ECO-SERVE
Cluster 4 Pavements

Collection of data and stakeholder mapping for semi-rigid pavements

Task 2 report
May 2004

Contents

1. Introduction

ECO-SERVE Cluster 4 deals with innovative pavement design. It is the objective based on assessment of available research and design methods to select the most suitable approach for design of low strength, cementitious base course layers.

Task 2 in Cluster 4 has the objective of collating information on design methodologies, specifications and best current practise for semi-rigid pavements. Especially, examples of pavements with enhanced performance and/or ECO-SERVE type pavements are sought. Parallel to this activity is a mapping of stakeholders with interest in the topic.

Initially, a literature survey was carried out in order to identify already existing state-of-the-art reports etc. Based on this, a questionnaire was set up and circulated through the ECO-SERVE partners to as many countries as possible. The aim of the questionnaire was to get information on design methods, strength requirements, construction practices and in-service experiences. The questionnaire survey also forms the basis for the stakeholder mapping.

2. Reports on semi-rigid pavements

2.1 PIARC-report 1991

In 1991, the two PIARC committees on flexible and concrete roads issued a joint report about semi-rigid pavements (1). The report summarises the state-of-the-art for design, materials composition, construction techniques etc. As this report offers the most comprehensive overview of the subject area that has been found, it will be referenced here, even though some of the actual data can have changed during the 13 years since the publication of the report.

Design

Regarding the design of semi-rigid pavements, the authors suggest a general concept with three different options for the function of the hydraulically bound layer, as shown in Figure 1 taken from the report.

Structural role assigned to the layers bound with hydraulic or pozzolanic binders	Cracking tendency of hydraulically bound materials to be obtained by means of mix design	Elasticity modulus (MPa)	Design criteria	Typical layer thicknesses according to traffic and subgrade conditions (cm)	Risk of reflection cracking	Risk of damages due to loss of adhesion between bitum. and hydraulically bound layers due to water infiltration	Consequences of unsealed cracks	Crack sealing required	Acceptability of reflected cracks	Antireflection cracking measures
1. No contribution to flexural resistance	Microcracks	1000 - 2000 (1)	Fatigue resistance of bituminous layers	Bit. layers: 20-32 approx. Treated layers: 15-20 approx.	Low	Low	Negligible	Occasional	Generally no problem	None
2. Almost total flexural resistance assigned to the hydraulically bound layers	A. Microcracks	1000 - 2000 (1)	Fatigue resistance of treated materials	Bit. layers: 4-14 approx. Treated layers: 25-50 approx.	Low	Low	Negligible	Occasional	Generally no problem	None
	B. Wide cracks, regularly spaced at long intervals	15000 - 30 000 (2)	Fatigue resistance of treated materials	Bit. layers: 4-8 approx. Treated layers: 25-50 approx.	High	High	Troublesome in wet climates in absence of efficient subsurface drainage system	Extensive	High traffic: unacceptable Low traffic: acceptable	Yes None
3. Both bound and bituminous layers contribute to flexural resistance	A Narrow cracks, regularly spaced at closer intervals	7000 - 10000 (3)	Fatigue resistance of both bituminous and treated materials	Bit. layers: 12-27 approx. Treated layers: 20-22 approx.	Low to medium	High	Measures to be taken in wet climates in absence of an efficient subsurface drainage system	Medium to occasional	Acceptable	None
	B. Wide cracks, regularly spaced at long intervals	15000 - 30000 (2)	Fatigue resistance of both bituminous and treated materials	Bit. layers: 12-27 approx. Treated layers: 20-22 approx.	Medium to high	High	Cares to be taken in wet climates in absence of an efficient subsurface drainage system	Medium to high	High traffic: unacceptable Low traffic: acceptable	Yes None

(1) Equivalent modulus (laboratory dynamic moduli could be in the range of 2.000 - 8.000 MPa)

(2) Laboratory static modulus (laboratory dynamic moduli could be in the range of 25.000 - 45.000 MPa)

(3) Equivalent modulus (laboratory dynamic moduli could be in the range of 8.000 - 15.000 MPa)

Figure 1: Different design approaches for semi-rigid pavements. From (1).

This approach leads to three different types of mix design for the treated material: A high rigidity mix (lean concrete) with a 7-day compressive strength greater than 10 MPa (2B and 3B); a low strength soil cement or sand cement type mix with a 7-day compressive strength less than 2 MPa (1 and 2A) or an intermediate mix type with 7-day compressive strengths of 2.5 – 4.5 MPa (3A).

Examples of national pavement designs are given, either based on experimental and theoretical considerations as for France, Italy, Belgium, Germany, Spain and Australia or purely experimentally based (empirical) as for UK, Switzerland and Austria. Some countries base their design on avoidance of fatigue cracking whatever the importance of the road, whereas others restrict the avoidance strategy to heavily trafficked roads. For the lower strength soil cement type mixes the design criteria is more focused on durability than fatigue. The different design approaches previously described can be recognised in the predominant pavement types in the individual countries, e.g. Switzerland uses a low strength soil cement (2A), Italy uses a medium strength base (3A) and Belgium, Germany and France uses a high strength lean concrete corresponding to the design 3B. Generally, the design approach 3 where both the bituminous and hydraulically bound layers contribute to the flexural resistance of the pavement seems to be the most widely adopted.

Furthermore, an overview of durability requirements, especially in the form of frost resistance testing is given. Typically, change of length or compressive strength is measured after a number of freeze-thaw cycles.

Mix design

Shrinkage cracking is generally considered as inevitable, especially thermal shrinkage whereas primary shrinkage during the setting process may be controlled to a large extent by adequate composition and construction. Reflection of these cracks to the surface of the bituminous overlay is only accepted by some countries as long as these cracks remain hairline cracks. Some conclusions regarding mix design, which will positively influence the formation of many narrowly spaced cracks, are:

- Adequate, e.g. not too high water content
- Thermal expansion coefficient of the treated material
- Strength and rigidity of material at the moment of crack formation influencing the spacing and consequently the width of cracks

Swiss experiences recommend water content at the “dry” side of the Proctor optimum, possibly at 75% water saturation.

Limestone aggregates are preferable for narrow cracks having about half the expansion of siliceous aggregates (France).

Austrian experiences indicate a content of 10-15 % fines smaller than 63 µm in gravels as favourable.

Undesirable high strength and elevated rigidity result from high temperatures at laying, use of quick setting and hardening binders, use of coarse aggregate of a gradation > 0/20 mm, high dosage of binder leading to excess of strength.

The report states that pozzolan or lime bound mixes with a slow strength development rarely develop reflective cracking, even with relatively thin layers of bituminous material (5-6 cm). For these mixes shrinkage cracking is negligible and the unavoidable thermal cracking is retarded and appears as micro cracks diffused in the material mass.

Measures against reflective cracking

Apart from mix constituents, other measures for dealing with the reflective cracking problem are described. Generally, three approaches can be taken:

- Choosing a structure where the hydraulically bound layer is covered with thick asphalt layers, often up to 20-30 cm. Only relevant for high traffic roads.
- Accept reflective cracking and regularly seal the cracks. Mostly relevant for low traffic roads, where inconvenience of the sealing work to traffic is of limited importance.
- Making special arrangements to delay propagation of cracks and retard their subsequent evolution.

For the latter approach, again three modes of action can be suggested:

- Improving the capacity of the bituminous layers to withstand the cracking tendency of the hydraulically bound layer. This can be accomplished e.g. by using polymer modified bitumen.

- Inserting an obstacle between the hydraulically bound layer and the bituminous layers either in the form of a bond-braking layer or an anti-cracking stress diffusion membrane.
- Reducing the loadings applied by the hydraulically bound layer to the bituminous layers by making the amplitude of crack opening small and making the relative displacement of the two edges of the crack during traffic load small.

Small crack openings can be achieved as a result of proper mix design as previously described. Another important factor is the friction (adhesion) between the road base and its substrate, as a higher friction results in shorter crack distances.

Pre-cracking

In many countries, various methods for pre-cracking of the hydraulically bound base are increasingly gaining in acceptance and use. These methods all aim at ensuring relatively closely spaced active transverse cracks in order to counteract reflective cracking.

In principle, there are two main categories of methods; a) notches formed after compaction of the layer before setting of the material and b) cracks induced in the hardened base.

The simplest way of inducing cracks in the base layer is to use a vibrating plate with a welded vertical steel blade, which is pushed across the base layer. In this way a groove with a depth of around half the layer thickness is formed. A bitumen emulsion or plastic film is placed in the groove and the layer is re-compacted. Under the influence of temperature and traffic induced stresses a crack will eventually penetrate the rest of the layer under the notch. This principle of crack formation can be performed manually (labour intensive) or semi-automatic by using equipments like CRAFT and OLIVIA mounted on a vehicle. Another system is the French Active joint, where two special machines put down a corrugated PVC profile across the non-hardened base layer. The added cost of a base layer with these pre-cracking treatments is allegedly 2-8%. International experience points to an optimal crack spacing of around 3 m for all of the methods mentioned.

Additional to the wet-formed joints, also methods for inducing cracks in the hardened state exist. This can be done either by guillotine/steel ball drops or by early rolling of the hardened base with a vibratory roller. It has been observed in several countries that when a road base with hydraulic binder is opened to traffic when it has not finished setting there is a smaller cracking tendency. The experiences with early vibratory rolling have been mixed where this option was tried (France, Germany and Austria). The effect seems to be better for relatively weak and thin layers (max. 15 cm).

2.2 Update 2002

An update of the country information in the PIARC report from 1991 was recently published in a report from the Austrian Ministry for Traffic, Innovation, and Technology (2). A new questionnaire was sent to eight countries. Answers from some of the countries are summarised in Tables 8.1 and 8.2 later in this report.

The strength level for base layers generally falls in two groups: High strength lean concrete with compressive strengths of 6-10 MPa in Belgium, Germany, Spain, UK and Sweden and low strength materials with compressive strength 2-4 MPa (Austria and Switzerland).

Regarding the measures to minimise reflective cracking, Germany, France and Spain opt for pre-cracking by notching the "wet" base layer. Other countries are currently making test in this area, most notably UK.

The early rolling process, which was previously used quite a lot in Germany and other countries, is according to the report almost not used anymore. In Austria, the effectiveness of this method is believed to be highly dependant on the subgrade. In Steiermark it has given good results, whereas other areas have had little success.

The report summarises the conclusions from an international symposium about measures against reflective cracking held in Vienna in February 2000. 21 experts from 8 countries put forward the following comments/conclusions:

- Thick asphalt layers: Too expensive. A few cracks can still reflect as a result of poor uniformity of the bound base layer.
- Reinforcement of the asphalt layers: Not always successful because of loss of adhesion between asphalt base and wearing course.
- Covering cracks in the hydraulically bound layer with e.g. 15 cm wide paper strips (in order to lengthen asphalt strain area): Damages as a result of loss of bond.
- Unbound layer between bound base and asphalt: Drawbacks regarding bearing capacity and rutting and still risk of reflective cracking.
- Hydraulically bound base with low strength/low cement content: More frost damages and by heavy traffic sometimes map cracking in the wheel tracks – and still examples of reflective cracking
- Vibratory rolling of the "young" base layer: Only successful in some regions.
- Pre-cracking by notching: Long term practise in Germany, Spain and France, being introduced in UK and Hungary.

The report concludes by recommending some form of pre-cracking for Austrian cement bound base layers either by notching or for areas with relatively soft subgrade early vibratory rolling.

2.3 Cost 333 Development of New Bituminous Pavement Design Method

This European Cost action ran for three years from 1996 to 1999 (3). The overall objective was to contribute to the development of a harmonised European Pavement Design Method for Flexible and Semi-rigid (in this report called composite) pavements.

General material data and design methods

In the report, various properties of hydraulically bound road base materials are dealt with. A general distinction between three different types of materials is initially made, namely hydraulic soil stabilisation, sand cement and hydraulic bound base layers.

Strength and E-values for different types of mixes are referenced. The following table taken from the report shows stiffness values found in the literature and used in various design methods.

Type of material	Condition	E-modulus [MPa]	Poisson's ratio	Author
Lean concrete	Uncracked	15000		Verstraeten
	Uncracked	15000 – 38000	0.15	Golden 1986
	Post cracked	1000		
Sand cement	Uncracked	15000	0.25	Bolk
Cement bound aggregate		20000	0.25	Autret
Sand cement		12000	0.22	Autret
Cement bound gravel		2000 – 2500	0.22	Gschwendt
Stabilised soil		1200	0.25	Gschwendt
Crushed Stone	Uncracked	14000	0.35	Freeme
	Post cracked	1500		
Gravel	Uncracked	8500	0.35	Freeme
	Post cracked	750		

Table 1: E-values for various materials from COST 333

Furthermore, various formulations of the fatigue law for hydraulic bound base layers found in the literature are given in a table in the COST report:

Author	Fatigue law
Autret et al (1982)	$\frac{\sigma_N}{\sigma_0} = 1.20 - 0.132 \times \log N_f$
Darter (1977)	$\frac{\sigma_N}{\sigma_0} = 0.094 - 0.056 \times \log N_f$
Verstraeten et al (1982)	$\frac{\varepsilon_N}{\varepsilon_0} = 1 - 0.05 \times \log N_f$
Freeme (1982)	$\frac{\varepsilon_N}{\varepsilon_b} = 1 - 0.109 \times \log N_f$
Golden (1988)	$\frac{\sigma_N}{\sigma_0} = 0.868 - 0.0326 \times \log N_f$

Table 2: Fatigue laws for hydraulically bound base layers (COST 333)

During this COST-action questionnaires were sent to all the participating countries. The questionnaire on composite pavement design was responded to by 11 countries (Austria, France, Germany, Greece, Hungary, Italy, Poland, Portugal, Spain, Switzerland and United Kingdom).

General descriptions of the design methods in these countries are given together with specific information gained from the questionnaire. Some of this will be summarised in the following.

The design life of composite pavements is in most countries 20 years, except for France where 30 years is applied. The terminal condition is usually defined as need of strengthening. The most frequent deterioration mechanisms that are considered in the design methods are load associated cracking and reflection cracking.

From the 11 countries, 7 indicate that the design method is analytically based, 2 indicate it as empirical and 2 unspecified.

The countries also responded to the in-service pavement performance with an evaluation of the different forms of deterioration. Transverse reflection cracking was judged to be the most common form of deterioration, followed by rutting in the bituminous layers, loss of skid resistance and longitudinal cracking.

Examples of model designs

Finally, each country was asked to give examples of the most commonly used pavement designs for cumulative traffic levels of 1, 10 and 100 million 80 kN standard axles and a subgrade CBR of 5 %.

The results of the individual designs are illustrated in Figure 2. A summary of design thicknesses for the asphalt and hydraulically bound layers are given in Table 3.

		Cumulative traffic		
		1 msa	10 msa	100 msa
Thickness of asphalt [mm]	Minimum	40	120	150
	Mean	115	183	222
	Maximum	150	240	290
Thickness of cemented base [mm]	Minimum	150	150	150
	Mean	203	242	234
	Maximum	240	330	300

Table 3: Design thicknesses from national methods (COST 333)

Generally, the composite pavement design methods are conceptually very similar to those used for flexible pavements. The report concludes with recommendations for the development of a new European Design Method. It should be considered if thermally induced stresses can be included in the design calculations. Only one current design method (UK) includes this feature, whereas all other countries only consider traffic induced stresses. Furthermore, it should be considered to develop and include a model for reflective cracking since this is the major form of deterioration for composite pavements.

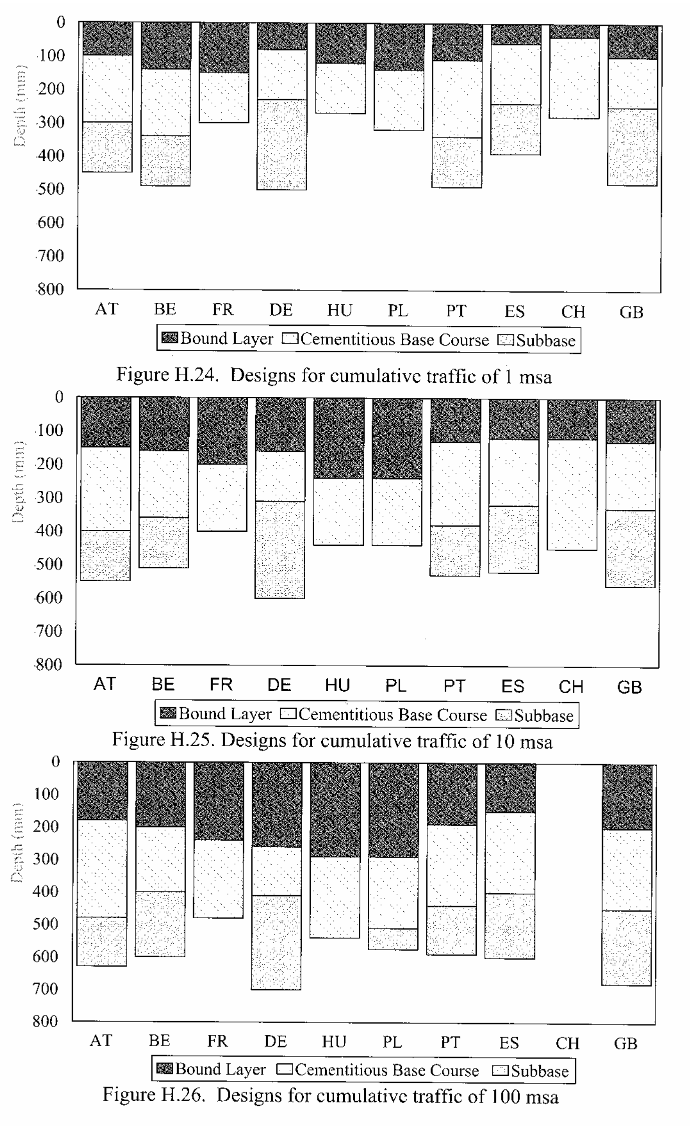

Figure 2: Semi-rigid pavement designs for different traffic loads (COST 333)

2.4 New CEN-standards

The new CEN-standards for hydraulically bound materials will constitute the framework for further utilisation of cement bound base layers in Europe. The most important standards and proposals are:

ENV 13282:2000: Hydraulic road binders - Composition, specifications and conformity criteria

EN 13242:2002: Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction

prEN 14227-1: Unbound and hydraulically bound mixtures - Specifications - Part 1: Cement bound mixtures for road bases and subbases prEN 14227-2: Unbound and hydraulically bound mixtures - Specifications - Part 2: Slag bound mixtures - Definitions, composition, classification

prEN 14227-3: Unbound and hydraulically bound mixtures - Specifications - Part 3: Fly ash for bound mixtures - Definitions, composition, classification

prEN 14227-4: Unbound and hydraulically bound mixtures - Specifications - Part 4: Fly ash for hydraulically bound mixtures - Definitions, composition, classification

prEN 14227-5: Unbound and hydraulically bound mixtures - Specifications - Part 5: Granular materials bound with hydraulic road binders - Definitions, composition, classification

CEN TC 227 has also been working with more than 20 test methods for hydraulically bound materials.

The CEN standards will not be treated in detail here, except for examples of strength classifications from two of the standards that can be of special relevance in relation to ECO-SERVE. Initially, the minimum cement content for cement bound mixtures is given in Table 4:

Maximal nominal aggregate size [mm]	**Minimum cement content [% by mass]**
> 8 to 31,5	3
2,0 to 8,0	4
< 2,0	5

Table 4: Minimum cement content according to prEN 14227-1

Strength class	**28-days compressive strength [N/mm²]**	
	Characteristic strength (R_{ck})	
	Cylinders or Cubes H/D[a] = 1,0[b]	**Cylinders H/D = 2,0**
CB 1	2	1,5
CB 2	4	3
CB 3	6	5
CB 4	9	7
CB 5	13	10
CB 6	18	14
CB 7	24	19
[a] H/D = ratio between the height and the diameter of the specimen [b] H/D = 0,86 to 1,2 included		

Table 5: Characteristic compressive strength according to prEN 14227-1 (system I)

Another option for the classification is System II, where six classes (CT0 – CT6) are defined according to 28-day values for tensile strength and modulus of elasticity.

EN 13282 specifies Hydraulic Road Binders (HRB), which refers to a mixture of two or more of the following: Fly ash, granulated blast furnace slag, lime, gypsum, cement. These factory produced blends are specially formulated for use in hydraulically bound road bases and exhibit slower strength gain than cement bound mixtures. prEN 14227-5 gives specifications for mixtures using HRB.

R_C class	R_{C1} [MPa]	R_{C2} [MPa
C 2/1,5	2	1,5
C 4/3	4	3
C 8/6	8	6
C 12/9	12	9
C 16/12	16	12
C 20/15	20	15
C 24/18	24	18
C 28/21	28	21
C 32/24	32	24
C 36/27	36	27

Table 6: Compressive strength classes (360 days) for mixes with hydraulic road binder, according to prEN 14227-5. R_{C1} and R_{C2} designate strength for slenderness ratios of 1 and 2 respectively.

As for the cement bound mixes another system with classification according to tensile strength and modulus of elasticity also exists.

3. ECO-SERVE questionnaire

A new questionnaire (see Appendix) was circulated to a number of countries in connection with the ECO-SERVE network. The formulation of the questions was inspired by the COST 333 questionnaire combined with the Austrian report previously mentioned.

3.1 Data tables

In the following tables 7-1 to 7-3, the questionnaire answers from nine European countries supplemented with three overseas responses (table 7-4) are shown.

In order to include some information from countries that have not answered the ECO-SERVE questionnaire, data adapted from (2) are shown with the same table setup in tables 8-1 and 8-2.

	Denmark	Norway	Sweden
General			
Length, primary road network [km]	1700	26934	15000
Semi-rigid pavements [%]	7%	3.2	1
In new construction [%]	<1	0.5	< 1
Design Method			
Name, type etc.	Design charts in Vejregel 7.10.03 (1984). Originally based on British experience, mainly Road Note 29.	Norwegian Pavement Design Manual, Hb 018, 1999 (under revision), Design Guide	ATB Väg 2003 / Computer program: PMS Object
Design pavement life [years]	20	20	20
<u>Terminal condition:</u>			
Need of strengthening	x	x	
Requiring reconstruction		x	x
Change of serviceability index			
<u>Parameters in design calculations:</u>			
Elastic stiffness modulus			x
value:			17000 MPa
Fatigue resistance		x	x
Strength of mix			
Coefficient of thermal expansion		x	
Subgrade characteristics	x		x
Other			
<u>Climatic factors considered:</u>			
No. of climatic zones			
Air temperatures			
Pavement temperatures			x
Frost index		x	
Frost penetration depth	x		x
Precipitation			
<u>Pavement deterioration considered in design:</u>			
Reflection cracking			x
Rutting in bituminous layers			x
Cracking of base by traffic			x
Cracking of base by thermal stresses			
Serviceability index			
Other		Subgrade distress, surface rutting	

Table 7-1: Results from ECO-SERVE questionnaire

	Denmark	Norway	Sweden
Materials and mix according to specification			
Specification	VD321 from 1968	Design Manual Hb 018	ATB Väg 2003
Strength requirement	Average 5 MPa compressive cylinder strength @ 7 days	7-day compressive strength: 5.3 MPa	7-day compressive strength from cores ≥ 9 MPa
Cement content	90 – 120 kg/m^3	Min. 80 kg/m^3	Not specified
Cement type		CEM I 32.5	CEM I, CEM II/A-LL
Content of fly ash, slag etc.		0	-
Plant-mix prescribed	Yes	Yes	No
Gradation envelope given	Yes	Yes	No
Crushed aggregate prescribed	No	No	No
Construction requirements			
Quality control	In-situ density	Density and compressive strength on cores	Compressive strength from cores, layer thickness
Compaction	92% of theoretical maximum (no air)	Min. 98 % modified Proctor	Not specified
Curing	Bitumen emulsion	Bitumen emulsion	Bitumen emulsion, geotextile, plastic sheet, water curing
Pre-cracking/notching	No	No requirement	Optional

Table 7-1: Results from ECO-SERVE questionnaire

	Denmark	Norway	Sweden
Typical pavement structure for heavy traffic			
Sub-base thickness [mm]	450	0 – 1000	300 – 600
Base course thickness [mm]	180 – 200	160 – 180	150 – 240
Asphalt thickness [mm]	120 – 160	80	90
Strength level [MPa]	5 – 20	10 – 15	> 9
Performance Record etc.			
In-situ pavement performance	Mainly reflection cracking	Most damages related to other parts of pavement, like frost heave, too narrow shoulders, cracking caused by thin and soft asphalt wearing course, varying strength of sub-grade material	Reflective cracking most common form of deterioration, but most cracks are harmless
Reflective cracking	~ 30 %	Present everywhere, but normally not recognised as a serious problem	1 %
FWD on semi-rigid pavements	2000 - 20000 MPa for 25 - 30 year old cement bound base layers.	4000 – 8000 MPa	8000 – 10000 MPa
Pre-cracking methods	No experiences, apart from vibratory rolling that did not prove successful at short test section	-	200 m test section with notching of base layer, good results after 3 years traffic
Special designs	Short motorway test section with cement bound sand base layer and 30 mm asphalt surfacing was not successful. Around 100 km motorway with cement bound base layers were constructed in the 1970'ies. Since then this pavement type has not been used on the main road network in Denmark.		Reflective cracking most common form of deterioration, but most cracks are harmless

Table 7-1: Results from ECO-SERVE questionnaire

	Belgium	Germany	Slovakia
General			
Length, primary road network [km]	1700		3531
Semi-rigid pavements [%]	36 % rigid, 64 % bituminous surface (semi-rigid unknown)		50
In new construction [%]			90
Design Method			
Name, type etc.	Dimensionnement des chaussées du Ministère des équipements et des transports (MET)		TS 0502 Design of flexible and semi-rigid pavements. Technical regulation. March 2002.
Design pavement life [years]	20	30	25
<u>Terminal condition:</u>			
Need of strengthening	x		x
Requiring reconstruction		x	
Change of serviceability index		x	
<u>Parameters in design calculations:</u>			
Elastic stiffness modulus	x		x
value:			1000 – 2500 MPa
Fatigue resistance	x		x
Strength of mix	x		x
Coefficient of thermal expansion	x	x	
Subgrade characteristics		x	x
<u>Climatic factors considered:</u>			
No. of climatic zones		x	x
Air temperatures	x		x
Pavement temperatures			x
Frost index	x	x	x
Frost penetration depth	x	x	x
Precipitation			
<u>Pavement deterioration considered in design:</u>			
Reflection cracking			
Rutting in bituminous layers	x		x
Cracking of base by traffic	x		
Cracking of base by thermal stresses	x		
Serviceability index			
Other			

Table 7-2: Results from ECO-SERVE questionnaire

	Belgium	Germany	Slovakia
Materials and mix according to specification			
Specification	Cahier des charges type RW 99 du MET, 1999	ZTV T-StB 95	STN 73 6124 Road Building. Aggregate bound with hydraulic binder, 1996 STN 73 6125 Road building. Stabilised base, 1996.
Strength requirement	Compression -R'bk = 10 MPa	28-day compressive strength > 3,5 MPa	Stabilised base For cement binder - compression after 7 days: 1,0 - 4,0 MPa For composite binder (cement + .. or lime + ..) compression after 28 days: 1,0 - 4,0 MPa Both according to quality class of mixture Aggregate bound with hydraulic binder Compression after 28 days 7,0 - 12,0 MPa according to quality class of mixture
Cement content	Min. 100 kg/m^3	> 3 % of dry aggregate weight	Aggregate bound with hydraulic binder 90 - 100 (max. 4,5% of mass of aggregate) Stabilised base from 6 to 10 % of mass of dry soil according to quality class of mixture
Cement type	CEM I 42,5 + must be HSR and LA if crushed concrete is used as aggregate	Cement acc. to DIN EN 197-1, DIN 1164, hydraulic road binder DIN 18506	CEM I 32,5
Content of fly ash, slag etc.	Max. fly ash: 8 %		8 % of mass of dry soil
Plant-mix prescribed	Yes	No	No
Gradation envelope given	No	Yes	Yes
Crushed aggregate prescribed	Yes	No	No

Construction requirements			
Quality control	Compression strength on bored cores, thickness, surface regularity	Testing on materials, mix and finished layer	Strength in compression, density, moisture content, frost resistance
Compaction	No	> 98 %	98 % Proctor for aggregate bound with hydraulic binder and 97% for stabilised base
Curing	Bitumen emulsion (0,7 l/m^2) + sand (3 kg/m^2)		Bitumen emulsion
Pre-cracking/notching	No	Transverse: Per 5 m for compressive strength > 9 MPa or layer thickness > 20 cm. Per 2,5 m for asphalt cover < 14 cm.	No requirement

Table 7-2: Results from ECO-SERVE questionnaire

	Belgium	Germany	Slovakia
Typical pavement structure for heavy traffic			
Sub-base thickness [mm]	200	350 – 450	250
Base course thickness [mm]	200	150	220
Asphalt thickness [mm]	200	200 – 260	200
Strength level [MPa]	10		
Performance Record etc.			
In-situ pavement performance	Most common probably rutting in bituminous layers		Rutting in the bituminous layers, transverse reflective and frost cracks, loss of skid resistance
Reflective cracking	Unknown	Unknown	Not evaluated
FWD on semi-rigid pavements	no	No	Surface modulus more than 900 MPa
Pre-cracking methods			Sections not realised
Special designs			Sections not realised

Table 7-2: Results from ECO-SERVE questionnaire

	Poland	UK[1]	Netherlands
General			
Length, primary road network [km]	18042	9000	3500
Semi-rigid pavements [%]	~ 15	20	>15
In new construction [%]	Unknown	50	>50
Design Method			
Name, type etc.	KTKNPiP 1997	DMRB vol. 7 based on TRL Report LR1132	VNC-SAG
Design pavement life [years]	20	20 or 40	20
<u>Terminal condition:</u>			
Need of strengthening	x	x	x
Requiring reconstruction	x	x	x
Change of serviceability index			
<u>Parameters in design calculations:</u>			
Elastic stiffness modulus	x	x	x
value:	4500 – 12900 MPa	20 – 40 GPa	AG = 3000, SC = 6000-8000
Fatigue resistance	x		x
Strength of mix	x	x	x
Coefficient of thermal expansion		x	
Subgrade characteristics	x	x	x
		Flexural strength 1 – 5 MPa	
<u>Climatic factors considered:</u>			
No. of climatic zones			
Air temperatures	x	x	x
Pavement temperatures	x	x	x
Frost index			
Frost penetration depth	x		x
Precipitation			
<u>Pavement deterioration considered in design:</u>			
Reflection cracking	x		x
Rutting in bituminous layers	x		x
Cracking of base by traffic	x	x	x
Cracking of base by thermal stresses		x	
Serviceability index			
Other			IRI

Table 7-3: Results from ECO-SERVE questionnaire

	Poland	UK	Netherlands
Materials and mix according to specification			
Specification	PN-S-96013:1997 Lean concrete for subbase and PN-S-96012:1997 Cement stabilisation for subbase and subgrade improvement	Manual of Contract Documents for Highway Works, volume 1, series 1000	Standaard RAW from 2000
Strength requirement	28-day compression: 2.5 – 5 MPa (cement stab.) 6 – 9 MPa (lean concrete)	7-day compressive cube strengths: Strength classes 4, 5, 7 or 10 MPa for sub-bases 7, 10, 15 or 20 MPa for road bases	Asphalt granulate (AG): @7-day compr. strength ≥1,5 MPa @28-day compr. strength ≥2,0 MPa Sand cement (SC): @28-day compr. strength ≥2,0 MPa In-situ for both mixes required compressive strength of 1,5 MPa
Cement content	5 – 7 %	80 – 180 kg/m^3	Asphalt granulate 40-80 kg/m^3 Sand cement 100-180 kg/m^3
Cement type	CEM I-IV 32.5	Mostly CEM I 42.5 and 52.5	Not prescribed, but the following types are used mainly: CEM III/B 42,5 CEM II/B 32,5
Content of fly ash, slag etc.	30 – 80	PFA 50% of total cement GGBS 65%	slag:0-25%
Plant-mix prescribed	No	Yes (road base)	No
Gradation envelope given	Yes	Yes	Yes
Crushed aggregate prescribed	No	No	No
Construction requirements			
Quality control	Compaction, compaction strength, thickness, humidity, grading	Density by nuclear density meter	In-situ density and cores for compressive strength measurements, layer thickness
Compaction	98 % of lab. compaction	95% of cube density	Asphalt granulate : min. 98%, average ≥ 102% Sand cement : min. 95%, average ≥ 100% relative to maximum proctor density (not specified in terms of normal or modified proctor)
Curing	Coating agent, plastic film etc.	Covering with impermeable sheeting or bituminous spray or curing	Bitumen emulsion or asphalt overlay of min. 60 mm within 24 hours,

		compound	not prescribed but performed at Asphalt granulate is treatment with water
Pre-cracking/notching	35 % of depth, 3 – 5 mm width, spacing < 18h (h ≥ 20 cm) spacing < 11h (h ≤ 14 cm)	At 3 m centres, for CBM3 or better, i.e. 7-day strength in excess of 7 MPa	Not prescribed, but pre-cracking is performed often with a vibrating roller. Notching performed at compressive strengths > 6 MPa, also not pre-scribed

Table 7-3: Results from ECO-SERVE questionnaire

	Poland	UK	Netherlands
Typical pavement structure for heavy traffic			
Sub-base thickness [mm]	220	150 – 350 dep. on sub-grade CBR	1000, sand
Base course thickness [mm]	130 – 160	250 mm CBM3	250 – 300
Asphalt thickness [mm]	130	Up to 200 mm	≥200
Strength level [MPa]	Lean concrete: 3.5 – 5.5 MPa (7 days) 6 – 12 MPa (28 days) Cement stabilisation: 1 – 1.6 MPa (7 days) 1.5 – 2.5 MPa (28 days)	Min. 7 – 10 MPa	in-situ compressive strength ≥ 1,5 MPa
Performance Record etc.			
In-situ pavement performance	Transverse reflective cracking Rutting in bit. layers Long. unevenness Low temp. cracking Longitudinal cracking General surface cracking Ravelling Loss of skid resistance	Reflection cracking, rutting	Ravelling in wearing coarse of porous asphalt Rutting in wearing coarse of dense asphalt or in layer below wearing course
Reflective cracking	-	Ref. ISAP 1997 paper	If pavement thickness > 140 mm and compressive strength in-situ < 6 MPa, no problem
FWD on semi-rigid pavements	Non-cracked lean concrete layer: 6000 – 12000 MPa Non-cracked cem. stab. 4500 MPa		Performed at end of life span to evaluate remaining strength and pavement life
Pre-cracking methods		Ref. TRL Report 248 + Salamanca 2001 paper	Pre-cracking with vibrating roller and notching at compressive strengths of > 6 MPa
Special designs	Thin bituminous wearing course becoming more popular	Ref. Reflective Cracking Conferences, papers	Stress relieving modified sand asphalt layer with thin wearing coarse

Table 7-3: Results from ECO-SERVE questionnaire

	New Zealand[2]	USA[3]	Australia[4]
General			
Length, primary road network [km]	11500	-	50000
Semi-rigid pavements [%]	> 10	-	1
In new construction [%]	> 10	-	1
Design Method			
Name, type etc.	Austroads Pavement Design Guide and mechanistic design using CIR-CLY computer program	Mechanistic – empirical procedure used by respondent, similar to 2002 Design Guide Method	Austroads Pavement Design Guide 1992, mechanistic model using CIRCLY linear elastic model
Design pavement life [years]	25	20	30 – 40 (urban), 20 (rural)
Terminal condition:			
Need of strengthening	x	x	x
Requiring reconstruction	x		
Change of serviceability index	x		
Parameters in design calculations:			
Elastic stiffness modulus	x	x	x
value:	> 1500 MPa	strength dependent	2000 – 5000 MPa
Fatigue resistance	x	x	x
Strength of mix	x	x	
Coefficient of thermal expansion			
Subgrade characteristics	x	x	x
Climatic factors considered:			
No. of climatic zones			
Air temperatures		x	
Pavement temperatures		x	x
Frost index			
Frost penetration depth		x	
Precipitation		x	
Pavement deterioration considered in design:			
Reflection cracking		x	
Rutting in bituminous layers	x	x	
Cracking of base by traffic		x	x
Cracking of base by thermal stresses			
Serviceability index			
Other		IRI	

Table 7-4: Results from ECO-SERVE questionnaire

	New Zealand	USA	Australia
Materials and mix according to specification			
Specification	Project specific	-	Each state has specs.
Strength requirement	7-day compressive strength	Mix M: 7-day compr. strength > 3.5 MPa Mix L: 7-day compr. strength > 5.2 MPa	7-day compressive strengths: 2 MPa for E = 2000 MPa material 3 MPa for E = 5000 MPa material.
Cement content		Mix M: 3 – 9 % Mix L: 4 – 9 %	
Cement type		Type I, II or IP	Portland and Blended cements
Content of fly ash, slag etc.	Lime and stabilising agents from steel slag waste frequently used	-	
Plant-mix prescribed	Yes	No	Yes
Gradation envelope given	No	No	Yes
Crushed aggregate prescribed	No	No	Yes
Construction requirements			
Quality control	Density check or Clegg hammer, often post construction FWD	Density and cores for strength measurements	Density, thickness, cementitious content, grading, moisture content, crushed rock quality
Compaction	Ref.: Vibrating hammer	> 95 % modified Proctor	95 % modified Proctor
Curing	Seal coat membrane	Water or asphaltic membrane	Water or bitumen emulsion
Pre-cracking/notching	No, usually open to traffic while constructing, pre-cracking by traffic assumed, often modified with lime to get slow strength gain and avoid shrinkage cracking	No requirement	No

Table 7-4: Results from ECO-SERVE questionnaire

	New Zealand	USA	Australia
Typical pavement structure for heavy traffic			
Sub-base thickness [mm]	100 – 200	No requirement	150
Base course thickness [mm]	150	150	150 – 200
Asphalt thickness [mm]	40 mm or seal coat only	100	200 – 250
Strength level [MPa]		Compressive strength > 5.2 MPa	7-day compressive strength 2 – 3 MPa
Performance Record etc.			
In-situ pavement performance	Modified lime pavements very common – low strength. Only covered with seal coat. Gives +25 years life before densification in wheel paths. Then reconstructed in-situ.	Rutting in asphalt layers Longitudinal cracking Reflection cracks Ravelling	Rutting in bituminous layers
Reflective cracking	Not considered a problem because of low strength and slow strength gain.	Not relevant	With min. 175 mm asphalt no problem
FWD on semi-rigid pavements		Done during LTPP program	2000 – 20000 MPa, highly variable
Pre-cracking methods	-	Not relevant	-
Special designs	Construction procedure on almost all NZ rural highways: Subgrade improved to CBR 4 or better, granular layers up to 450 mm, either partly or fully modified/stabilised, first seal coat, open to traffic. After 12 months, second seal coat.	Low base strength pavements in Montana and Texas. Monitoring for less than 5 years. Thin asphalt surfacings have generally shown poor performance	

Table 7-4: Results from ECO-SERVE questionnaire

	Austria[5]	France	Italy
General			
Length, primary road network [km]			
Semi-rigid pavements [%]			
In new construction [%]			
Design Method			
Name, type etc.			
Design pavement life			
<u>Terminal condition:</u> Need of strengthening Requiring reconstruction Change of serviceability index			
<u>Parameters in design calculations:</u> Elastic stiffness modulus value: Fatigue resistance Strength of mix Coefficient of thermal expansion Subgrade characteristics Other			
<u>Climatic factors considered:</u> No. of climatic zones Air temperatures Pavement temperatures Frost index Frost penetration depth Precipitation			
<u>Pavement deterioration considered in design:</u> Reflection cracking Rutting in bituminous layers Cracking of base by traffic Cracking of base by thermal stresses Serviceability index Other			

Table 8-1: Data from (2), adapted in ECO-SERVE table

	Austria	France	Italy
Materials and mix according to specification			
Specification	RVS 8S.05.13 "Mit Bindemittel stabilisierte Tragschichten" 2002		
Strength requirement	7-day compressive strength ≥ 2,5 - 3.5 MPa (depending on cement type)	Splitting tensile strength @ 360 days ≥ 1.1 MPa (≥ 0.66 MPa @ 28 days)	7-day compressive strength 2.5 – 4.5 MPa, 7-day splitting tensile strength 0.25 MPa
Cement content	Min. 90 kg/m^3 for mix-in-place, min. 80 kg/m^3 for mix-in-plant or mix-in-place with slurry or +3 passes	Min 70 kg/m^3	60 – 100
Cement type	CEM 32.5 N, CEM 32.5 R, CEM 42.5 N, HRB 22.5 E	CEM I, II or III 32.5	CEM 32.5
Content of fly ash, slag etc.	≤ 35 %	≤ 80 kg/m^3	40 FA
Plant-mix prescribed	No	Yes	No
Gradation envelope given	No	Yes	Yes
Crushed aggregate prescribed	No	Yes	Yes, min.30 – 60 %
Construction requirements			
Quality control			
Compaction	Min 97 % Proctor	98 % modified Proctor	100 % mod. AASHTO
Curing	Bitumen emulsion	Bitumen emulsion + sand	Bitumen emulsion
Pre-cracking/notching	Required under asphalt, either by vibrating roller the day after compaction or notching 1/3 depth for HRB and 2/3 depth for cement	Per 3 m	No

Table 8-1: Data from (2), adapted in ECO-SERVE table

	Austria	France	Italy
Typical pavement structure for heavy traffic			
Sub-base thickness [mm]			
Base course thickness [mm]	250 – 300	150 – 250	200 – 300
Asphalt thickness [mm]	150 – 170	140	200 – 250
Strength level [MPa]			
Performance Record etc.			
In-situ pavement performance			
Reflective cracking	Yes	No	No
FWD on semi-rigid pavements			
Pre-cracking methods			
Special designs			

Table 8-1: Data from (2), adapted in ECO-SERVE table

	Spain	Switzerland	
General			
Length, primary road network [km]			
Semi-rigid pavements [%]			
In new construction [%]			
Design Method			
Name, type etc.			
Design pavement life			
<u>Terminal condition:</u> Need of strengthening Requiring reconstruction Change of serviceability index			
<u>Parameters in design calculations:</u> Elastic stiffness modulus value: Fatigue resistance Strength of mix Coefficient of thermal expansion Subgrade characteristics Other			
<u>Climatic factors considered:</u> No. of climatic zones Air temperatures Pavement temperatures Frost index Frost penetration depth Precipitation			
<u>Pavement deterioration considered in design:</u> Reflection cracking Rutting in bituminous layers Cracking of base by traffic Cracking of base by thermal stresses Serviceability index Other			

Table 8-2: Data from (2), adapted in ECO-SERVE table

	Spain	Switzerland	
Materials and mix according to specification			
Specification			
Strength requirement	Compressive strength at 7 days ≥ 6 MPa or ≥ 9 MPa at 90 days. Splitting tensile strength at 7 days ≥ 0.5 MPa or ≥ 0.75 MPa at 90 days	7-day compressive strength ≥ 2-4 MPa	
Cement content	Usually 90 – 100 kg/m^3	Min. 60 kg/m^3	
Cement type	CEM IV/B 32.5	CEM I 32.5	
Content of fly ash, slag etc.	36 – 55 %	0	
Plant-mix prescribed	Yes		
Gradation envelope given	Yes		
Crushed aggregate prescribed	Yes, min. 50 %		
Construction requirements			
Quality control			
Compaction	97 % modified Proctor	97 % modified Proctor	
Curing	Bitumen emulsion + sand	Bitumen emulsion	
Pre-cracking/notching	Since 1997	No	

Table 8-2: Data from (2), adapted in ECO-SERVE table

	Spain	Switzerland	
Typical pavement structure for heavy traffic			
Sub-base thickness [mm]			
Base course thickness [mm]	220 – 250		
Asphalt thickness [mm]	150		
Strength level [MPa]			
Performance Record etc.			
In-situ pavement performance			
Reflective cracking	Often, when no notching	Often	
FWD on semi-rigid pavements			
Pre-cracking methods			
Special designs			

Table 8-2: Data from (2), adapted in ECO-SERVE table

Data in tables 8-1 to 8-2 for Austria, France, Italy, Spain, Switzerland partly or fully based on tables from (2). Data valid for heavy traffic applications.

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[1] Combined from three responses
[2] Partly combined from two responses
[3] Filled in by respondent who has been doing consultancy work for various US DOT's. Does not cover all US practises.
[4] Two responses, data mostly based on response valid for new urban semi-rigid pavements
[5] Some additional data provided by H. Sommer

3.2 Special comments from questionnaire

In the questionnaire, special comments and references relating to ECO-SERVE type pavements and pavements with superior performance were requested.

Denmark: More than 100 km of semi-rigid motorway pavement was constructed in the 1970s. Some of these sections have shown superior performance in the sense that the original wearing course is still present after 23 years service and more than 10 mil. 10-ton ESALs. Serious reflective cracking is only observed on around 1/3 of the total length with this pavement type. A recent investigation showed that the core strength for intact cores from these old pavements varied from 10 – 25 MPa. It was not possible to differentiate between the core strengths for successful sections with no reflective cracking and unsuccessful section with extensive reflective cracking. However, stiffness values from FWD-testing on a section from 1977 with reflective cracking ranged from 12.000 – 20.000 MPa, whereas the stiffness for successful sections from 1972 and 1980 with no reflective cracking ranged from 1.500 – 12.000 MPa. The investigations indicate that the performance in relation to reflective cracking was better for low-stiffness, variable strength materials than for high-stiffness, uniform quality base layers.
Another factor that seems to have an effect is the time of the year when paving is done. Base layers constructed in spring and summer seem to have a higher risk of developing reflection cracking than layers constructed in the autumn. The explanation is probably that cold-weather temperature contractions at a time when the strength is still rather low, facilitates early development of many fine transverse cracks in the base layer.

UK: D. York: UK experience is with high strength CBM for roadbases. History has shown a strong relationship between pavement life and roadbase strength.
Nunn refers to papers on special designs and methods for avoiding reflective cracking. One of the papers (4) gives a performance validation based on 649 km semi-rigid pavements constructed between 1959 and 1987. The layer thickness ranges were 150 – 250 mm CBM with 100 – 200 mm asphalt overlay. These roads have carried up to 100 mil. 80 kN standard axles. The road sections have undergone a variety of maintenance operations, generally replacement of asphalt layers or addition to them. Less than 9% have required reconstruction including removal of the roadbase. Based on the performance validation, it is concluded that the current UK design with 200 mm asphalt on 250 mm CBM3 should be sufficient to carry more than 100 mil. 80 kN axles.
In 1996, 12 experimental sections were constructed in the UK in order to investigate pre-cracking of cement bound base layers (5). Various methods were used, both wet-formed joints and guillotine drops. After 5 years of monitoring, the level of cracking has been substantially lower than for control sections with no pre-cracking. This has led to a specification for pre-cracking of cement bound base layers (CBM3 or better) in the UK.

USA: Semi-rigid pavements were built more commonly in the US in the 1970's and 1980's. Some state agencies have decreased their use especially on high volume roadways, while others have restricted their use because of poor performance in localized areas.
Low base strength mixtures have been used in Montana and Texas. Montana has a monitoring program for some of these pavements, but it has been running for less than five years. Thin HMA surfacings have been used above CTB layers, but the performance, in general, has not been good.

4. Conclusion

Based on the literature references and the questionnaire answers, there is obviously a general trend, that the countries with larger volume construction of semi-rigid pavements either for many years have used or currently are moving towards various techniques for pre-cracking, mostly in the form of wet-formed transversal joints with a distance of 3-5 metres. These countries often prescribe relatively high strengths (7-day compressive strengths > 6 MPa). Other countries that do not use pre-cracking have relatively low strength requirements (7-day compressive strengths of around 3-7 MPa).

References to thin asphalt surfacings have until now been limited. Cement bound base layer thicknesses are normally 150-250 mm with 100-200 mm asphalt surfacing.

5. Stakeholder mapping

The following persons have either answered to the ECO-SERVE questionnaire (*italics*) or in other ways been mentioned for the individual countries:

Country	**Name**	**Organisation**	**e-mail**
Austria	Herman Sommer		sommerh@a1.net
	Johannes Steigenberger	VÖZ - Association of the Austrian Cement Industry	steigenberger@voezfi.at
	Günter Breyer	Bundesministerium für Verkehr, Innovation und Technologie	guenter.breyer@bmvit.gv.at
Belgium	*Johan Maeck* *Eric Van den Kerkhof*	Belgian Road Research Centre	J.Maeck@brrc.be E.Vandenkerkhof@brrc.be
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France			
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Italy			
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	Øystein Myhre, Jan Erik Dahlhaug, Karl Melby	Norwegian Public Roads Adminstration	
Poland	*Wojciech Bańkowski*	Road and Bridge Research Institute	wbankowski@ibdim.edu.pl

	Piotr Jaskuła	Gdansk University of Technology	pjask@pg.gda.pl
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	George Vo-robieff	Australian Stabilisation Industry Association	vorobieff@auststab.com.au
New Zea-land	*Michael Hay-don*	Works Infrastructure	michael.haydon@works.co.nz
	Bryan Pidwerbesky	Fulton Hogan Ltd	bryan.pidwerbesky@fh.co.nz
USA	*Harold von Quintus*	Applied Research Asso-ciates ERES Consultants Divi-sion	hvonquintus@ara.com

Table 9: ECO-SERVE Cluster 4 stakeholders

References

(1) Chaussees Semi-Rigides / Semi-Rigid Pavements, PIARC, 1991.

(2) H. Sommer, G. Hartl, E. Tschegg: Überarbeitung der RVS 8.05.13 Zementstabilisierte Tragschichten, Bundesministerium für Verkehr, Innovation und Technologie, Heft 520, Wien 2002.

(3) COST 333 Development of New Bituminous Pavement Design Method, 1999.

(4) Parry, A.L. et al.: UK Design of Flexible Composite Pavements, ISAP-conference, Seattle, 1997.

(5) Ellis, S.J.: In-Service Performance of Full-Scale Trials Incorporation the Pre-Cracked Cement Bound Materials in the UK, 1st International Symposium on Sub-grade Stabilisation and In-Situ Pavement Recycling using Cement, Salamanca, 2001.

Appendix: ECO-SERVE Questionnaire

Semi-rigid pavements

Introduction

The European Thematic Network *ECO-SERVE - European Construction in Service of Society* was launched by the European Commission in November 2002. The Network will run for 4 years and has been set up by around 50 participants representing the European cement, concrete and pavement construction industry.

The specific objectives of the Network are:

- Reducing the adverse environmental impact of the pavement and concrete construction industry on the external environment
- Improving the working environment within this industry
- Ensuring European growth and wealth by increasing the productivity and competitiveness of the raw materials, production and the construction industry as well as enhancing the quality, durability and service life of pavements and concrete structures through sustainable developments

The ECO-SERVE Cluster 4 will deal with innovative pavement design. It is the objective based on assessment of available research and design methods to select the most suitable approach for design of low strength, cementitious base course layers.

Such base course layers may be produced using materials (sand, gravel), which are available at the location of construction instead of applying standardised high quality components with proven performance.

The Cluster will address possible new types of unbound or cementitious pavements, materials and the correlated design models, which will allow for the introduction of:

- Local materials, possibly of marginal quality compared with standard materials
- Pozzolanic binders with low CO_2-emission during production
- Design of pavements based on present needs (load) with future strengthening options built-in (stepwise design and construct principle)
- Reduction of the bituminous pavement layers.

The aim of the Cluster is to develop performance based criteria and guidelines for ECO-SERVE type pavements, i.e. pavements that ideally fulfil all of the following requirements: Low strength base course, hydraulically bound, no reflective cracking, thin asphalt surfacing, based on local materials, low environmental impact, low cost, maintenance free.

Current members of ECO-SERVE Cluster 4 are Dansk Beton Teknik, COWI Consulting Engineers, Technical University of Denmark and Danish Road Institute (Denmark), Dura Vermeer and Intron (Netherlands), LCPC (France), TRL (UK), Road and Bridge Research Institute (Poland), Hellenic Cement Research Centre (Greece) and Centre of Laboratorial Tests (Lithuania).

The first cluster activity is a mapping of design methodologies and pavement performance data for semi-rigid pavements. The questionnaire will form the basis for this activity.

Notes for guidance

A semi-rigid pavement is defined as a pavement with a bituminous surfacing and a hydraulically bound material as the main structural layer (base course).

The first part of the questionnaire aims at establishing the general situation (design, requirements etc.) for semi-rigid pavements in the individual countries, whereas the last section *Performance Record etc.* gives the opportunity to contribute experiences with standard semi-rigid pavements and also alternative materials, designs and construction methods.

Both traditional mixes with cement bound sand/gravel and more special mixes with alternative aggregates or binders like fly ash or blast furnace slag can be included.

The *Design Method* section is partly based on questions from the *COST 333 – Development of New Bituminous Design Method* questionnaire.

The *Materials* and *Construction* questions are mainly focused on the base course layer. Specific comments relating to other pavement layers like subgrade or wearing course can be given in the *Comment* fields.

The questionnaire is only concerned with the Primary Road Network, as it is defined by the individual countries.

Please indicate *not relevant*, *no requirement* etc. where appropriate. Supplementary information to the individual questions can be given in the *Comments* field of each section.

At the end of this document we have included three pages with tables, where some of the data for a number of countries are given for information. The tables are based on data from an Austrian report by H. Sommer et al*: Überarbeiten der RVS 8.05.13 Zementstabilisierte Tragschichten, Austrian Ministry for Traffic, Innovation and Technology, Heft 520, 2002*, supplemented with data for a few other countries.
Please consult these tables for guidance and feel free to correct/update the tabled values via the questionnaire answers.

Thank you for your help!

General

Length of Primary Road Network in km

Percentage of Primary Road Network constructed with semi-rigid pavements
(All roads, i.e. historic situation)

Semi-rigid pavements in new construction on Primary Road Network (%)
(Current situation)

Comments

Design method

Design method
(Name, year, type: design guide, pavement catalogue or computer program)

Design pavement life
(Years)

Terminal condition at the end of pavement design period
(More than one tick box can be marked for this and the following questions)
Need of strengthening ☐
Requiring reconstruction ☐
Change of serviceability index ☐
Other

Parameters used in design calculations
Elastic stiffness modulus ☐
value:
Fatigue resistance ☐
Strength of mix ☐
Coefficient of thermal expansion ☐
Subgrade characteristics ☐
Other

Climatic factors considered in design
Number of climatic zones ☐
Air temperatures ☐
Pavement temperatures ☐
Frost index ☐
Frost penetration depth ☐
Precipitation ☐
Other

Pavement deterioration controlled by design criteria
(What types of distress are considered?)
Reflection cracking in wearing course ☐
Rutting in bituminous layers ☐
Cracking of base layer by traffic ☐
Cracking of base layer by thermal stresses ☐
Serviceability index ☐
Other

Comments

Materials and mix according to specification

Specification
(Name, publication year)

Strength requirement
(Please also state test method, e.g. compression or splitting tensile and number of days)

Cement content
(kg/m^3)

Cement type
(According to EN 197, e.g. CEM I 32.5)

Content of fly ash, blast furnace slag etc.
(Maximum allowable)

Mixing in plant prescribed (Yes/no)	no
Gradation envelope given (Yes/no)	no
Crushed aggregate prescribed (Yes/no)	no

Comments

Construction requirements

Quality control
(Density, coring, FWD etc.)

Compaction
(e.g. % Proctor, please state reference)

Curing
(e.g. bitumen emulsion)

Pre-cracking/notching of base layer
(Method, spacing etc.)

Comments

Typical pavement structure for heavy traffic

Sub-base thickness
(Unbound material, mm)

Base course thickness
(Hydraulically bound material, mm)

Asphalt thickness
(All asphalt layers, mm)

Strength level
(MPa, as constructed, e.g. compressive strength from cores)

Comments

Performance record etc.

In-service pavement performance
(Common forms of deterioration, please list by severity, distress types e.g. rutting in the bituminous layers, rutting originating in the subgrade, transverse reflective cracking, general surface cracking, longitudinal cracking in wheel-path, longitudinal unevenness, loss of skid resistance, ravelling, wear due to studded tyres, low temperature cracking, frost heave)

Reflective cracking
(Serious cracking, estimate % of total length with semi-rigid pavements)

FWD testing on semi-rigid pavements
(Range of E-values, reference to reports, papers)

Pre-cracking methods
(Test sections with various methods, experiences, references to reports, papers)

Special designs
(Test sections with ECO-SERVE type pavements, i.e. low strength base course and/or thin bituminous wearing course, no reflective cracking, references to reports, papers)

Comments

General comments/suggestions

(Relating to semi-rigid pavements with the following characteristics: Low strength base course, hydraulically bound, no reflective cracking, thin asphalt surfacing, based on local materials, low environmental impact, low cost, maintenance free)

Other contact persons

(In your country who could be interested in contributing to and communicating with the ECO-SERVE Network cluster 4 on semi-rigid pavements)

Questionnaire filled in by:

Name

Organisation

Address

Telephone

E-mail

Tables adapted from *H. Sommer et al: Überarbeiten der RVS 8.05.13 Zementstabilisierte Tragschichten, Austrian Ministry for Traffic, Innovation and Technology, Heft 520, 2002.*

Country	Austria	Belgium		Switzerland	Germany (Niedersachsen)		Spain		
Pavement layer	sub-base/base	base			sub-base		sub-base	base	
		light traffic	heavy traffic		light traffic	heavy traffic		light traffic	heavy traffic
Minimum strength c (compression) or st (splitting tensile) (days)	$R_{c7} \geq 2,5$	$R_{c90} \geq 10$ (average)	$R_{c90} \geq 10$ (single values)	$R_{c7} \geq 2\text{-}4$	$R_{c28} \sim 7$		$R_{c7} \geq 2,5$ or $R_{c28} \geq 3,8$	$R_{c7} \geq 6$ or $R_{c90} \geq 9$ $R_{st7} \geq 0,5$ or $R_{st90} \geq 0,75$	
Cement content (kg/m^3)	min. 90	min. 100		min. 60	uniform sand ~180 well-graded aggregate ~ 95		usually 100-120	usually 90-100	
Cement type	CEM II 32,5	CEM I or CEM III/A 32,5 or CEM III/A 42,5		CEM I 32,5	CEM I 32,5		CEM IV/B 32,5		
Fly ash/slag content (%)	≤ 35	≤ 65		0	0		36-55		
Plant mix prescribed	no	yes			no		no	yes	
Gradation prescribed	no	no			no		no	yes	
Crushed aggregate prescribed?	no	yes			no		no	no	yes min. 50%
Compaction (% Proctor)	min. 97			97	min. 98		100	97 mod.	
Curing	Bitumen emulsion	bitumen emulsion + sand		bitumen emulsion	keep moist		bitumen emulsion + sand		
Groove joints	no	no		no	per 2,5 m (asphalt < 14 cm)	per 5 m (asphalt > 14 cm)	no	no	since 1997
Asphalt cover (cm)	15-17 (heavy traffic)	15	17-18		≥ 12	30		12	15
CTB thickness (cm)	25-30	20	20			15 – 20	20	20	22-25
Reflective cracking	yes	often		often	none, when groove joints			often, when no groove joints	
Experience	35 years	25 years		30 years	groove joints since 1982			since 1988 300 km with groove joints	
Max. axle load (kN)	105	130		100	115		130		

Country	France			UK			Italy
Pavement layer	sub-base	base		sub-base	base		sub-base for heavy traffic
		light traffic	heavy traffic		light traffic	heavy traffic	
Minimum strength c (compression) or st (splitting tensile) (days)	$R_{st360} \geq 1,1$ ($R_{st28} \geq 0,66$)			3 classes: R_{c7} 4,5; 7 and 10	3 classes: R_{c7} 10; 15 and 20		R_{c7} 2,5 -4,5 R_{st7} 0,25
Cement content (kg/m^3)	min. 70						60 – 100
Cement type	CEM I, II or III 32,5						CEM 32,5
Fly ash/slag content (%)	≤ 80						40 FA
Plant mix prescribed	no	partly	yes	no	yes		no
Gradation prescribed	partly	yes	yes	no	yes		yes
Crushed aggregate pre-scribed?	no	partly	yes	no	yes		yes, min. 30 – 60%
Compaction (% Proctor)	95 mod.		98 mod.	min. 95			100 (mod. AASHTO)
Curing	bitumen emulsion + sand			bitumen emulsion			Bitumen emulsion
Groove joints	no	per 3 m		being investigated			no
Asphalt cover (cm)		6-8	14	0	10-15	20	20-25
CTB thickness (cm)	15-25	15-25 depending on traffic and subbase		min. 15	15 – 25 depending on traffic and CTB type		20 – 30 depending on subbase
Reflective cracking	no			yes, with no groove joints			no
Experience	25 years, 5000 km main roads, 1500 km motor-ways			25 years			20 years, 3500 km
Max. axle load (kN)	130			105			120

Country	Denmark (1968)	Sweden (ATB Väg 2003)	Netherlands
Pavement layer	base	base, heavy traffic	Base
Minimum strength c (compression) or st (splitting tensile) (days)	$R_{c7} \geq 5$	$R_{c7} \geq 9$ average on cores from base layer (E_{dim} = 17000 MPa)	asphalt granulate: $R_{c7} \geq 2{,}5$ / $R_{c28} \geq 3{,}0$ MPa sand: $R_{c28} \geq 5{,}0$ MPa in situ: $R_c \geq 1{,}5$ MPa
Cement content (kg/m^3)	90 – 120		asphalt granulate: 75 – 125 kg/m^3 sand: 100 – 200 kg/m^3
Cement type		CEM I, CEM II/A-LL	CEM II/B-V or CEM III/B
Fly ash/slag content (%)			Slag: 0 – 25 %
Plant mix prescribed	yes	no	No
Gradation prescribed	yes	yes	coarse granulates: yes sand: no
Crushed aggregate prescribed?	no	no	no
Compaction (% Proctor)	92% of max. theoretical density (no air)		asphalt granulate:≥ 98 % average ≥ 102 % sand: ≥ 95 % average ≥ 100 %
Curing	bitumen emulsion	bitumen emulsion, plastic sheets or water	bitumen emulsion + fine crushed aggregate
Groove joints	no	optional	no
Asphalt cover (cm)	12 - 16	9	12 – 20 cm
CTB thickness (cm)	18 - 21	24 (Väg 94)	12 – 25 cm
Reflective cracking	sometimes		Sometimes
Experience	30 years		asphalt granulate: 15 years sand: > 40 years
Max. axle load (kN)	115		no requirement