards Bern.

Structure. Concrete Slab, Concrete Quality. These two pavements have been constructed in the same way and according to the same specifications as pavements Nr. 1 and Nr. 2 described above. The only difference is the thickness of the granular subbase, which amounts here to 800 mm.

Subbase and Subgrade. The modulus of reaction of the subbase is at least 140 MPa$\cdot$m^{-1} (500 pci). The subgrade is a clayey silt with sand mixtures. Its modulus of reaction was of 70 MPa$\cdot$m^{-1} (250 pci) on pavement Nr. 3 and of 30 to 60 MPa$\cdot$m^{-1} ($\sim$100 to 230 pci) on pavement Nr. 4.

Pavements Nr. 5, 6, 7, 8 and Nr. 9

Location. Pavements Nr. 5 to 9 (4, 5) are part of the main road T10 Lucerne-Bern near the village of Malters. This road is a two-lane highway with bi-directional traffic. Pavements Nr. 5 and Nr. 6 are in the direction of Lucerne, pavements Nr. 7 to Nr. 9 in the direction of Bern.

Structure. The concrete pavement on the main road T10 is essentially a conventional, two-layer, doweled and reinforced pavement with a total slab thickness of 200 mm, corresponding in its construction data and quality to those previously described (slab size for the T10: 5.25 by 8.0 m). A 700 m long part of this road however was constructed as a test road with a continuously reinforced concrete pavement (CRCP). Pavements Nr. 5, 8 and Nr. 9 are conventional pavements, or partially in the transition zone to CRC pavements, the two others, Nr. 6 and Nr. 7 are CRC pavements. The following details are given only for these CRC pavements.

Concrete Slab. The concrete has been placed in two layers, an upper one of 60 mm thickness and a lower one of 120 mm, with a total thickness of 180 mm. The pavement was constructed in two separate lanes, each 5.25 m wide. Connection to the adjacent lane is provided by tie bars Ø 12 mm every 0.5 m. The reinforcement has a percentage of 0.548 % longitudinal, steel and of 0.04 % transversal steel (steel strength 640 MPa/90'000 psi). The overlapping distance for longitudinal steel is 0.6 m. Reinforcement steel was placed on top of the lower concrete layer. Some signs of steel corrosion appeared at the surface of the pavement in 1979 due to the action of thawing salts in winter maintenance during many years and the improper position of the steel at some locations (too high) together with an air entrainment product which is not in use any more.

Concrete Quality. Quality of the concrete in the CRC pavements is the same as for the conventional pavements already mentioned.

Subbase and Subgrade. All the pavements lay on 350mm of gravel subbase topped by totally 50mm of a transition layer with sand and fine gravel. The modulus of the subgrade is again >140 MPa$\cdot$m^{-1} (>500 pci). The subgrade consists partially of sand and partially of silty and clayey fine sand. As the thickness of the subbase may be defined over-designed in the pavements Nr. 1 to Nr. 4, the 350 + 50 mm chosen here take into consideration the better behaviour of a concrete pavement under frost action (frost penetration depth: 1.3 m).

Acquisition of Field Data.

Present Serviceability Index (PSI

The observation of the performance of a pavement in view of controlling the AASHTO-Desing method requires the measurement of those pavement qualities which are connected with the design method itself. Determination of the present serviceability index was therefore done using the results of profilometer measurements for the influence of the longitudinal profile (slope variance). These measurements were carried out by the Otto-Graf-Institute of the University of Stuttgart. The term considering the influence of cracks and patches on pavement serviceability had not yet to be taken into account, as the observed pavements still show only neglectable signs of this type of distress. The system-dependent cracks of the CRCP pavement sections (Nr. 6 und Nr. 7) were not considered as "cracks" for a reduction of the present serviceability index. Repair works executed very carefully with special mortars on some transverse joints of pavement Nr. 3 because of damages due to a column of army tanks were also not taken into account in the serviceability equation.

Some measurements at an early pavement age show an "increase" in serviceability. Accurate investigations of this phenomenon have shown that this astonishing result is an actual reality. Some influence may however also be due to a certain scattering of the measurements (transverse position) up to a maximum of 0.1 and to a somewhat higher extent, up to 0.3, to the condition of the joint sealing (depending on accuracy of maintenance work and contraction/extension of the pavement slab) at the moment of the measurement (6).

Traffic (Equivalent Axle Load)

Determination of traffic values for this research program, that is the number [W] of 18 kip (8.16 t) standard axles by use of traffic equivalence factors given by the AASHTO design method, has been done in three different steps.

The first step is the determination of total traffic on the pavement lane. These results are the easiest ones to get (7), as it was possible for each pavement to use the values obtained from automatic traffic counters located nearby. These values for bidirectional total traffic were divided by two to get traffic in one direction and then eventually adjusted (10 % reduction for pavements Nr. 1, 2 and Nr. 3, 90 % reduction for pavement Nr. 4) for traffic distribution on different lanes in one direction.

The total amount of commercial traffic is determinded in step two. For this purpose commercial traffic is defined as all vehicles with a total admissible weight of more than 3.5 tons (according to Swiss legal limits and vehicle definitions). A special campaign of traffic counts by hand is organised in Switzerland every 5 years (8), covering all automatic counting stations. These counts are done on totally 15 selected average days round the year and they also separate every category of vehicles, giving thus the percentage of commercial traffic from the total. The percentages for the years in between are interpolated. The total numbers of commercial vehicles per year are obtained by these percentage values and the total traffic on the lane determined in step 1.

The third, and most important step, i.e. the transformation of the number of commercial vehicles in the number of 18 kip (8.16 t) standard axles, had to be done with a lower level of precision due to the lack of a sufficient number of data. A factor "number of standard axles per commercial vehicle" has been determined from a weight measurement of all commercial vehicles in one direction for a 9 hour period on a randomly selected day (9). A repetition of this axle weight control with a portable balance has only been possible on one motorway (pavements Nr. 1 and Nr. 2), but according to experience with these values on other roads in Switzerland, the error involved by using these factors should not exceed 10 % on motorways.

The total number of standard axles per year is found by multiplying the total number of commercial vehicles (step two) by the factor (number of standard axles per commercial vhicle) of step three.

The very high difference of the number of standard axles between pavements 1 and 2 (relation 1:3) located at the same point in different directions derives from the effect of the Rhine river harbour in Basle, where besides other goods an important percentage (34 %) of Swiss oil imports comes in and goes then along mostly on the road. All the oil transporting trucks are thus empty on their way back.

Climate

All the pavements are situated at comparable altitudes (between 300 and 500 meters above sea level) and with a typical central european climate without extreme conditions. No particularly severe winters occurred during the observation period, althougt they should not have had serious consequences due to the thick granular subbases with non-frost susceptible materials.

Theoretical Performance of the Pavements

In order to get an answer to questions whether the AASHTO design method gives over- or under-designed pavements it was decided to compare the actual, measured performance (evolution of serviceability) of the pavements with a calculated, theoretical one.

The calculations were made on the basis of the general equation of the AASHO -Road-Test and a particular approach.

One transformation of the general equation is:

$$\log W_{t18} = 7.35 \log (D+1) - 0.06 + \frac{G_t}{\beta} \quad (1)$$

where $G_t = \log \frac{1}{3} \quad (4.5 - p_t)$ (2)

and $\beta = 1.0 + \frac{1.624 \cdot 10^7}{(D+1)^{8.46}}$ (3)

and D = slab thickness in inches

p_t = serviceability at the time t

W_{t18} = number of standard axles at the time t

The different values of W_{t18} being known (for every year or every time t corresponding to a measurement), the equation must be solved for p_t.

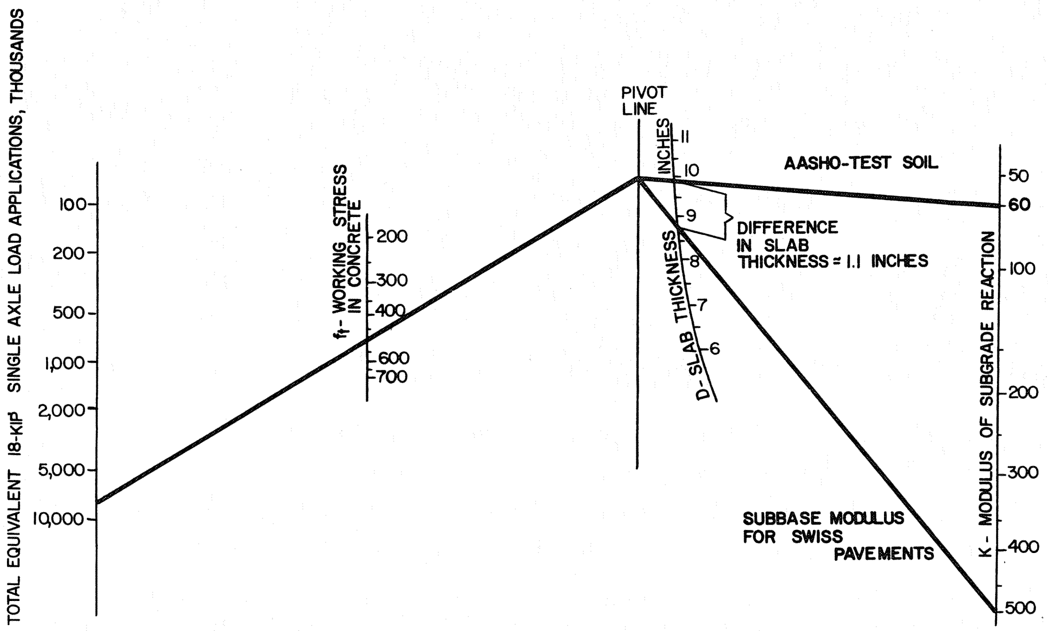
$$\log \frac{1}{3} (4.5-p_t)=\beta \; [\log W_{t18} + 0.06-7.35 \log (D+1)] \quad (4)$$

This equation is valid for conditions corresponding to those of the road test, especially as far as quality of the concrete (modulus of elasticity, working stress) and bearing capacity of the subgrade are concerned (reaction modulus of the subgrade, k).

In the case of our pavements there are one small and one big difference to the road-test conditions. The small difference concerns working stress of the concrete, which is slightly lower than the test conditions according to swiss specification requirements. The big difference is in the subgrade support value, AASHO-Test-Soils having a modulus k of 60 pci, at the lower end of the scale (Figure 1), whereas on top of the granular subbases for swiss pavements a value corresponding to the opposite end of the k-scale in the design nomograph, k ∿ 500 pci, may be assumed.

This difference of modulus of subgrade reaction leads to a thickness reduction of 1.1 inches in the design chart for a pavement with a good quality granular subbase. On the other hand, a performance curve based on the formula for AASHO-Soils represents in this particular case the behaviour of a pavement with a slab thickness reduced by 1.1 inches. Theoretical performance curves for the test pavements were therefore calculated with the formula indicated above, but with a correction of + 1 inch in slab thickness

Figure 1. Correction of slab thickness for calculation of the theoretical performance curve (Design chart for rigid pavements, pt = 2.5, AASHTO Interim Guide)



in all cases. This standard correction compensates also the differences in working stress of the concrete. The possible error involved shoud not exceed 0.1 points in serviceability.

Interpretation of Results

The results of both the field measurements of performance (present serviceability index, PSI) and the theoretical curves are given individually for all the 9 pavements in Figures 2 to 10 together with the corresponding values of traffic (number of 18 kip/ 8.16 tons standard axles) on a time scale.

The first thing to note is a quite good agreement in general between the two curves. This alone would give a first confirmation of the validity of the method, the imprecisions and assumptions involved in all aspects of this research work being definitely smaller than all the assumptions which have to be taken at the stage of design, i.e. well in advance of the start of construction.

As far as design life consumption is concerned, which might be defined here in terms of passed traffic, one could separate three different groups of pavements:

1. pavements with a high amount of traffic (pavements Nr. 2 and Nr. 3),
2. pavements with a lower amount of traffic (pavements Nr. 1 and Nr. 5 to 9),
3. 1 pavement with a small amount of traffic (pavement Nr. 4).

In the first and most representative group the measured performances are distinctly above the theoretical curve. After a first phase, where measured values follow the theoretical curve at a constant distance (∿ 0.4 points higher), the curves now get apart from each other at a stage where a value of 3.0 should be expected. The temporary "stabilisation" of measured performance indicates a possible greater service life than originally designed for. This would also confirm other research results for 200 mm (8 in) concrete slabs (10).

Figure 2. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.

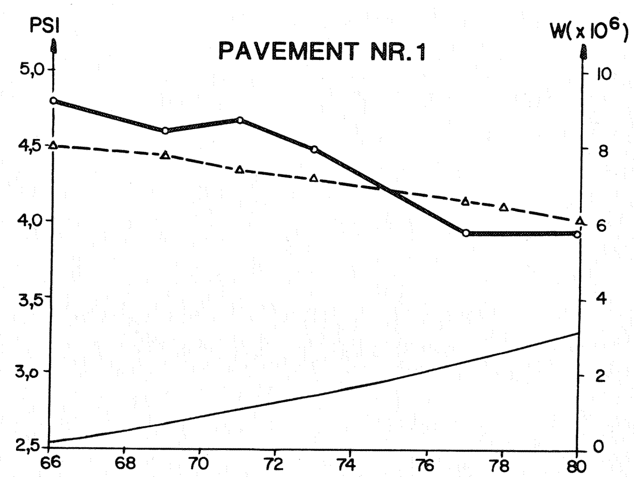


Figure 3. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.

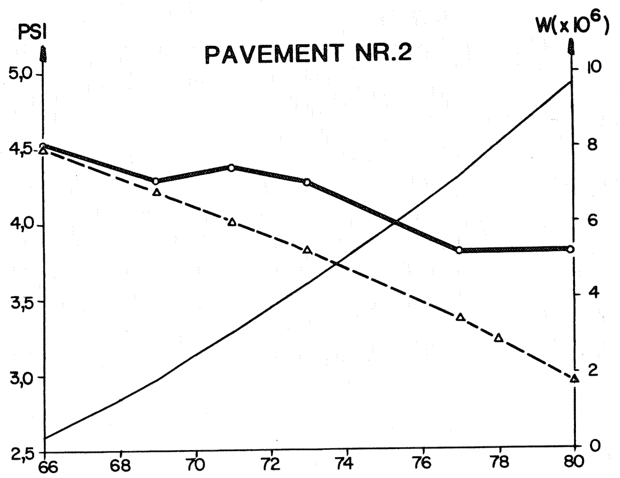


Figure 4. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.

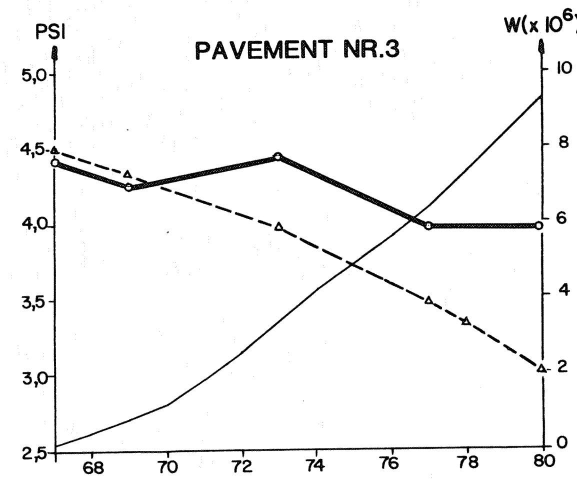


Figure 5. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.

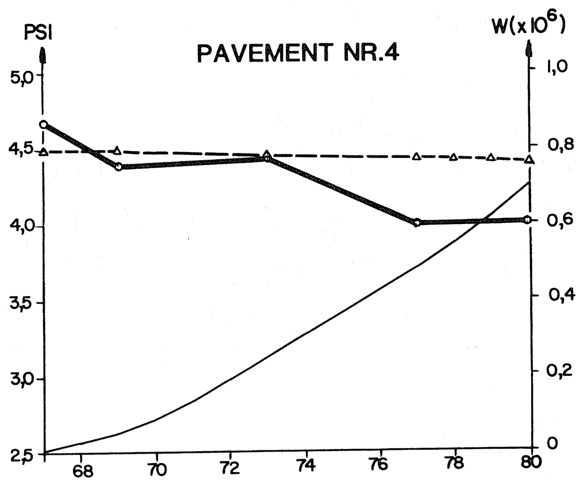
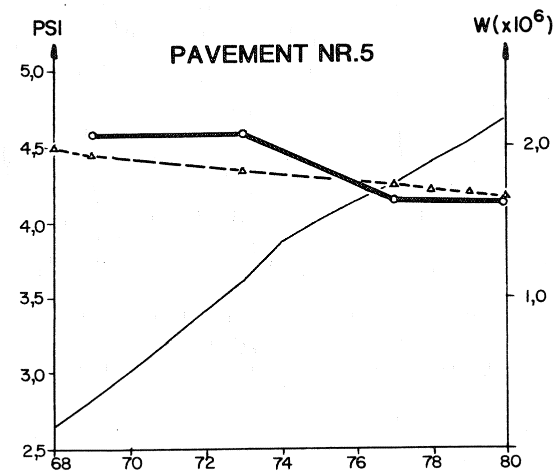


Figure 6. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.



In the second group the real performance of the two CRC pavements is just above the expected values whereas the other pavements get slightly under the theoretical line since a few years. At comparable traffic there are signs for a better performance of the 180 mm CRC pavement compared to the 200 mm thick doweled and reinforced pavements.

The pavement on an overtaking lane with the smallest amount of traffic is again distinctly below the expected values. Based on the experience with the other cases, an interpretation indicating a "failure" of the design method would certainly be wrong. Instead it would seem that the method relies on the "assumption" that traffic should occur in a manner more closely to the traffic values for the design period. If this is not the case, then the method does not take into account some losses of serviceability due to "natural aging" under given climatic conditions and traffic action by passenger cars. An eventual additional effect due to incremented truck traffic because of temporary deviations (accidents, measurements, maintenance and repair works) cannot be absolutely denied but it is not possible to quantify such an effect.

Conclusions

A number of concrete pavements has been observed in Switzerland during up to 15 years of traffic (normal design period: 20 years). These pavements are characterized by a relatively low slab thickness on one side and good quality, thick subbase with non-pumping material on the other side. Drainage is also provided on all pavements.

The comparison of measured performance values with calculated values from the AASHO-Road-Test equation (theoretical performance curve) shows in general

Figure 7. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.

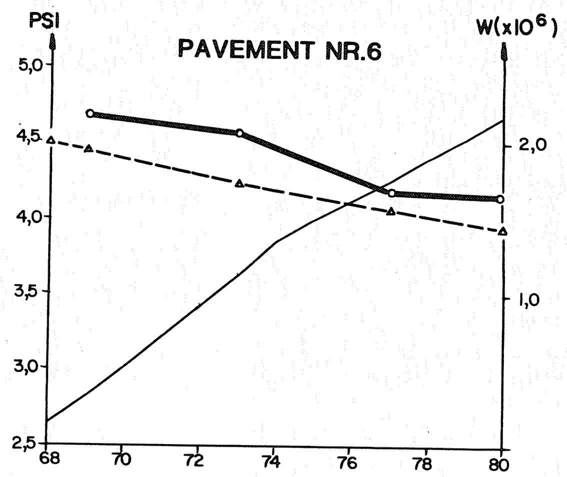


Figure 8. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.

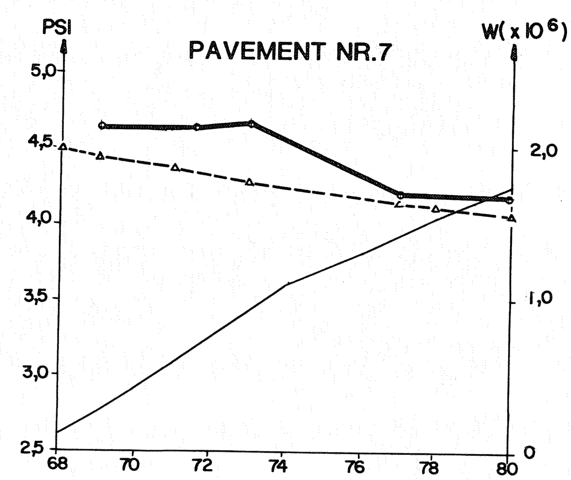


Figure 9. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.

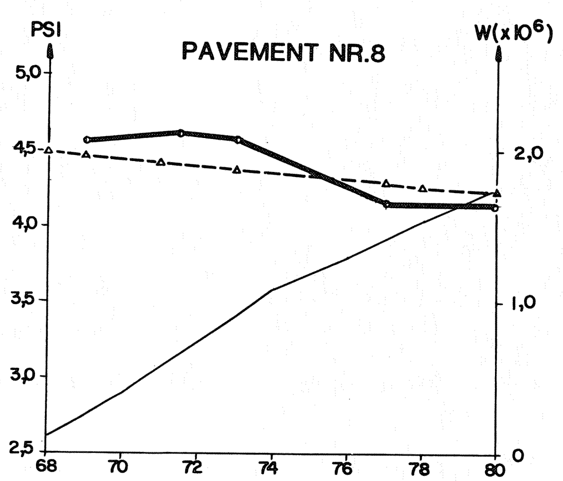
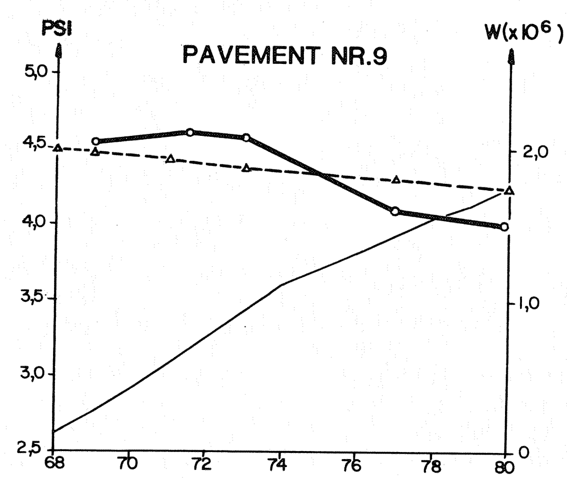


Figure 10. Development of present serviceability index (PSI) and equivalent axle load (W) until the end of 1980. The dotted line indicates theoretical values.



a good agreement and even a performance better than expected on the pavements with the highest traffic. This difference in the present serviceability index is however not yet so great as to indicate uneconomically overdesigned pavements.

Unless other types and qualities of concrete pavements are going to be constructed in Switzerland, it is not necessary for the moment to abandon the actual design method. For the concrete pavements built in Switzerland up to now, the AASHTO Interim Guide for Design of Pavement Structures 1972 is an accurate design method with adequate safety.

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