Economically effective revitalization of portland cement concrete pavements by asphalt layers overlay

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ABSTRACT

This paper describes experiences and results gained from common research project of Brno University of Technology and Skanska a.s., which was co-financed by Technology Agency of the Czech Republic. The purpose of this research project was to develop more effective processes and approaches in field of revitalization of the old Portland Cement Concrete (PCC) pavements by asphalt layers overlay. The main focus was concentrated on areas like optimization of PCC pavement segmentation step, development of high performance Stress Absorbing Layer (SAL) for mitigation of reflective cracking and development of methodology for asphalt layers overlay pavement design.

In this paper, there are presented results of the field tests by Falling Weight Deflectometer (FWD), results of laboratory tests of asphalt mixtures for Stress Absorbing Layer application like Wheel tracking test (EN 12697-22), Bending beam test and Relaxation test as well as a results and experiences about carrying out of experimental trail sections. In field of SAL mix design and laboratory testing, there were compared different types of high performance asphalt binders like polymer modified bitumen and crumb rubber modified bitumen.

Keywords: Bearing capacity, Crack propagation, Design of pavement, Overlays, Rubber

1. INTRODUCTION

Very often discussed topic of present in area of road structures is rehabilitation of PCC (Portland Cement Concrete) pavements at the end of their service life. Total PCC road reconstruction is very expensive operation, but there exist also alternatives which are highly cost effective compared to total replacement. One of the alternatives for cost effective rehabilitation of old PCC pavement is C&S (Crack and Seat) method with additional asphalt overlay. There is experience with this technology in many countries around the globe as well as occasionally experiences in the Czech Republic. C&S method with further asphalt overlay is based on partial retain of old PCC pavement bearing capacity and elimination of reflective cracking in asphalt overlay. However there still exist many opportunities how to optimize C&S technology with further asphalt overlay and make it more efficient from financial and technological point of view. This was also main topic of common research project of Skanska company and Brno University of Technology TA02030612 "Economical effective revitalization of Portland cement concrete pavements by asphalt layers overlay". This research project was carried out from 2012 to 2014 and co-financed by Technological Agency of the Czech Republic. The main target of this research project was optimization of processes used for C&S method with further asphalt overlay and optimization of asphalt mixture mix designs for layer with high resistance against the reflective cracking SAL (Stress Absorbing Layer).

Above mentioned research project involved below mentioned topics:

- Mix design of different types of asphalt mixtures for SAL with different types of asphalt binders. Testing and comparison of mechanical, physical and functional properties.
- Optimization of segmentation step for PCC pavements before asphalt overlay.
- Methodology of road structure design for C&S method with further asphalt layer overlay.
- Verification of designed technologies by experimental road sections.

2. MIX DESIGN AND TESTING OF ASPHALT MIXTURES FOR SAL

In first step of laboratory testing before mix design of asphalt mixture for SAL application there were carried out functional tests of different types of asphalt binders. As a significant test was chosen relaxation test in DSR (Dynamic Shear Rheometer). There were tested three different types of asphalt binders: non-modified bitumen with penetration grade 50/70, polymer modified bitumen (PmB 45/80-65) and crumb rubber modified bitumen (CRmB 25/55-65) with content of 18% crumb rubber in total binder. The temperature of the test was 50°C, shear deformation was 1% and time of loading was 10 seconds. The test results of relaxation in DSR are mentioned in figure 1 below.

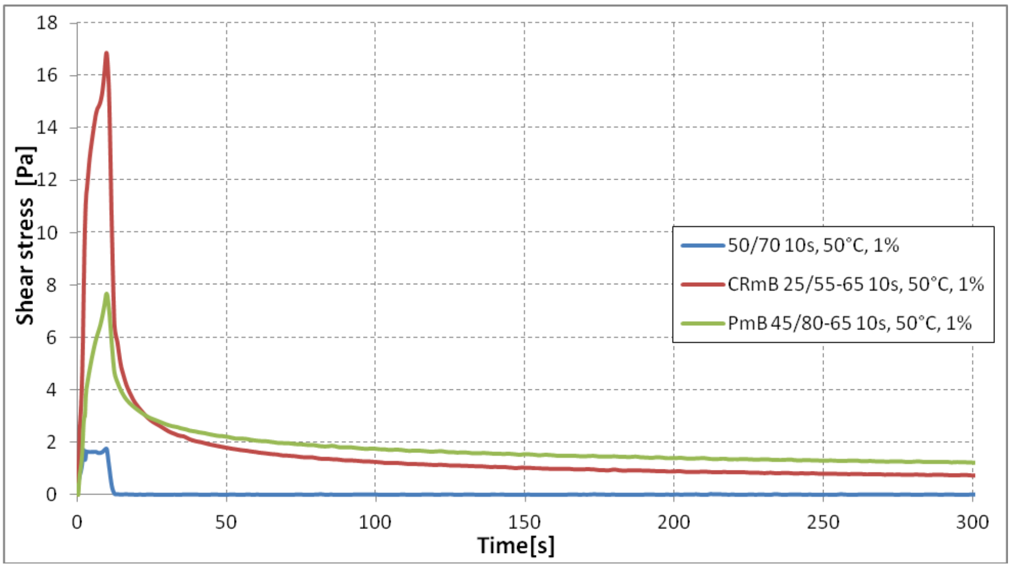

Figure 1: Relaxation of shear stress in Dynamic Shear Rheometer

Next step was mix design of asphalt mixture for SAL in several variants. There were assembled laboratory testing plan which consist of below mentioned tests:

- Rutting test according to ČSN EN 12697-22
- Bending beam test
- Relaxation test

Subsequently there were created several mix designs of asphalt mixtures for SAL. On these asphalt mixtures were tested above mentioned properties. There were used two different types of asphalt binders modified by crumb rubber CRmB-AR (Crumb Rubber modified Bitumen – Asphalt Rubber type), CRmB-TB (Crumb Rubber modified Bitumen – Terminal Blend type) and two types of polymer modified bitumen. In case of PmB, the mix design was performed in accordance with technical specification of Czech Ministry of Transportation TP 147 [6]. In case of CRmB were taken into account experiences and recommendations used for similar application in USA Arizona [3, 4] and technical specification of Czech Ministry of Transportation TP 148 [7]. Used requirements for CRmB are mentioned in table 1 below.

Table 1: Requirement for crumb rubber modified bitumen CRmB

Type of binder	**CRmB-AR**	**CRmB-TB**
Quantity of crumb rubber in total binder (% of weight)	15-20	5-15
Viscosity ČSN EN 13302	1,5 – 4,0 (temperature of measurement 175°C)	0,5-2,0 [1)] (temperature of measurement 160°C)
Penetration 25°C ČSN EN 1426	25-75	25-75
Softening point ČSN EN 1427	min. 60	min. 55
Resilience 25°C ČSN EN 13880-3	min. 20	min. 15

[1)] Recommended range for viscosity. If is viscosity of CRmB-TB different from this recommendation, the producer of the binder have to provide oven viscosity requirements, which have to be verified by verification test.

In table 2 there are mentioned results of rutting test according to ČSN EN 12697-22. The temperature of testing was for asphalt mixtures with CRmB 50°C, because there were considerations about usage of SAL with this type of bitumen for binder course, which is the same way how is this type of asphalt rubber mixture used in some states of USA for PCC pavement rehabilitation without previous segmentation. For asphalt mixtures with PmB was temperature of testing in accordance with technical specification of Czech Ministry of Transportation TP 147 [6] which is 40°C.

Table 2: Rutting test results – ČSN EN 12697-22

Number of asphalt mixture	Type of asphalt mixture	Asphalt binder content B (% weight)	Temperature (°C)	WTS_{AIR} [1)] (mm/10^3 cycles)	PRD_{AIR} [2)] (%)
1	SAL CRmB-TB 25/55-65	11,0	50	0,15	8,5
2	SAL CRmB-AR 25/55-65	11,0	50	0,03	3,1
3	SAL CRmB-AR 25/55-65(variant 1)	9,0	50	0,04	3,5
4	SAL CRmB-AR 25/55-65 (variant 2)	9,0	50	0,04	2,1
5	SAL PmB 45/80-65 (variant 1)	7,5	40	0,01	3,1
6	SAL PmB 45/80-65 (variant 2)	7,6	40	0,03	3,0
7	SAL PmB 40/100-65	7,6	40	0,05	2,0

[1)] Wheel tracking slope
[2)] Proportional rut depth

In table 3 there are mentioned results of bending beam test and relaxation test. Dimensions of the asphalt samples for these tests were 40 x 40 x 160 mm. The temperature of testing was 0°C. The distance between supports was 100 mm. The bending force was situated in the middle of the beam.
During the bending beam test there was measured maximum tensile strength. During the relaxation test the sample was preloaded by 2/3 of maximal bending force from bending beam test and there were measured decrease of tension in time. As a crucial values for relaxation test were established values of residual tension stress after 18 and 120 seconds according to [13].

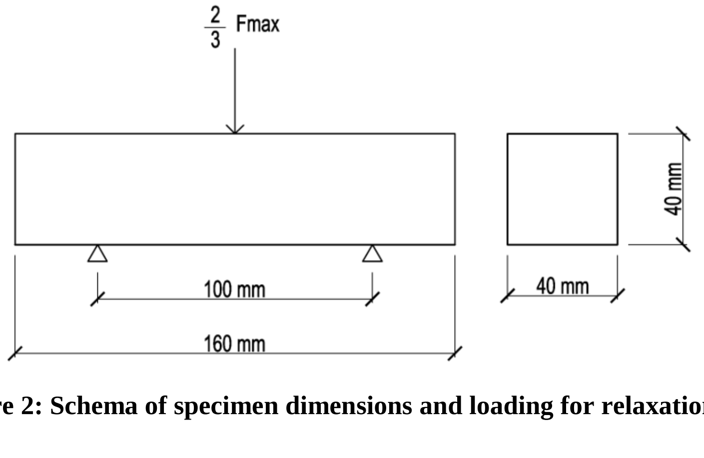

Figure 2: Schema of specimen dimensions and loading for relaxation test

Table 3: Bending beam test and relaxation test results

Number of asphalt mixture	Type of asphalt mixture	Asphalt binder content B (% weight)	R_i (MPa) [1)]	Residual stress σ_{18} (%)	Residual stress σ_{120} (%)
1	SAL CRmB-TB 25/55-65	11,0	8,4	57,6	29,0
2	SAL CRmB-AR 25/55-65	11,0	10,1	63,4	34,2
3	SAL CRmB-AR 25/55-65(variant 1)	9,0	10,3	65,8	33,9
4	SAL CRmB-AR 25/55-65 (variant 2)	9,0	8,1	48,4	25,2
5	SAL PmB 45/80-65 (variant 1)	7,5	5,4	31,0	15,0
6	SAL PmB 45/80-65 (variant 2)	7,6	7,4	54,2	28,6
7	SAL PmB 40/100-65	7,6	5,9	50,7	23,0
[1)] Maximum tensile strength measured during the bending beam test					

On the bases of above mentioned results asphalt mixtures number 4 and 5 were chosen for experimental road section realization. In figure 3 and 4 are shown full relaxation curves for these two asphalt mixtures.

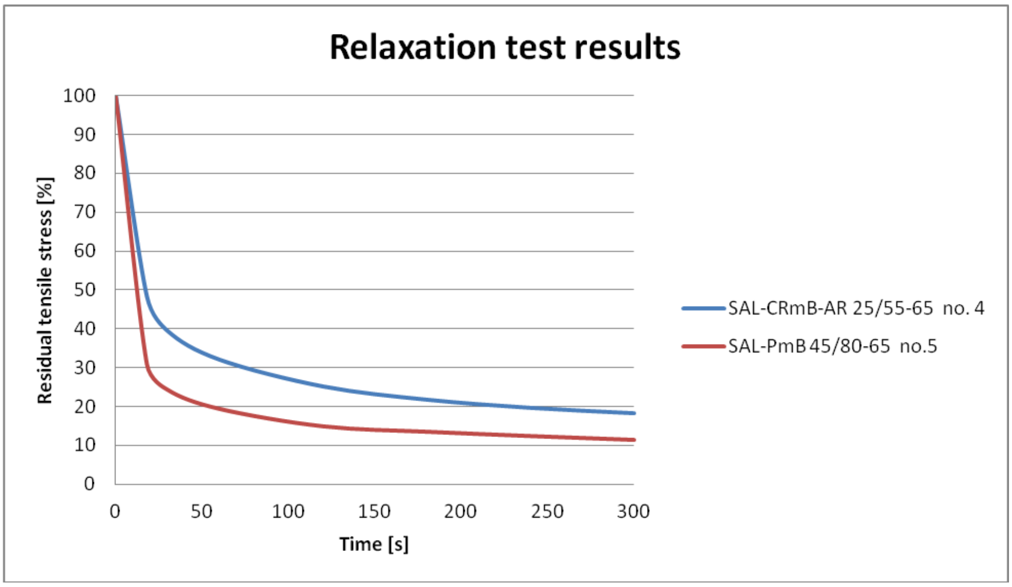

Figure 3: Relaxation curves of asphalt mixtures selected for experimental road section – residual stress (%)

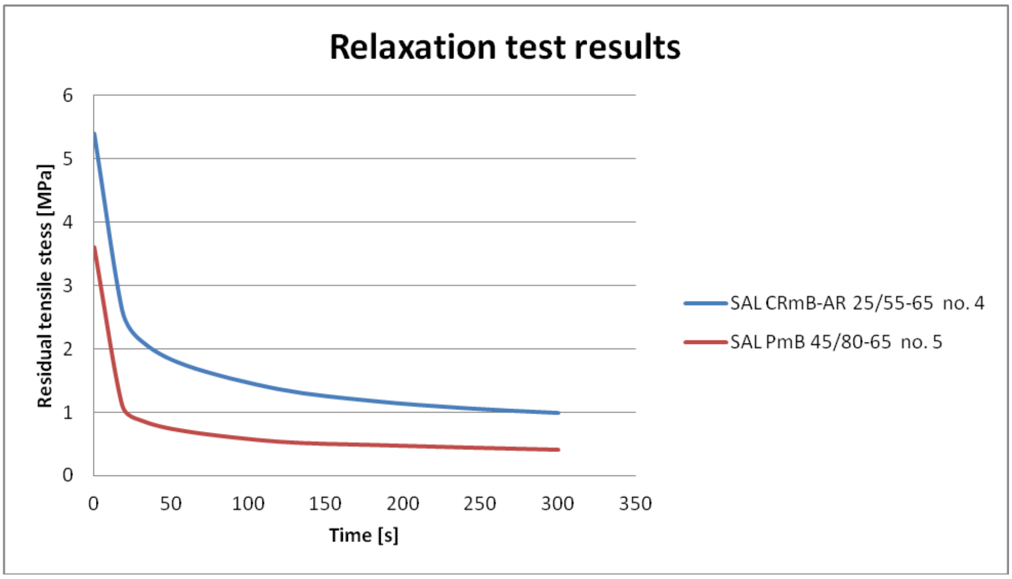

Figure 4: Relaxation curves of asphalt mixtures selected for experimental road section – residual stress (MPa)

If we compare relaxation curves of asphalt mixtures shown in figure 3 and 4, there is visible that percentage reduction of tensile stress is faster in PmB case, but from curves of tensile stress reduction in MPa absolute numbers is visible that in case of CRmB-AR binder was achieved 50% higher maximal tensile strength during bending beam test.

3. OPTIMIZATION OF C&S METHOD FOR PCC PAVEMENTS

Optimization of segment sizing was another major item of research project TA02030612. Pavement testing methodology was developed to reach this goal. It is described below.
The goal of the methodology is to find out an optimal step for slab segmentation which is followed by asphalt overlaying. The methodology was designed for plain PCC pavement without dowels and anchors and with use of simple segment guillotine. The methodology may be used also for other types of pavements after initial testing examination.

A) Evaluation of bearing capacity variability of pavement intended for C&S

FWD (Falling Weight Deflectometer) measurement is carried out at the entire site length/area with step between adjacent measured points of 100m. Pavement testing is always carried out at center of slab. Evaluation is focused to calculation of general pavement strength where parameters e.g. surface modulus E_0, ISM (Impulse Stiffness Modulus), etc. Used measuring device (deflectometer) must hold valid certificate issued by the Czech Ministry of Transportation.

As tested pavements are due their rigid surface layer obviously much stronger than standard asphalt pavements, used FWD must be able to induce load higher than 50kN. Based on the national standard ČSN 736192 [9] it is necessary to reach at least deflection of 200 µm at sensor under loading plate and 20 µm at sensor positioned 1800mm or further from the centre of loading plate.

Notes:
Above mentioned deflections at PCC pavements are usually reached with applied forces in range of 100-150kN. Pulse time must be within a range of 25-30ms.

B) Choice of a representative homogenous section

FWD measurement must be carried out directly on PCC surface. In case of previous asphalt overlay it is necessary to mill the overlay out. Pavement section chosen for the experiment must show high level of bearing capacity and homogeneity before test initialization (as shown in figure 5).
Selection of the pavement section is done based on the FWD measurement carried out with step of 100m alternatively in two pavement lanes. The FWD testing is carried out at slab centers and on slab joints as well. The experiment may not be carried out close to bridges (30m), on cracked slabs or other objects having bad influence on pavement stiffness homogeneity. The testing must be carried out at minimum number of adjacent slabs which enables statistic evaluation and impact of the segmentation on original pavement. Recommended minimum number of adjacent slabs is 17.

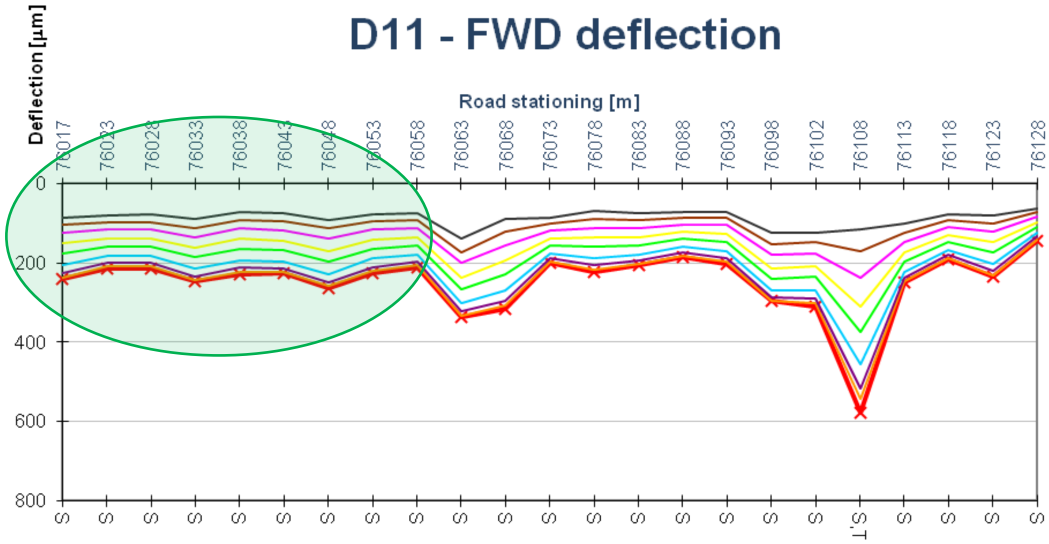

Figure 5: Selection of homogenous section for segmentation experiment

Coefficient of variation taken from ISM/E_o for selected homogenous section must be equal or less than 15%. In case the pavement has different structures in different road lanes, the homogeneity must be evaluated separately for each road lane. The entire homogenous section is split into separate links/subsections including at least three consequential PCC slabs. Each subsection is tested with different segmentation step. For case where three subsections are in scope it is recommended to split the homogenous section as follows:

- Three slabs without segmentation are used as approaching section.
- Subsection „A“ is created with three consequential slabs. Segmentation is carried out with „A“ segmentation step (for example 400 mm).
- At least one slab where no segmentation is carried out must divide two adjacent subsections „A“ and „B“.
- Subsection „B“ is created with three consequential slabs. Segmentation is carried out with „B“ segmentation step (for example 800 mm).
- At least one slab where no segmentation is carried out must divide two adjacent subsections „B“ and „C“
- Subsection „C“ is created with three consequential slabs. Segmentation is carried out with „C“ segmentation step (for example 1200 mm).
- Three slabs without segmentation are used as departure section.

The segmentation step means longitudinal distance between two adjacent guillotine impacts. For PCC pavement segmentation is used special equipment called drop hammer, which generate breaking energy by raising and dropping their hammer onto the pavement. The example of this equipment is shown in figure 6.

Figure 6: Drop hammer – machine for PCC pavement segmentation

C) Experiment for optimization of segmentation step

Bearing capacity measurement serves as a tool for segmentation step decision. Pavement testing must be carried out under conditions allowed and stated in national standard [9].

Phase 1

Detail FWD measurement prior pavement segmentation is carried out with spacing of loading plate at slab centers. When three subsections are in scope, nine slabs have to be tested. Readings from all FWD sensors are taken and stored.

Phase 2

Segmentation is carried out. It must be emphasized that slabs may not contain dowels and anchors. Segment size may be within a range of 400-2000 mm. Compaction of segmented pavement is carried out by heavy rubber-tire compactor. Mass of compactor should be 22 tons or higher.

Phase 3

Detail FWD measurement is carried out after pavement segmentation and compaction.

- General conditions - Loading plate may not be laid on two segment boundary.
- Measurement carried out at small pavement segments - For segments with side length of 400mm each second segment is recommended to measure. Circular loading plate with radius of 300mm is laid on segment centre. For segments with side length beyond 400mm each segment may be tested.

D) Evaluation of experiment for optimization of segmentation step
Optimum segmentation step is designed after completing the whole experiment. Statistic evaluation of dependence between segment size and reduction of general pavement stiffness e.g. ISM or E_o serves as a decision tool. Desired modulus of elasticity required for segmented PCC layer can serve as another decision tool. The modulus of elasticity should be within a range of 3500-7000MPa.

4. ASPHALT OVERLAY DESIGN FOR PCC PAVEMENTS

Asphalt overlay design for PCC pavements is based on effective thickness calculation according to Asphalt Overlays for Highway and Street Rehabilitation – Asphalt Institute MS 17 [1]. This overlay pavement design method is based on model of multi-layered half-space and this method is applicable for rigid pavements as well as for flexible pavements. In case of usage of this method for asphalt overlay of old PCC pavement is necessary to take in to account facts like transversal joints, longitudinal joints and pumping slabs.
This pavement structure design method is based on expectation that all types of road structures deteriorate their properties in relation to traffic load and weather conditions. There is expected behavior like road structure layers have lower thickness in time (reduction of effective thickness in time). The thicknesses of all layers in pavement structure are converted on equivalent thicknesses of asphalt layers by coefficients according to material and type of the layer. Thickness of asphalt overlay is difference between thickness of pavement layers designed for particular traffic load and time period and calculate equivalent thickness current road structure before rehabilitation.

$$\mathbf{T_e = \sum T_i\, C_i} \qquad \text{(Equation 1) [1]}$$

T_e = effective thickness
T_i = real thickness of particular layers
C_i = conversion factor depending on type of layer and level of deterioration

$$\mathbf{T_o = T_n - T_e} \qquad \text{(Equation 2) [1]}$$

T_o = thickness of overlay
T_n = total thickness of pavement after overlay designed for particular traffic load and time period

Example of overlay thickness calculation
This calculation was carried out for pavement structure on D11 highway in the Czech Republic. Design traffic load was taken from 2010 traffic census.
Recalculation on single axle load 100 kN was performed according to technical specification of Czech Ministry of transportation TP 170 [8]. Design period was calculated 25 years and design number of 100 kN single axle passes was calculated 43 169 006.
Recalculation of traffic load from 100 kN axles on equivalent 80 kN axles (ESAL) used in USA was carried out according to equation 3.

$$\mathbf{ESAL = \left(\frac{100\ t}{80\ t}\right)^4 \times Ncd} \qquad \text{(Equation 3)}$$

ESAL = equivalent single axle load 80 kN per design period
N_{cd} = number of single axle 100 kN passes per design period

T_n was taken from graph in figure 7 below according to subgrade stiffness modulus M_R and according to expected ESAL traffic load. For this pavement structure design was taken in to account subgrade stiffness modulus $M_R \approx 50$ MPa (measured by FWD).

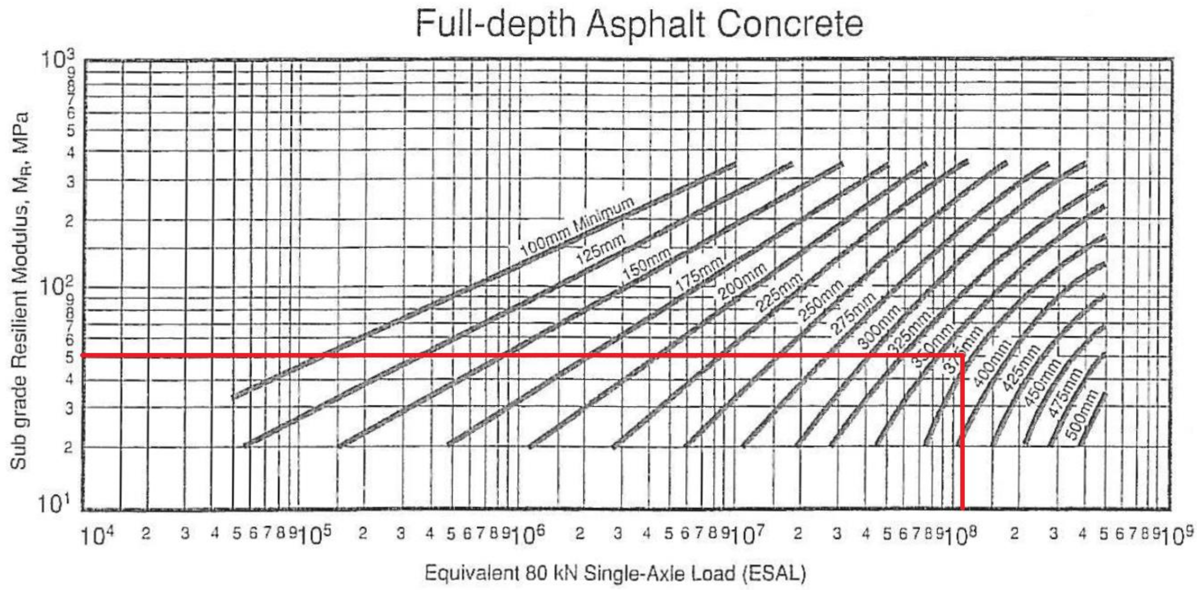

Figure 7: Quantification of total pavement thickness based on number of equivalent single axle load and subgrade stiffness modulus [1]

Total pavement thickness after asphalt overlay → T_n = 370 mm

Calculation of effective thicknesses for particular layers in pavement structure – highway D11:

T_e (Portland cement concrete)	= 240 mm * 0,7	= 168 mm (after segmentation)
T_e (asphalt concrete)	= 40 mm * 0,5	= 20 mm
T_e (hydraulic stabilized gravel)	= 150 mm * 0,4	= 60 mm
T_e (gravel)	= 150 mm * 0,1	= 15 mm
$\sum T_e$ (total effective thickness)		= 263 mm

T_o = 370 mm – 263 mm = **107 mm**

Asphalt overlay of segmented and settled PCC pavement was figured out according to above mentioned calculation on 107 mm.

Possible road structure for asphalt overlay on highway D11 project could be for example:

Stress absorbing layer	SAL 8	25 mm
Asphalt concrete	AC 22	60 mm
Stone mastic asphalt	SMA 11	40 mm

Additional factors influencing overlay design:
There have to be taken in to account below mentioned factors, during the PCC pavement asphalt overlay:

- Actual surface conditions.
- Slabs movement in vertical and horizontal direction.
- Soil properties in the subgrade.
- Drainage and changes of vertical alignment.
- Some of the properties in above mentioned pavement structure design are calculated by C_i coefficient. This coefficient is established from certain interval on bases like type and conditions of pavement structure layer etc.

5. EXPERIMENTAL ROAD SECTION REALIZATION

As a part of research project TA02030612 Skanska company carried out two experimental road sections based on methodology described above in this paper. First of these experimental road sections was performed in 2013. There was used stress absorbing layer SAL with crumb rubber modified asphalt binder CRmB 25/55-60. Second of these experimental road sections was performed in 2014. There was used stress absorbing layer SAL with polymer modified bitumen PmB 45/80-65. The asphalt mixtures for stress absorbing layers SAL used on experimental road sections were chosen on bases of mechanical and functional testing described in chapter 2 of this paper.

Schedule of jobsite works:

1. Bearing capacity measurement of old PCC pavement by FWD. Optimization of segmentation step (chapter 3 of this paper).
2. PCC pavement segmentation in accordance with optimization of segmentation step.
3. Verification of bearing capacity after segmentation.
4. Tack coat spraying – modified asphalt emulsion.
5. SAL paving. Thickness of SAL was 30 mm.
6. Tack coat spraying – modified asphalt emulsion.
7. Asphalt concrete AC 22 paving. There was used variable thickness of AC 22 binder course for requested change of road transverse slope. Thickness of binder course was in range from 70 to 120 mm.
8. Tack coat spraying – modified asphalt emulsion.
9. Stone mastic asphalt SMA 11 paving. Thickness of SMA 11 was 40 mm.

There are mentioned basic technical information about asphalt overlay on D11 highway project in tables 4 and 5 below.

Table 4: General technical information about PCC pavement asphalt overlay – D11 km 24,385 – km 25,568

Asphalt layer		**Thickness**
Type of asphalt mixture	**Type of used asphalt bitumen**	
SMA 11	PmB 45/80-65	40 mm
AC 22	PmB 25/55-65	70 – 120 mm
ARC-SAL 8 [1)]	CRmB 25/55-65	30 mm

[1)] Asphalt rubber concrete – stress absorbing layer with maximal size of mineral aggregate 8 mm. Mixture was developed during research project TA02030612 (mixture no. 4 – chapter 2 of this paper).

Table 5: General technical information about PCC pavement asphalt overlay – D11 km 10,915 – km 13,500

Asphalt layer		**Thickness**
Type of asphalt mixture	**Type of used asphalt bitumen**	
SMA 11	PmB 45/80-65	40 mm
AC 22	PmB 25/55-65	70 – 120 mm
SAL 8 [1)]	PmB 45/80-65	30 mm

[1)] Stress absorbing layer with maximal size of mineral aggregate 8 mm. Mixture was developed during research project TA02030612 (mixture no. 5 – chapter 2 of this paper).

All asphalt mixtures used for above mentioned experimental road sections were produced on Ammann Uniglobe stationary asphalt batch plant by Skanska company. Asphalt rubber binder used for ARC-SAL 8 was produced on asphalt plant in special asphalt-rubber blending equipment in cooperation with G-Asfal company.

In table 6 are mentioned basic properties of used asphalt mixtures and layers for SAL application on described experimental road sections.

Table 6: General properties of used asphalt mixtures and layers for SAL application on D11 project

Asphalt mixture	**ARC-SAL 8**	**SAL 8**
Type of bitumen	CRmB 25/50-65	PmB 45/65-65
Bitumen content (% of weight)	9,0	7,5
Bulk specific gravity ρ_{bssd} ($Mg.m^{-3}$)	2,413	2,444
Maximal specific gravity ρ_{mv} ($Mg.m^{-3}$)	2,492	2,496
Air voids content V_m (% of volume)	3,2	2,1
Rutting PRD_{AIR} (%)	2,1 [1)]	3,1 [2)]
Rutting WTS_{AIR} (mm/10^3 cycles)	0,04 [1)]	0,01 [2)]
Bending beam strength R_i (%)	8,1	5,7
Relaxation test – residual tensile stress σ_{18} [3)] (%)	48,4	31,0
Relaxation test – residual tensile stress σ_{120} [4)] (%)	25,2	15,0
Air voids content in layer (% of volume)	2,2 – 3,9	1,4 – 2,7

[1)] Temperature of rutting test was 50°C.
[2)] Temperature of rutting test was 40°C.
[3)] Residual tensile stress after 18 seconds.
[4)] Residual tensile stress after 120 seconds.

After two/one years the performance of above mentioned experimental road sections is without any reflective cracking propagation. The experimental road sections will be observed and evaluated continuously in the future, which will provide necessary information for more complex evaluation of tested technologies.

6. FINANCIAL BENEFITS OF PCC PEVEMNT REHABILITATION BY C&S METHOD WITH ADDITIONAL ASPHALT OVERLAY

Evaluation of financial benefits is crucial for assessment of various technologies. Therefore estimation of financial benefits was a part of total evaluation of experimental road sections on D11 highway described in chapter 5 of this paper. Based on the results of initial FWD measurement carried out on PCC pavement before segmentation, there were assessed below mentioned variants of PCC pavement rehabilitation/reconstruction.

- Variant 1 – replacement existing old PCC pavement with new PCC pavement.
- Variant 2 – replacement existing old PCC pavement with new asphalt pavement.
- Variant 3 – PCC pavement rehabilitation by C&S method with additional asphalt overlay as described in chapter 5 of this paper.
- Variant 4 - PCC pavement rehabilitation by C&S method with additional asphalt overlay as calculated in chapter 4 of this paper (optimized road structure overlay design).

Results of above mentioned variants comparison are shown in figure 8.

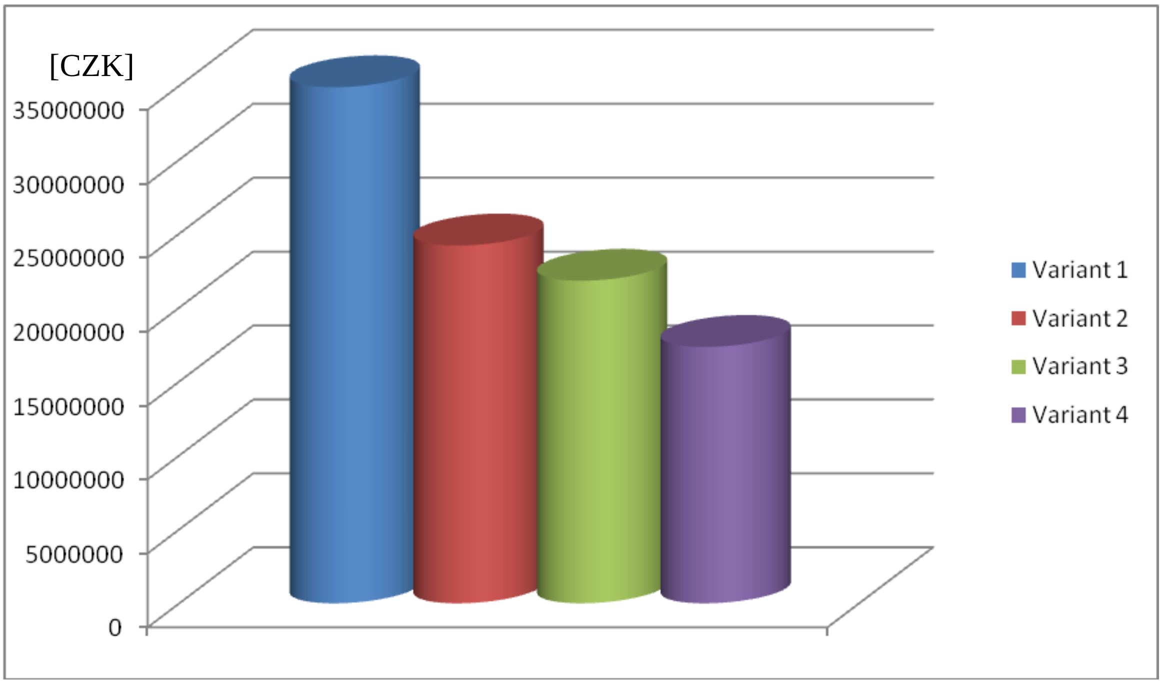

Figure 8: Comparison of estimated costs including rehabilitation and maintenance for design period 25 years – D11 highway experimental road section 10 000 m^2 [12]

7. CONCLUSION

Within research project TA02030612 "Economical effective revitalization of Portland cement concrete pavements by asphalt layers overlay" there were achieved below mentioned goals:

- Laboratory verification of particular functional properties for different SAL mix-designs with different types of asphalt binders (PmB, CRmB-AR, CRmB-TB).
- Development and verification of methodology for PCC pavement segmentation (C&S method) under practical conditions on jobsite.
- Verification of road structure design for PCC pavement asphalt overlay with usage of C&S method.
- Realization of two experimental road sections with usage of two different types of asphalt mixtures for SAL application.

Based on the results of performed research project there is possible to announce, that C&S method with additional asphalt overlay can be very effective approach for PCC pavement rehabilitation, but there is very important to evaluate suitability of this technology for each particular case. Correct usage of this technology could have positive financial effect, but both described experimental road sections need to be observed and monitored in the future, to verified final durability and financial benefits.

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