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Road quality service levels and innovations to meet user expectations

Summary

Technology and organisation of maintenance operations and repair works in order to provide the best service to users

- Maintenance management on the national motorway network: main criteria and preparation of decisional elements
- Roadway pavements of recycled concrete
- Research work in the field of investigating the real loadings of motorway traffic

Abstract

Application of maintenance management systems for roads can provide an improvement of the level of service given to the road user. The first chapter of the report describes the current state of development in this area with special attention on already implemented guidelines for the organisation of maintenance construction sites, data collection efforts for monitoring the condition of pavements and structures and finally the conceptual developments for maintenance management systems. The proposed solution will lead in the short and medium term to the use of separate management systems for pavements, structures and electro-mechanical installations. these systems will be integrated at a later date into a road management system.

In Switzerland deposits of gravel are growing scarce. For this and ecological reasons an effort is being made to recycle material, i.e. material produced by roadway demolition –instead of being dumped-should be re-used in a way to achieve the highest possible quality. This means orderly reconstruction and separation of the materials strictly according to grade. In the course of constructing new motorways initial tests were carried out on the reusability of old concrete pavements. It was thereby proved that –provided appropriate preparatory measures are taken- a high-quality concrete pavement able to withstand thawing salt can be produced, without primary raw materials having to be added. The concrete test pavements (two short motorway sections) have been carrying traffic since 1990 and 1991, respectively.

Traffic loads have a determinant influence on the performance of pavements. It is therefore very important to be able to forecast and to quantify this factor as precisely as possible. The last chapter of the report presents the results of a research project with the analysis of automated weight measurements of traffic loadings in order to increase the degree of reliability of conversion factors of different traffic loads into a number of equivalent standard axles.

Maintenance management on the national motorway network: main criteria and preparation of decisional elements

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Introduction

In a country with a federal structure such as in Switzerland all responsibilities for the construction and for the maintenance lie within the Cantons. 24 Cantons out of a total of 26 Cantons and half-cantons hold and maintain a part of the "national" motorway network over a length between 11.5 and 229.2 km (planned length of the network). Within a project of redistribution of tasks between the Federal Government and the Cantons to be realized by 2010 the national motorway network will go under Federal ownership and operational responsibility. Until now the Federal Office of Highways had essentially the task of a financing and supervising agency.

In the current situation and in particular during the last 20 years coordinating activities have been influenced to a large extents by the disadvantages of a federal system, i.e. decisions often taken without considering the intentions of the neighbouring Cantons. Disadvantages resulting from this situation have been emphasized under the effect of important motorway traffic increases during the last years and the responsible agencies, in particular the Federal Office of Highways have been forced to take special actions in order to improve the conditions.

This part of the report shows on one side the different criteria which have been adopted for the maintenance management of the motorway network and on the other side different measures which have been implemented in order to ensure the application of the selected criteria.

Decisional criteria for motorway maintenance construction sites

A comprehensive study covering different aspects of the maintenance of the national motorway network was completed in the year 1998 with the publication of the final report of a group of experts assigned the task to define "How to ensure a technically satisfactory maintenance and conservation of the national motorway network at least costs?". The experts came up with a list of 17 different measures which are now being implemented in subsequent steps.

The different actions proposed in this study can be applied either immediately or after completion of a number of detailed studies, conducted with the scope of developing the corresponding tools, in particular in the field of management systems.

In addition to standard management criteria such as deciding whether optimisation should be carried out on the basis of a global indicator (which one?) or on the basis of a specific indicator (for instance: safety) and with or without considering user costs the Federal Office of Highways has adopted a number of boundary conditions meant to reduce the nuisance to road users:

- minimal distance between construction sites: 50 km
- maximum length of a construction site: 15 km
- minimal duration of time between subsequent maintenance treatments on the same site: 10 years

The application of these conditions means in practice the necessity to conduct maintenance at the same time on all the different parts of the infrastructure, i.e. pavements, structures and electromechanical components. It is quite obvious that this requires very detailed planning and preparation of maintenance works, where coordination of the different work groups is determinant. this type of "global maintenance action" has already been carried out with success on different construction sites.

Collection of information: condition monitoring of pavements and structures

Applicable methods for survey and evaluation of the condition of pavements and structures, still in continuous evolution, are described in detail in specifications, different research reports as well as in specialized manuals, in particular with respect to structures.

Condition monitoring of pavements

The evaluation of pavements requires the determination of the following indices:
- I1: Index of surface distress*
- I2: Index of longitudinal evenness (roughness)
- I3: Index of transversal evenness (rutting)
- I4: Index of skid properties
- I5: Index of bearing capacity

*: it is currently proposed to "disassemble" this index and to create other indexes grouping the main families of distresses.

In the past the Cantons had conducted independently and without central co-ordination condition surveys on their portion of the network. Since 1999 the Federal Office of Highways co-ordinates and even organizes condition network wide conditions surveys.

The first systematic survey of surface distress over the whole motorway network was carried out in 1999. The survey itself had been required by the Federal Office of Highways but the practical organisation was left to the Cantons and this resulted in the adoption of different ways to conduct the collection of distress data:
- walking visual survey by personnel of the Cantons,
- walking visual survey by personnel of consulting companies or highway laboratories,
- visual survey from driving vehicles by specialized road monitoring companies, partially in conjunction with automated measurements (for the parameter "deformations").

The adoption of different solutions for the visual survey and the employment of a large number of different people for this task has led to a very high influence of subjective evaluations. However, and in spite of the fact that justified doubts on the comparability of the results still subsist, it has been possible to generate a first general overview map of the surface distress condition of the national motorway network.

For data collection regarding the indices I2 and I3, i.e. the evaluation of longitudinal and transversal (rutting) evenness the Federal Office of Highways decided for a centralised organisation with an international competition. Measurements were carried out during the spring 2000 by means of a single multifunctional automated device for the whole network and both indices.

The following year, 2001, network wide surveys were completed with the collection of data on skid resistance. The measurements were again organised by the Federal Office of Highways with an international competition.

Bearing capacity issues are generally not the main concern of the motorway administrations in Switzerland. The application of a conservative method for the structural design of pavements, frequently in conjunction with increased sub-base thickness to resist possible frost action, and a rather low increase in traffic volumes during the first years, associated with a rather low percentage of heavy traffic when compared to conditions in other European countries, have prevented so far the appearance of real problems associated to poor bearing capacity and also forms of fatigue damage are not frequent. However, a limited sample of motorway sections over a total length of 200 km, selected on the basis of the results of the visual survey, was tested for bearing capacity by means of a falling weight deflectometer (FWD) in 2002.

At the current moment the analysis of the results of this monitoring programme of bearing capacity is not yet completed. The analysis will cover first the quality control of the data and the eventual detection of areas which might be in need of urgent remedial action. Further work will be conducted by means of statistical analysis to determine the "health condition" of the network or its service level, to estimate the necessary amount of work at short and medium term, to highlight the main problems with possible links to other parameters such as the traffic volume and the quality of the materials of the pavement structure. The results of this analysis will also allow to further refine a number of decision criteria to be implemented in maintenance management systems.

Condition monitoring of structures

Monitoring of the condition of structures is a much more "individualised" task than monitoring of the condition of pavement surfaces. In fact structures differ much more from another than pavements and are practically "unique" structures. It is also for this reason that the use of automated devices, differently than for pavements, is almost impossible. So among the standard solutions for the inspection of structures we find in a minority of cases inspections carried out by personnel of the road administrations whereas in the majority of the cases work is outsourced to specialised consulting companies.

However, standardized procedures with an evaluation scale of 5 levels have been adopted for the inspection of structures. These procedures are organised as follows:

- intermediate inspection,
- main inspection,
- supplementary inspection.

Developments in the field of management systems

Development work related to management systems is currently being done in three different areas, in particular:

- pavements,
- bridges and other structures,
- electro-mechanical installations.

Conceptual studies, data modelling and programming work for specific software solutions related to the technical areas mentioned above are currently being conducted At the same time different studies and research projects investigate the issue of the integration of the three "sub-systems" in view of finally getting to a real road management system.

Applicable prioritisation and optimisation criteria must take into consideration on one side the interest of the user – which is in accordance with the Federal law on national motorways and is being taken care for by a set of different conditions for the organisation of maintenance sites - and on the other side of different technical and economic criteria. The different software development activities mentioned above are mainly concentrating on the issue of maintaining satisfactory operational conditions and complying to safety requirements.

The preparation of a first five year plan for maintenance works and for the adaptation of the national motorway network represents one of the first tangible results of these coordinated efforts. Further updating and improvements of this plan will follow as soon as other determinant development steps will have been accomplished.

Roadway pavements of recycled concrete

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General

In Switzerland it is becoming increasingly difficult to utilize the remaining reserves of high-grade gravel, while on the other hand there is a shortage of space on which construction rubble can be dumped. This resulted in recent years in an increased readiness to switch from a consumer to a recycling society.

Philosophy

To achieve an optimal recycling of building rubble, certain fundamental considerations regarding the handling of such materials are required. By creating a general standard for recycled building materials [1] the following main objectives were formulated:

- The rubble produced should not be referred to and treated as waste, but as secondary raw material.
- Material recycling should be the main aim.
- The rubble produced should be reused in the same field as it comes from.
- Multiple uses should be aimed at.
- The secondary raw material must comply with the standards existing for the purpose for which it is intended.

In order that this philosophy may be put into practice, there are a number of conditions that have to be fulfilled. Among others reconstruction must take place in an orderly fashion, i.e. the secondary raw materials produced have to be sorted strictly according to type in order that a good quality can be achieved when they are reused. On this basis various guidelines were created including one for the use of recycled concrete [2].

Construction of pavements with granulated concrete

The main question was to what extent the concrete pavements concerned are suitable for reuse. What proportion of secondary raw material may be used in the aggregate for the new pavement mix. In the course of reconstruction of a section of the Rhine valley motorway between Sargans and St. Margarethen it was possible to find a complete answer to this question.

A concrete pavement well over 20 years old was destressed and demolished centrally crushed and processed to concrete granular aggregate. This was intended as sub-base reinforcement in the cement stabilisation. To check its suitability as aggregate for production of the pavement slab, some of the material was set aside for a trial pavement placing. Thus two motorway sections (of 300 m’ each) were built in 2 stages between 1990 and 1991.

Preliminaries

(a) *Additional tests on recycled granulate*

- Chloride ion concentration
  The salt content measured in the old concrete was very low indeed – 0.24 kg/m³ concrete – and therefore insignificant for the purpose envisaged.

- The polished stone value PSV at 48 was only slightly below the figure of 50 specified for the intended stresses.

(b) *Preparatory measures*
- To exclude partial absorption of the mix water by the cement paste in the recycled concrete, the crushed aggregate was sprayed with water during 48 hours immediately before the concrete was mixed, thereby ensuring that the cement paste was completely saturated.

Concrete processing and placing

The recycled concrete was processed and placed using the equipment available on site and had to be integrated in the concreting work currently in progress. The concrete was actually placed by means of fixed form pavers, the mix design for lower and upper layer concrete being identical for technical reasons.

The concrete of mix design 1 gave rise to difficulties. Although the tested overall mix had the desired grain-size distribution, the material was severely demixed during storage in the stockpile and the transport from the depot to the mixing plant. Irregularities in the water content and thus considerable fluctuation in the consistency of the concrete resulted. These problems were also reflected by the strength of the concrete, which did not attain the specified values.

The placing of mix design 2 concrete caused no trouble at all. By removing and replacing the 0-4 fraction by natural and crusher sand, the remaining recycled granular aggregate was also split into fractions (4-8, 8-16, 16-32 mm) and could thus be used for the new concrete mix without difficulty.

Table 1: concrete mix designs

Mix design	1	2	3	4
Aggregate	100 % recyc granulate 0-32mm (total mixture)	Fraction 0-4mm, 100% natural & crusher sand Fractions 4-8, 8-16, 16-32mm 100% recycled granulate	Fraction 0-4mm 60% recyc.granulate, 40% nat.sand, Fractions 4-8, 8-16, 16-32 mm 100% recycled granulate	100 % recyc.granulate in fractions 0-4, 4-8, 8-16, 16-32mm
Cement	Portlandcement 375 kg/m³ *	Portlandcement 375 kg/m³ *	Portlandcement 375 kg/m³ *	Portlandcement 375 kg/m³ *
Additives	Air-entraining Fro V5 (Sika) 0.7-0.9 % by wt of cement Plasticizier Plastiment FN (Sika) 0.7-0.8 % by wt of cement	Air-entraining Fro V5 (Sika) 0.7-0.9 % by wt of cement Silicafume Sikacrete-PP1 ** 2.4 % by wt of cement	Air-entraining Fro V5 (Sika) 1.3 % by wt of cement Plasticizier Sikament 10 (Sika) 0.71 % by wt of cement Silicafume Sikafume-HR ** 4.75 % by wt of c cement	Air-entraining Fro V5 (Sika) 1.3 % by wt of cement Plasticizier Sikament 10 (Sika) 0.71 % by wt of cement Silicafume Sikafume-HR ** 4.75 % by wt of c cement
Target W/C Ratio	0.40 (0.50)	0.40 (0.50)	0.40 (0.50)	0.40 (0.50)
Slump (Walz)	1.2-1.4	1.2-1.4	1.3-1.4	1.1-1.2
Mixing time	90 s	90 s	70 s	70 s
Percentage recyc. granular aggregate in total mixture	100%	66%	87%	100%
Workability	moderate	moderate	very good	very good

* Compared with normal pavement concrete made of primary materials the amount of cement was increased by 25 kg to 375 kg/m³.
** To improve the quality a silicafume additive was also used.

When mix design 2 was used it was still necessary to add 34% primary material (the whole 0-4 mm fraction), so that an attempt was made to reduce this fraction in mix design 3 by replacing only 40% of the recycled 0-4 mm fraction. Thus the total proportion of recycled granular aggregate rose to 87%. Mixing and placing were carried out without any problems.

But the main objective still was to produce a high-grade concrete pavement without any primary raw materials in the aggregate, i.e. with 100% crushed concrete aggregate. This was achieved when mix design 4 was applied, for which purpose the experience gained during the foregoing trials was utilized. With the consistent demand to split the recycled granulate into four fractions, despite an optimal grain-size distribution in the overall mixture, it proved possible to attain the main objective without problems.

Tests on fresh and hardened concrete

a) *Tests on fresh concrete*

The tests performed hourly yielded the following (mean) values:

Table 2: Values for fresh concrete

Mix design	**1**	**2**	**3**	**4**
Proportion of recycled granulate	**100 %**	**66 %**	**87 %**	**100 %**
Wet density [kg/m³]	2.330	2.310	2.320	2.293
Dry density [kg/m³]	2.170	2.150	2.141	2.096
Water: cement ratio	0.45	0.41	0.47	0.53
Air pore content at mixing plant [%]	6.2	6.4	5.0	5.5
Air pore content when placing [%]	4.6	5.4	4.0	4.5
Slump [Walz]	1.34	1.33	1.28	1.20

b) *Tests on solidified concrete*

The specified flexural tensile strength after 28 days was 5.2 N/mm². Apart from mix design 1 (5.04 N/mm²) the minimum value was exceed without difficulty (5.66 – 6.70 N/mm²).

Table 3: Development of compressive strength after placing in 1990/91

Mix design	**Proportion of recycled granulate**	**Compressive strength [N/mm²] after**			
		28 days	**1 year**	**2 years**	**3 years**
1	100 % (total mixture)	32.4	-	36.5	-
2	66 % (4 fractions)	39.7	-	39.6	54.1
3	87 % (4 fractions)	44.31	46.3	59.3	
4	100 % (4 fractions)	42.2	46.6	58.6	
Ref. concrete	0 % (8 fractions)	39.2	44.7	-	

As can be seen in Table 3, the strengths of the concrete developed as has been hoped and did not differ fundamentally from those of a concrete made entirely of primary materials.

Visually too, the placed pavement made of concrete with crushed rubble aggregate shows a perfect appearance. The surface of the pavement is still being periodically inspected.

Conclusions

The concrete of old roadway pavements can be used to make a high-grade, salt-resistant cement concrete pavement, such as is needed for heavily trafficked concrete pavements.

To attain mentioned high standards, the two following requirements must be met:

- The concrete granular aggregate must be split into the four fractions 0-4, 4-8, 8-16 and 16-32 mm.
- The cement paste in the old concrete aggregate must be fully water saturated by spraying the crushed material with water for at least 48 hours before concrete mixing.

Increasing the cement dosage and/or adding silica fume notably improves the ultimate concrete strength.

Since the concentration of chloride ions in the old concrete was very low, no importance had to be attached to it when placing a new (unreinforced) concrete pavement.

The complete or partial substitution of natural or crusher sand for the 0-4 mm fraction does not necessarily produce higher strengths.

Literature

[1] Swiss Standard SN 640 740: Verwertung von Bauschutt, Allgemeines (Recycling of construction rubble, General)
[2] Swiss Standard SN 640 743: Verwertung von Betonabbruch (Recycling of concrete rubble)

Research work in the field of investigating the real loadings of motorway traffic

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Performance of flexible pavements

The importance and mainly the frequency of maintenance activities with all the traffic nuisances and sometimes even closures to traffic resulting from construction sites can be influenced by different factors. Initial quality of the pavement, including the aspects of structural design and the optimal choice of materials is one of the most important and determinant influencing factors together with environmental conditions and traffic loadings during the service life of the pavement. The last one of these parameters, traffic loadings, can only be estimated at the time of construction and it is common experience that the large majority of traffic forecasts underestimate by considerable amount traffic loads during service life in terms of total frequencies as well as in terms of the number and weight of the axles.

A number of research projects related to the development on new technologies has been completed with success in the field of flexible pavement structures for roads with heavy traffic volumes and loads. Changes in the optimisation of the composition of the mixes of bituminous layers are an example for this progress. Mix designs on the basis of the Marshall test are being substituted by methods relying on more sensitive tests such as the wheel tracking test of LCPC and the gyratory compaction test. The time needed to transfer research results on "special mixes" for heavily trafficked pavements to standardisation and current use in construction is getting shorter and shorter.

Evolution of traffic loads

A considerable evolution of traffic loads has occurred on the Swiss national motorway network during the most recent years. Changes in the regulations on maximum gross vehicle weight, brought from 28 to 40 tons by the legislator, have been one of the reasons of this increase. This modification of the total allowable gross weight as well a new fiscal regulations have had an immediate influence on traffic loadings in spite of the fact that no changes have occurred in relation to the limits of the allowable axle loads. Most recently a new phenomenon now comes in addition to the other already well known influencing factors of traffic loads. Vehicles standing in long waiting lines in traffic congestion situations as well as heavy commercial vehicles circulating at crawling speed and heat radiations emanating from the engines lead to an intensified thermal stresses of the surfacing layers. This can weaken the resistance to traffic loads of the bituminous mixes, in particular during the most hot periods of the summer month's.

A research project completed in 2001 with the scope of verifying coefficients for the estimation of the number of equivalent standard axle for different vehicle categories has allowed to determine the consequences of changes in the regulations on vehicle weights on the loads actually measured on the roads.

Research work for the determination of equivalent traffic loads

The method currently used in Switzerland suggests the use of conversion factors for different traffic classes, different types of vehicles and finally also for different road categories for the determination of equivalent traffic loads (number of equivalent standard axles). Equivalent traffic loads are defined as the product of the conversion factor with the number of heavy commercial vehicles. For a given road the equivalent traffic load is defined as the sum of the equivalent traffic loads of each category of vehicles.

Data from a total of five different measuring sites with automated WIM (weigh in motion) equiment at various locations on the national motorway network and collected during a period of two weeks each in the years 2000 and 2001 have beeen analysed in detail within the research project mentioned above. This analysis, in which axle equivalence coefficients derived from the results of the AASHTO road test had been applied, was meant to verify the conversion factors for different vehicle categories and to develop, if necessary, a set of new conversion factors. During the year 200 the current weiht regulations were allowing a total vehicle gross weight of 28 tons, which was then raised to 34 tons for the year 2001. The selection of measurement periods in two subsequent years with different regulations concerning the maximum weight wa s also made in view of possibly extrapolating the results to an upcoming situation in which the allowable gross vehicle weight would be set at 40 tons.

Four different categories of vehicles have been analysed:

- trucks (no trailer)
- truck-trailer combinations
- articulated vehicles (semi-trailers)
- busses: this category has been added to the previously used scheme; the results obtained are only applicable on long distance passenger transport (tourist busses) and do not trake into consideration the specific situation of cities and large urban areas.

The following conversion factors, applicable on motorways, have been developed for different vehicles categories and an allowable gross vehicle weight of 40 tons.

vehicle category	existing method		proposal	
	flexible pavements	rigid pavements	flexible pavements	rigid pavements
trucks	1.0	1.3	0.9	1.0
truck and trailer	2.2	2.2	1.9	2.0
truck/semi-trailer	1.4	1.4	1.7	2.0
busses	-	-	2.3	2.3

The following conversion factors, applicable for the sum of all heavy vehicles, have been developed for different road categories and an allowable gross vehicle weight of 40 tons.

vehicle category	existing method		proposal	
	flexible pavements	rigid pavements	flexible pavements	rigid pavements
motorways	1.5	1.5	1.6	1.7
express roads	1.3	1.5	1.4	1.5
main roads	1.2	1.4	1.3	1.5
secondary roads	1.0	1.3	1.0	1.3

The study recommends finally to re-evaluate the results of the WIM measurements by means of an analysis over a period of minimum 5 years in order to obtain after the current "transition" period definitive conversion factors.