New opportunities in performance based contracts

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Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.063

ABSTRACT

In the Netherlands clients were used to define fixed specifications for road works. The requirements are shifting into functional specifications where the contractor is free to design and select materials provided that the pavement construction is able to bear the traffic loads for the design period. Only the asphalt top layer is specified by acoustic properties. Clients validate the process with verifications instead of supervision at site.

Because the contractor is now responsible for the long term maintenance, 20 to 25 years instead of the standard periods (5,7 or 10 years) a higher quality level has to be reached. Thus, the contractor is triggered to design in terms of life-cycle because too much maintenance leads to high lane rental costs. There is more opportunity for design optimizations which reduces costs and/or lead to less risks in the life-cycle. However, too large discrepancies in the as-built situation leads to unexpected maintenance which results in high lane rental costs. This causes the need for new measuring methods and control systems. Expert knowledge is therefore required. The pavement consultant was used to have a minor role and was often characterized as Gyro Gearloose. Nowadays comparison with Steven Spielberg suits more. The pavement consultant has a greater role in the DBFM-contract and is more challenged on his skills.

The consultant is not only involved in the calculation of the pavement construction, but also with the verification of design specifications, optimization of the geometrical design, converting system requirements into specifications for construction and above all predict the impact of shortcomings in construction on the maintenance of the pavement construction. The new role of the pavement consultant will be demonstrated with experiences of the DBFM-contract "the widening of motorway A15 Maasvlakte-Vaanplein", the most heavy-duty motorway in the Netherlands.

Keywords: Asphalt, Design-Build-Finance-Operate, Heavy-duty pavements, Maintenance, Quality assurance

1. INTRODUCTION

The pavement consultant in the Netherlands used to work for the road authorities and engineering firms. The main activities of the pavement consultant consisted of delivering technical reports: review literature, calculations pavement constructions and contract specifications. The pavement constructions were used as input for the geometric roads design, but the pavement consultant wasn’t directly involved in the process of optimization. The pavement design was handled by the project leaders and road designers. During execution the pavement consultant examined alternatives that reduced costs or led to a shorter execution period. At the end of the execution stage the consultant supported the quality control in situations when shortcomings occurred.
In most cases the pavement consultant was asked to participate shortly based on his expertise in a supporting role. This was suitable in the classic way of Dutch contracts, where the principal provided the design and wrote the contract and alternatives were not allowed. This traditional way of contracting disappeared in the last couple of years for the large road building projects at motorways.

Nowadays performance based contracts are used like

- Design and Construct (D&C)
- Design, Build and Maintain (DBM)
- Design, Build, Finance and Maintain (DBFM).

In these type of contracts the principal makes a functional specification of the desired product. The contractor provides the design, execution and maintenance and in some case even finances the project. It challenges the contractor to take decisions based on lifecycle. Because the contractor is now responsible for the long-term maintenance, 20 to 25 years, quality has become more important. For each choice in design and execution consequences for the long term must be taken into account. By thinking in maintenance strategies in the design stage decisions are made which initially seem more expensive but in the long term become cheaper or lead to less risks.

In the last years it is to be seen that the pavement consultant directly works for the contractor. Because of his expertise he is asked to participate in the tender stage and for projects in execution. In between the classic roles like executioners, planning engineers and project managers the consultant has a new role. The consultant distinguishes himself by his theoretical expertise and was often seen as the “mad scientist”. The consultant thinks in theoretical models and mechanistic properties like stiffness modulus and fatigue instead of numbers of tonnes asphalt to be produced and applied.

The pavement consultant is now asked to do also other activities like:

- determination of risk-benefit balance
- verification of the pavement design
- optimizing the geometrical road model
- translating the functional specification into an execution specification
- investigation of consequences when shortcomings occur

The new role of the pavement consultant will be illustrated by the experiences gained on the project “Motorway A15 Maasvlakte-Vaanplein”.

2. DESCRIPTION PROJECT

The most important arterial road in the port and industrial area of Rotterdam, motorway A15, has been widened in the period 2011-2015. The goal of the widening was to achieve less traffic jams and to have better traffic flow.
In the new situation the road network is transformed into main and parallel roads between Vaanplein and the intersection with the motorway N218, exit number 15 in Figure 1. Between the motorway N218 and the intersection with motorway N57 the existing roads have been widened. The existing provincial road between the intersection with the N57 and the Maasvlakte (exit 8 in Figure 1has been turned into a national highway.

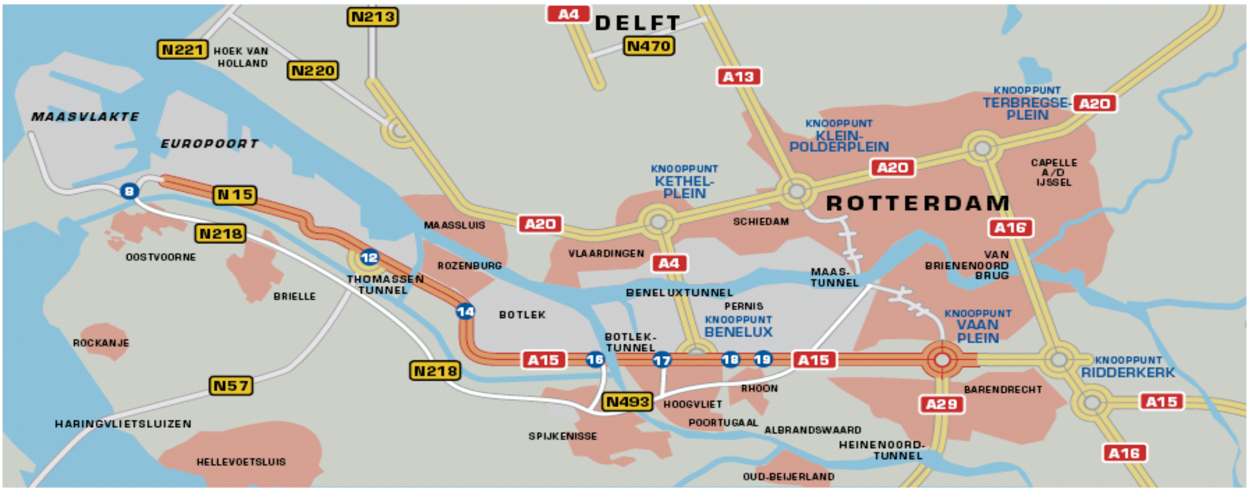

Figure 1 Map of the project

It is the goal of the Dutch Road Authority (Rijkswaterstaat) to finish the execution of the 37 km long road stretch in association with the consortium A-lanes-A15 by the end of the year 2015. A-lanes-A15 – a cooperation of Ballast Nedam, John Laing, Strabag and Strukton – has been responsible for the design, build, finance and maintain of the motorway.

The contract consists of a payment scheme which has been based on the availability of the road. In the design and execution stage there are several milestones where specific road stretches have to be finished and made available for traffic. When a milestone was reached in the project, the Dutch Road Authority issued a certificate of availability and approved the payment. For A-lanes-A15 it was very important to reach the milestones, because their financial model had been based on these payments. The loan was carefully tuned on the moments of payment to reduce the interest costs. The financial incentive is also present in the maintenance stage by the use of lane rental costs. In the tender stage A-Lanes A15 delivered maintenance plans including the expected reduction of availability during maintenance. When it will appear that during the maintenance stage the plan is not complied resulting in unplanned loss of availability, the Dutch Road Authority will reduce the payment.

3. SYSTEMS ENGINEERING

It is not sufficient anymore to just open the road for traffic, also the process has to be controlled carefully. In each project phase the contract requirements have to be compliant by using Systems Engineering. The DBFM-contract consists of functional specifications. The functional specifications have been decomposed in requirements which can be verified transparently. The decomposition was performed in the different design phases and continued in the construction phase. The requirements for design and maintenance were converted into construction requirements. This conversion has been done in two ways: defining requirements from the design reports and the determination of material specifications. For example from the design point of view it might be necessary to define the work method during construction to assure the interface with other disciplines. The material specifications are based on guidelines and norms in which clearly has been defined how the quality properties will be measured and controlled. In the pavement design specifications have been prepared for several aspects like:

- the repair of cracking in the milled surface
- the water impermeability of asphalt layers on concrete bridges
- sufficient initial skid resistance of porous top layers

In the requirements test methods have been defined together with the corresponding limits. Subsequently, the construction team incorporated the requirements in the quality control plan.

4. DESIGN ACTIVITIES

The task of the pavement consultant in the design phase in general can be divided in two parts: overlay design of the existing asphalt pavement and the dimensioning of the new constructions. The next sections describe which activities have been performed.

4.1 Overlay design existing asphalt pavement

The goal of the overlay design (redesign) is to determine the sections where the asphalt pavement construction has no more residual life and has to be overlaid with extra asphalt thickness. The pavement consultant determines the structural condition of the pavement construction by analysis of cores of the pavement construction, visual inspections and Falling Weight Deflection (FWD) measurements. In the tender phase the Dutch Road Authority supplied research data of the asphalt pavement. FWD data of somewhat 100 sections and the construction build-up of more than 1.300 asphalt cores have been collected in the GIS (Geographic Information System) viewer. The GIS viewer is an appropriate aid to present a large amount of data of different kind for this large project (2 x 37 km length). It is remarked that the asphalt pavement on the Motorway A15 is relatively young. The cores showed not much difference in the materials of the construction build-up. The subgrade near the Maasvlakte (25 km) consisted of sand fill applied in layers of several meters thickness. The deeper subgrade near Vaanplein (12 km) consisted of soft subsoil layers which in the past often led to differential settlements. Due to the frequent profiling measurements in the past 40 years the asphalt pavement thickness showed a lot of variation. At some locations asphalt thickness of 1,80 m has been found directly on the sand bed. Some extra FWD measurements have been carried out in 2011 as verification on critical spots and because some sections were not measured in the tender documents. Subsequently, the overlay design was carried out with the software program CARE 2.20.

4.2 Dimensioning asphalt pavement and selection materials

For dimensioning the number of the traffic loads and the material properties are crucial parameters. The most important parameters are the axle loads and the volume of the truck traffic. From the supplied tender information about traffic models in future and axle load distributions it was determined that in average 15,000 to 25,000 trucks per day are expected. It appeared that also in the future the motorway 15 from Maasvlakte to Vaanplein still will be one of the heaviest loaded motorways in the Netherlands.

For the new to be built constructions the stiffness modulus of the subgrade was determined from performed investigations in the tender and the experience of the involved parties. The base layer and the type of asphalt mixes were determined by means of risk-benefit balance, the so-called Trade Off Matrix. The Trade Off Matrix is presented as a table for assessment and selection of materials and constructions. At a single glance it can be seen how the different materials perform for specific applications. Important criterions to be discussed are quality, price, workability, risks and maintenance. An example is illustrated in figure 4. Regarding to maintenance is referred to which extent the necessary maintenance, the type of measurement and the repair time for a period of 20 years can be predicted.

Base layer

Finally two types of base materials have been applied: hydraulic mixed granular and cement bound asphalt granular (AGRAC). The AGRAC has been applied on a homogeneous and bearing subbase in the section where minimum differential settlements were to be expected. The AGRAC was produced according to the mix-in-plant method near the location to be applied. The advantage of the mix-in-plant method is that better mixing quality is achieved by continuous supply of cement which leads to less variation in the properties as compressive strength. This results in the AGRAC which needs less cement (1-2 m/m %) thus lower costs. Another advantage is that the risk of uncontrolled cracking is reduced. Due to hardening of AGRAC the time schedule of the execution had to be adjusted. Therefore it was decided to apply the first asphalt layer within 24 hours after construction of the AGRAC. This had been done because of the logistic process and minimum disturbance of the hardening of the cement bound base.

Asphalt mix base layer

Based on the Trade Off Matrix and several investigations it was decided to divide the cross section of the road into lanes for heavy loaded and light loaded traffic. In the heavy loaded lanes asphalt mixes with high stability and less variation in mix composition are applied in order to achieve less variation in execution tolerance. Main goal is to prevent premature failure of the pavement construction. For dimensioning the material properties for stiffness and fatigue were determined from the Type Test of the several mixes.

For the base asphalt layer AC Base OL-IB (highest quality level) had been applied with 50% reclaimed asphalt and conventional bitumen. On the light loaded lanes and emergency lane the EcoSTAB mix was applied as base layer. EcoSTAB is a sand skeleton mix with 50% eco granular[1] material and 50% reclaimed asphalt. The binder on the mentioned lanes was a conventional sand skeleton mix with conventional bitumen.

Asphalt mix binder layer

Regarding the high fees for extra maintenance the board asked the design team to assure that at any cost the binder may not fail before the top layer. It was decided to perform extra research and to consult the pavement consultants of the Dutch and German contractors. Looking to the high volume of truck traffic on motorway A15 and the pumping effect of water through the porous asphalt top layer for the binder high rutting resistance and low sensitivity to water were pointed as crucial. Thus, the main requirements for the binder were put on at higher level than the Dutch RAW Guideline. Adjusted criteria were determined for the air voids (design maximum 5%), the sensitivity to water (ITSR≥90%) and the resistance to rutting ($f_c \leq 0,1$).

Reference for the binder was the standard binder layer AC Bind TLZ-C, which stands for sand skeleton mix with conventional 70/100-bitumen. In Germany for this type of heavy duty loaded lanes it was common practice to use

[1] Eco granular material is the clean aggregate after removing tar in the incinerator from asphalt granular containing tar

modified bitumen in the binder. Therefore in the research also was looked to the influence SBS polymer-modified bitumen. In the research triaxial tests and Rolling Bottle Tests have been performed. The Rolling Bottle Test (NEN-EN-12697-11) gives information about the adhesion between coarse aggregate and bitumen. In this research two types coarse aggregate (Morene and Bestone) together with conventional and polymer-modified (SBS) bitumen have been tested. The coarse aggregate is covered with bitumen and water-immersed in a bottle. During some hours the aggregate will be shaken ("rolling bottle") in the test set-up. At the end of the test the coverage of the aggregate is visual examined. In common there is no evaluation criterion for the bitumen coverage of the aggregate. However, from the experience of Strabag it was known that in some federal states of Germany the bitumen coverage of the aggregate should be at least 60% after 24 hours of rolling time.

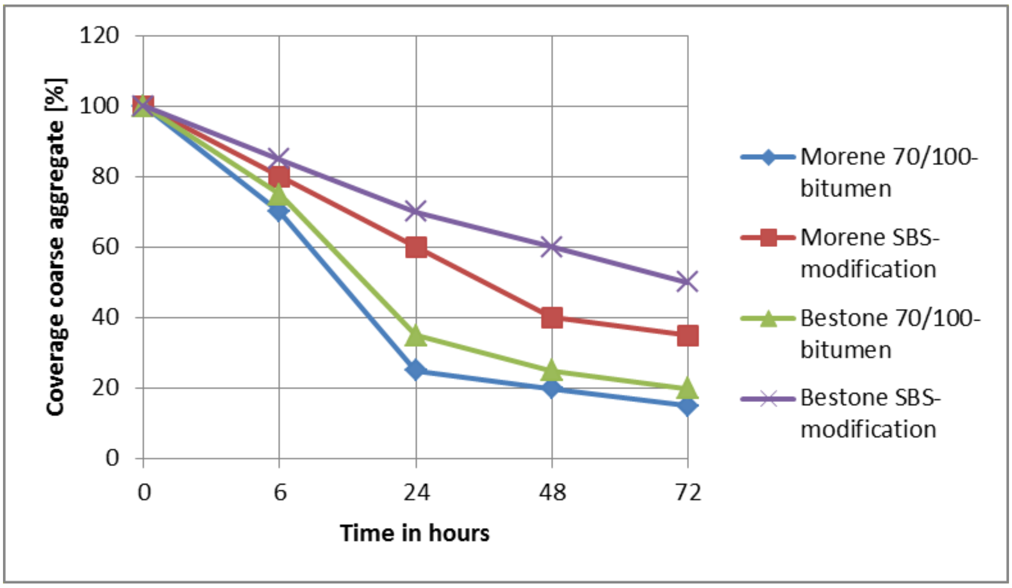

Figure 2 Results Rolling Bottle Test

Figure 3 Bestone with 70/100-bitumen after 24 hours Rolling Bottle Test

For the selection of the asphalt base layer the main criterion was variation of the asphalt mix during production and construction. In all investigations the experience of the pavement consultants was very useful. All the consultants was asked to make the Trade Off Matrix for the design of the best mix for the binder layer for the heavy duty lanes.

Finally, for the heavy duty lanes an adjusted sand skeleton mix with Bestone aggregate and SBS-modified bitumen had been selected. For the light loaded lanes a standard binder layer with Moraine aggregate conventional bitumen was found to be sufficient.

Version 2	NAME PROJECT PROJECT ID	A15 MaVa 616084	Trade-off Matrix Binder asphalt layer heavy duty lanes		A-Lanes A15 MOBILITY VOF
		WEIGHT	Tender reference	Option 1	Option 2
Criterion	**Requirements**		**Sand skeleton with 50% reclaimed asphalt, Norwegian granite and 70/100-bitumen**	**Modified sand skeleton with 40% reclaimed asphalt, Moraine (coarse aggregate)**	**Modified sand skeleton with 40% reclaimed asphalt, Bestone (coarse agggregate)**
Functional properties		2			
Adhesion coarse aggregate -bitumen with Rolling Bottle Test compared with German guidelines			Not compliant with German guidelines	SBS-modified bitumen significant higher than 70/100-bitumen and compliant with German guidelines	SBS-modified bitumen significant higher than 70/100-bitumen and compliant with German guidelines. Adhesion Bestone to bitumen 70/100 and SBS-modification is higher than Norwegian Granite and Moraine
Sensitivity to water			83% (CE-marking)	90% (CE-marking)	97% (CE-marking) - 91% (compaction 96%) - 92% (compaction 100%);
Resistance to rutting	Calculation with software program VEROAD (triaxialtest) en wheel tracking test (requirement Germany < 3 mm)		No significant differences	No significant differences	No significant differences
	SUBSCORE		5	7	9
Benefits		2			
			Many experience in the Netherlands as intermediate top layer and as binder for porous top layers	Comparable mix in Germany , research necessary for mix design. This mix has more texture and thus better interlock with top layer. Low risk for stripping because of air voids <5% and good adhesion.	Gives the best adhesion to 70/100-bitumen and SBS-modification. Comparable mix in Germany , research necessary for mix design. This mix has more texture and thus better interlock with top layer. Bestone is coarse aggregate belonging to class 3 (highest level), better able to withstand damage due to milling.
	SUBSCORE		6	7	9
Costs		3			
Ratio costs for production and transport mix per m2 (in %), reference is standard AC 16 Base OL-C mix			0	+13%	+25%
	SUBSCORE		8	7	5
Risks		4			
Construction time			No specific conditions for application	No specific conditions for application	No specific conditions for application
Quality			Variation in reclaimed asphalt is high; Extensive control bitumen quality at bitumen plant, strongly influences mechanical properties binder.	Variation in reclaimed asphalt is high; Extensive control bitumen quality at bitumen plant, strongly influences mechanical properties binder.	Variation in reclaimed asphalt is high; Extensive control bitumen quality at bitumen plant, strongly influences mechanical properties binder.
Intermediate top layer			Critical when applied longer than 1 winter and if high torsional loads occur. Partial replacement (15%) has to assumed when porous top layer is replaced.	If SBS-modiication is used, binder can withstand easily more than 1 winter. Small replacement (5%) when porous top layer will be replaced.	If SBS-modiication is used, binder can withstand easily more than 1 winter. Small replacement (2%) when porous top layer will be replaced.
	SUBSCORE		7	9	9
Score:			46	49	51

Figure 4 Trade Off Matrix selection binder layer (example)

Top layer

Special porous top layer was developed with the technical experts of the Dutch Road Authority. The main requirement were the acoustic properties that should be equal to two-layered porous asphalt according to the Dutch CROW-guideline 200 “The Cwegdek- method 2002 for road traffic noise”. Also other relevant properties had been investigated like skid resistance, sustainability and workability. The positive results resulted in approval of the Dutch Road Authority. Due to confidential investigation on the top layer the results are not reported.

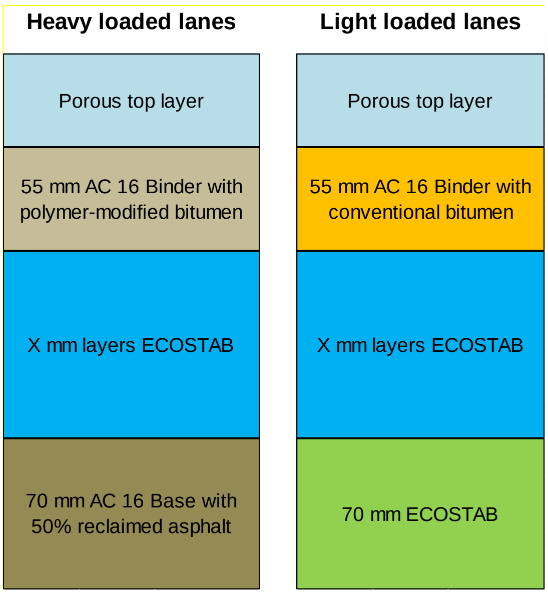

Figure 5 Construction build-up heavy loaded and light loaded lanes

5. RELATION ROAD AND OVERLAY DESIGN

A geometrical model, used in roads design, is a three dimensional model of the situation. There are at least two models necessary to carry out the road design: the DTM and the DRM.
The DTM, Digital Terrain Model, has been extracted from the survey of the existing terrain. The DTM of the A15 was constructed with the use of mobile mapping, executed with a laser scan mounted on a car. In the model the pavement can be extracted by the edges of the pavement and the markings on the pavement. By means of this data it is possible to determine the three dimensional status of the road in alignment and cross fall.
The DRM, Digital Road Model, contains the new future situation. For the A15 project Rijkswaterstaat provided A-lanes-A15 a DRM with the design of the so-called "Tracébesluit" (in the Netherlands used by Rijkswaterstaat to get the necessary permits). This design was based on an older guideline for highway design, the ROA 1990-1995. A-lanes-A15 had the contractual commitment to redesign the road model according the new guideline, the NOA for designing motorways.

Large parts of the new road situation coincided with the current situation. From an economical point of view it was best for project to reuse the existing pavement construction as much as possible. Therefor the pavement consultant and the road designer had to work closely together.

The pavement consultant delivered data based on redesign which road stretch should be strengthened and where it is possible to weaken the pavement construction i.e. to reduce the asphalt thickness. For the road designer the data delivered limits to design the road in between. Supplementary the road designer should take the contractual requirements into account. There were some fixed points/objects, like existing viaducts, where the road model must exactly connect on. For example, the clearance under existing constructions which passed the A15 delivered also fixed points. And the NOA-guideline had minimum and maximum values for crossfall, alignment and the relation between the road tracks. In the shoulders small height differences can be compensated. For larger height differences retaining constructions had to be used.
When the road designer had finished the positioning of the road tracks in height, he produced the height analysis. This showed how deep one has to cut in the existing pavement or how much extra asphalt layers one has to bring on to fill the gap between the existing and the new road. This analysis is an important tool for road designer and consultant. Together they can optimize the design to achieve an optimal reuse of the existing pavement.
Not always did the optimization succeed. Sometimes the existing road has sunk too uneven to meet the requirements and guidelines. Those road stretches still had be dismantled and built completely new.

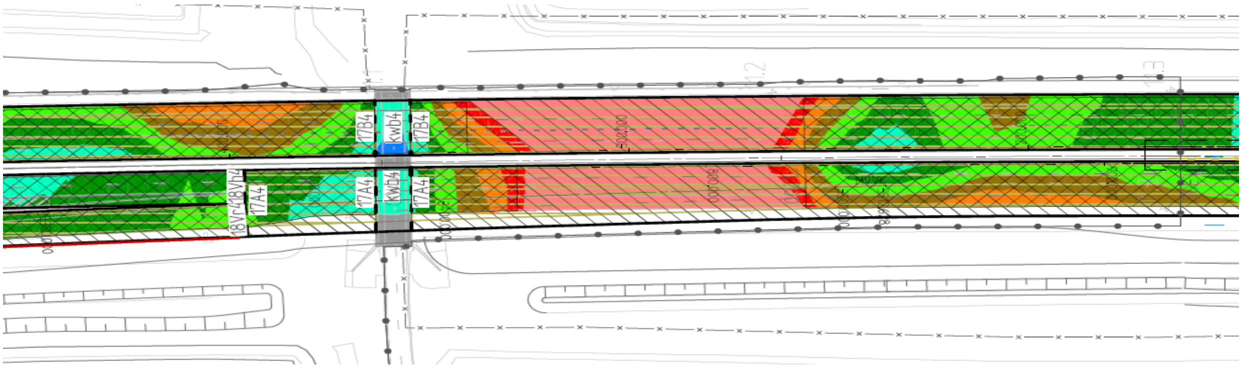

Figure 6 Example height analysis

6. QUALITY CONTROL

During the maintenance period of 25 years it was assumed that the porous top layer should be replaced once without any overlays. In order to prevent unexpected maintenance and thus reduced availability of the road extra requirements were set up for the base granular material and the subbase (sandbed 1 m thick). The requirements consisted of intensified initial checks, FWD-tests and the introduction of the Light Weight Deflection (LWD). Goal of these requirements was to verify the realized stiffness modulus in field and if necessary to do adjustments.

Therefore two stopping-moments were introduced during construction:

1. The base granular material should not be placed until the probing's of the sand bed have been approved (nuclear density gauge)
2. The base asphalt layer should not be placed until the stiffness modulus of the granular material have been approved. Minimum value for the dynamic E-modulus (FWD-tests) of the granular base of 350 MPa determined at least 2 days after construction or within the period of 4 weeks. The other option is to perform the

Light Weight Deflection (LWD) and analyse the surface modulus (E_0). The minimum value of the surface modulus should be at least 120 MPa measured directly on the base and at least 2 days after construction.

Advantage of the probing's of the sand bed is that the engineer gets a reliable indication for the dynamic stiffness modulus of the asphalt pavement to be built. There is no standard test method for verifying the stiffness of the base granular layer after finishing the base granular layer. FWD gives reliable results after installing preferably two asphalt layers on the granular base. It was advised also to use LWD test apparatus, because the results were earlier available and so it was easier in time to perform the adjustments if needed. Other benefit of the LWD was handy and easy use by the technicians.

The foundation surface modulus used in this paper is the composite value of the stiffness value with contribution of all underlying layers [1]. The surface modulus is computed using the following formula:

$$E_0 = \frac{2\left(1-\nu^2\right)\sigma_0 a}{d(0)}$$

Where:

- E_0 = surface modulus (MPa)
- S = plate rigidity factor (-)
- ν = Poisson's ratio (-)
- σ = contact stress (kPa)
- a = foot plate radius (m)
- d = peak value of centre deflection (mm)

In this case a plate rigidity factor of 2 was used (typical for a flexible plate) and a Poisson's ratio of 0.35. The surface modulus was computed as the average value of 10 drops.

Goal was to identify possible shortcomings in the base granular layer and adjust with extra compaction effort or more asphalt thickness. In the time schedule this had to be taken into account. For the use of the LWD a comparative research with nuclear density measurements had been performed on a trial section. Minimum value for the surface modulus (E_0) was experimentally determined comparing to nuclear densities. Afterwards FWD tests have been carried out after installing at least two asphalt layers with minimum thickness of 12 cm. The comparative research showed a moderate correlation between the LWD-apparatus and the nuclear density apparatus. Based on these research limits had been determined for the LWD test.

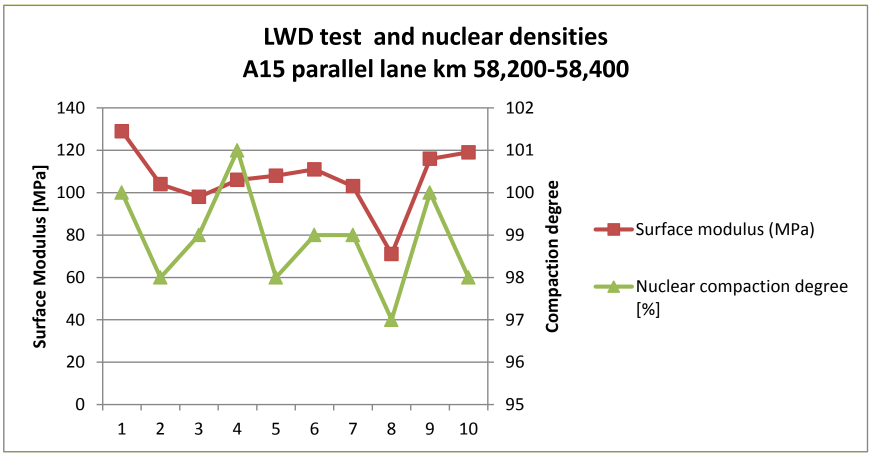

Figure 7 Results comparative research LWD test and nuclear densities

It is remarked that for measuring the bearing capacity of base granular layers there is no uniform standard or test method. The LWD test was therefore an indication and was applied in addition to standard quality checks for the granular base like mix composition, compaction degree and C.B.R.-test.
The LWD-test had also been used to assess the homogeneity of the installed base layer. From figure 7 it is good to be seen that the shape of the curve of the surface modulus is almost similar to the curve of the nuclear density gauge. The compaction degree measured by the nuclear density gauge should be minimal 98% and average 102%. This meant the compaction degree of the granular base did not comply to the quality criteria and was therefore re-compacted and more water had to be added.
It also appeared that in the procurement specifications for the granular base also quality aspects like mix composition and the C.B.R.- value have to be part of. This was also applicable for other excavated base materials in the project.

Figure 8 Execution LWD-test

7. CONCLUSIONS AND RECOMMENDATIONS

The high lane rental costs for performing unplanned maintenance demand an excellent risk management. Quality control becomes therefore even more important in the project. This starts when the procurement specifications are made and ends in the process when shortcomings have to be corrected. When is taken in mind that the asphalt maintenance is a great part of the maintenance costs during 25 years, it is obvious that the expertise of the pavement consultant becomes very important in the project.
From the Motorway A15 project it becomes clear that the pavement consultant has a broader role than providing technical reports. His role shifts from specialist to technical manager who collects all the expertise and translates the risks into consequences for the long term. Therefore it might be necessary to perform extra research, develop new test methods and to set up higher quality levels. The pavement consultant is no more the “mad scientist”, but is now key player in controlling all the quality issues of the asphalt pavement construction. The key success factor for this new role is support of the management board in the project.

Figure 9 Intersection Vaanplein from the southern part

7. REFERENCES

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ACKNOWLEDGEMENTS
The authors are grateful to have worked with the pavement consultants of Strabag, Strukton and Ballast Nedam. Furthermore we thank the Board of the A-Lanes A15 project to share our experiences with other pavement consultants around the globe.