Modieslab Innovative Concrete Pavement Structure: From Idea through Research to Implementation

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Abstract

In 1996 the Dutch Ministry of Transport, Public Works and Water Management launched the innovation program 'Roads to the Future'. One of the developed innovative pavement structures is a Modular Pavement Structure called Modieslab. This structure is designed as a bridge and it merely consists of precast concrete elements. Since 2001 several researches were performed.

Along the motorway A50 in the Netherlands a low-risk and not heavily loaded test section was constructed and monitored during 16 months. On this test section mainly the functional properties as well as construction and maintenance techniques were investigated. The main findings of this test section are reported.

The structural integrity of the structure was investigated by Accelerated Load Testing of another instrumented test section by means of LINTRACK. Some characteristic measurement results are presented.

Insight into the structural behaviour of both the total pavement structure and the most critical upper part of it was further obtained by means of 3D finite element modelling. Some typical calculation results are compared to measurement results.

Finally the materials research is briefly described. This research concentrates on the porous concrete wearing course. Research is ongoing to find solutions for skid resistance and ravelling problems that occurred to some extent on the test sections.

Given the rather positive experiences, both from a technical and an economical point of view, it was decided to actually construct an in-service road section of the radically innovative Modieslab pavement structure after only 4 to 5 years of research. Probably this project will be realized in 2005 or 2006 in an area with very poor subsoil.

Introduction

In 1996 the Dutch Ministry of Transport, Public Works and Water Management launched the innovation program 'Roads to the Future'. One of the themes in this program is "Road Pavement of the Future" which searches for innovations in infrastructure. This theme has generated a number of pilot projects, amongst which was the pilot "Modular Pavement Structures". This pilot project aimed

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at development of a modular pavement that is factory produced. This has a number of advantages, such as independence on weather conditions, better control of tolerances and quality in general, quick replacement of worn out pavement modules (at least 100 m per hour over the full carriageway width) on the road with a minimum of traffic hindrance, and the possibility of taking used modules back to the factory for recycling, refurbishing or modification. In 2000, the market was challenged to produce innovative design solutions for this concept. An extra requirement was that a noise reduction of at least 5 dB(A), compared to dense asphalt concrete, should be realized, i.e. a considerably greater reduction than porous asphalt (drainasphalt) that is normally applied on motorways in the Netherlands and that yields 3 to 4 dB(A) reduction compared to dense asphalt concrete.

In reaction to this challenge, 13 private consortia proposed 20 different designs. From these, a jury selected 4 designs for further development. These 4 designs showed wide-ranging approaches to the modular concept and were radically different from conventional pavements. Three out of 4 showed a very innovative structural design. Also, with one exception all pavements featured a newly developed wearing course.

The designs were so radically new that the uncertainty about their real-life performance was too significant to allow the construction of test sections on in-service motorways. Therefore the concepts were tested on parallel access roads to two rest areas along the motorway A50 near Apeldoorn, in the east of the Netherlands. These test sections, which were opened in November 2001, allowed 16 months monitoring of the concepts at these low risk locations. This monitoring aimed at assessing the functional properties and durability of the concepts. Furthermore the test sections provided experience with the installation and removal of the pavement modules. It was however clear that the durability under prolonged heavy traffic could only be assessed to a very limited degree at this test site, given the limited traffic loadings and short time period.

However, both the Ministry of Transport, Public Works and Water Management and a number of Regional Highway Agencies showed interest in possible larger–scale applications of one or more of the concepts, in motorway sections of several kilometres in length, on a time scale of 2 to 3 years. This implied that it was necessary to assess on rather short term if the pavement concepts were sufficiently capable of withstanding heavy traffic loadings, to allow a responsible implementation. This ruled out the traditional implementation procedures where new concepts are monitored over many years in test sections in low risk locations. To collect sufficient evidence about the durability of the concepts in a relatively short period, it was therefore decided to make use of all tools available and supplement the test sections along the motorway A50 with Accelerated Pavement Testing at the LINTRACK (Linear Tracking) test facility in Delft. Furthermore it was decided to perform advanced modelling and material testing.

This paper deals with a rather successful Modular Pavement Structure called Modieslab.

First a brief description is given of the Modieslab pavement structure, which merely consists of precast concrete elements.

Then the main findings about the low-risk and not heavily loaded test section along the motorway A50 are summarized. On this test section the functional properties as well as construction and maintenance techniques were investigated.

The structural integrity of the structure was investigated through Accelerated Load Testing, by means of LINTRACK, of another instrumented test section. Some characteristic measurement results are presented.

Insight into the structural behaviour of both the total pavement structure and the most critical upper part of it was further obtained by means of 3D finite element modelling. Some typical calculation results are compared to measurement results.

Finally the materials research is briefly described. This research concentrates on the porous concrete wearing course. Research is ongoing to find solutions for skid resistance and ravelling problems that occurred to some extent on the test sections.

Modieslab Pavement Structure

The Modieslab pavement structure is designed as a bridge. The structure consists of carriageway–wide precast concrete slabs. The standard dimension of the slabs in driving direction is 3.5 m. The slabs are connected to underlying precast reinforced concrete crossbeams with prestressed anchors and sliding plates; no dowel bars are present. The crossbeams can either rest on concrete driving piles (e.g. for new construction in areas with high settlements) or can be embedded in an existing pavement for reconstruction purposes.

The slabs consist of a reinforced concrete layer of 320 mm covered with a twin-layered porous concrete wearing course. The top 15 mm of this porous concrete is fine graded, while the bottom 35-55 mm is coarse graded. The slabs are produced wet-in-wet "upside down" in steel moulds, giving a very even surface. The slabs contain gutters for the discharge of rainwater penetrated through the porous concrete wearing course. The slabs further feature a pipeline system for regulating the temperature of the slabs, which allows control of dilatation, snow and ice control and even allows collection of solar energy in hot periods.

Photographs and drawings illustrating the Modieslab structure are included in the next chapters.

Test Site Motorway A50

Figure 1 gives an overview of the rest areas, named 'De Brink' and 'De Somp', along the motorway A50. On the access roads the test sections of the 4 Modular Pavement Structure designs were constructed in November 2001. Each test section has a length of about 100 m and a width of 5 m, and holds one traffic lane.

Figure 2 shows some pictures of the installation of the Modieslab test section for which heavy construction equipment was required.

At the end of May 2002 a Weigh-in-Motion system was installed for registration of the traffic loadings on the Modieslab test section over the period from June 2002 till January 2003. It appeared from the measurements that on average the test section was used by 46,000 vehicles per month while on average 328 axles per month with a load ≥ 100 kN were registered (Infra Engineering Delft and Grontmij Advies & Techniek b.v., 2003). The test section (located on the access road to a rest area) was thus neither very intensively nor very heavily loaded.

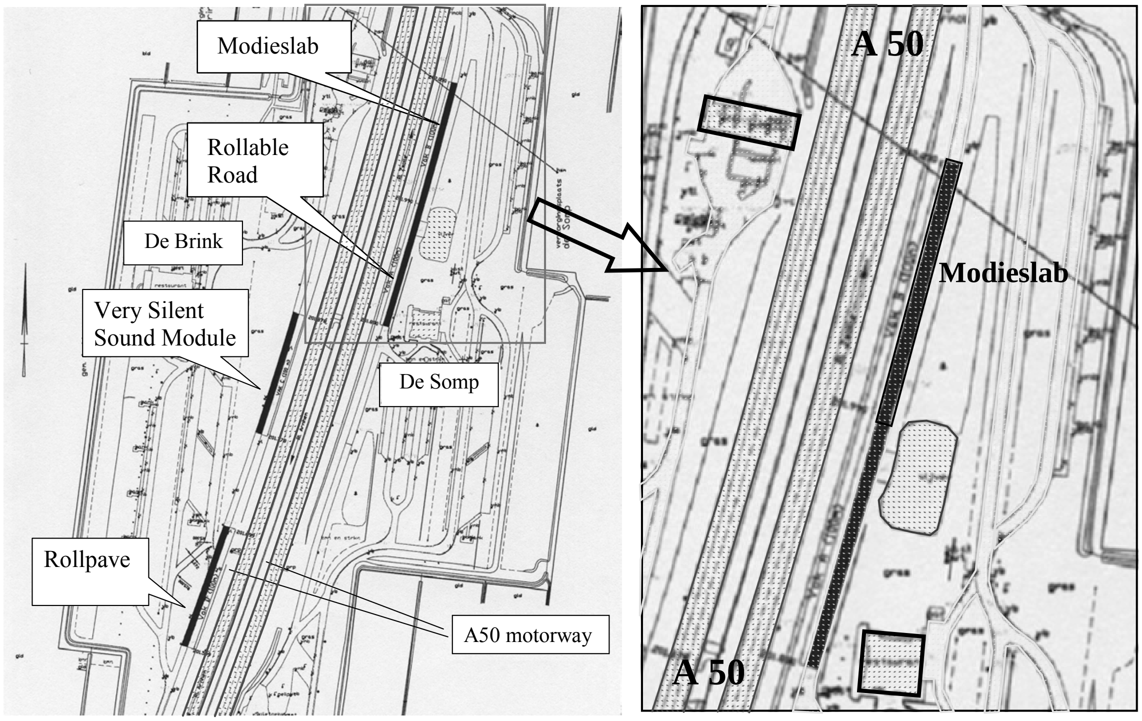


Figure 1. Four test sections on access roads to rest areas along motorway A50.

Figure 2. Installation (left) and leveling of the slabs (right) of the Modieslab test section along the motorway A50.

On the test site a number of (mainly functional) aspects have been evaluated during the 15 months monitoring period from November 2001 till January 2003 (Infra Engineering Delft and Grontmij Advies & Techniek b.v., 2003; Van Dommelen et al., 2004). These aspects and the evaluation results for the Modieslab test section are summarized in table 1.

Table 1 learns that the Modieslab test section performed well on a number of aspects, such as the traffic noise reduction, the deceleration during an emergency stop of a test vehicle, the structural strength and the resistance to a fire (created by putting a car on fire by purpose).

This rather small prototype test section was constructed with conventional equipment, resulting in a limited speed of construction and removal of the slabs (far below the target value of 100 m per hour). For larger scale applications dedicated equipment will certainly be developed.

Table 1. Evaluation results for Modieslab test section.

Priority	Aspect	Evaluation result*
High	Noise reduction	Satisfying
	Speed of application and removal of the slabs	Attention
	Durability of wearing course and structural layer	Attention
	Skid resistance	Inadequate
	Emergency brake deceleration	Satisfying
	Adhesion (bond between wearing course and structural layer	Satisfying
	Evenness (IRI-value)	Attention
	Raveling	Attention
	Crack development	Satisfying
	Fire resistance	Satisfying
Low	Water permeability	Satisfying
	Temperature behavior	Attention
	Chemical resistance (literature study)	Satisfying

* Satisfying: fully meets the specified requirement
Attention: not fully meets the specified requirement, but this is not considered as an impediment for application of the structure on an in-service road
Inadequate: needs to be solved prior to application of the structure on an in-service road

The longitudinal evenness of the test section was moderate, although it satisfied the Dutch specifications (IRI-value). From evenness measurements the transversal joints between the slabs clearly could be observed. The slabs also showed upward curvature in the longitudinal direction.

Due to the first high pressure cleaning of the porous concrete wearing course a number of slabs exhibited raveling. The slabs that survived this first cleaning did not show significant raveling until the end of the monitoring period. At the end 27% of the slabs exhibited serious raveling (according to Dutch definitions).

At the beginning of the monitoring period the skid resistance was very good due to the cement layer around the aggregate. The added polymers, however, caused the skid resistance to drop below the specified values due to the polishing action of the vehicle tires.

As a result of these findings the manufacturer of the Modieslab slabs has continued research, which concentrates on one hand on the manufacturing technique (to avoid the slabs to curl) and on the other hand on the composition of the porous concrete wearing course to increase both the resistance to raveling and the skid resistance (as the wearing course is apparently the weakest layer of the system).

LINTRACK Test Section

LINTRACK APT facility. Because the test sections along the motorway A50 were not really heavily loaded the four Modular Pavement Structure designs were also constructed at the outside test area of the Delft University of Technology and subjected to repeated heavy loadings by means of the LINTRACK test facility. LINTRACK (figure 3) is a device for Accelerated Pavement Testing and is jointly own by the Section Road and Railway Engineering of the Delft University of

Technology and the Road and Hydraulic Engineering Institute of the Dutch Ministry of Transport, Public Works and Water Management.

Figure 3. LINTRACK facility for Accelerated Pavement Testing.

LINTRACK is able to apply around 1000 tire load (either dual tire or wide base tire) repetitions per hour (Groenendijk 1998). The maximum tire load is 100 kN, and the maximum speed in the central 4 m measuring length is 20 km/h. The whole test facility is sheltered to exclude direct climatic influences. An infrared heating system is able to increase the temperature at the pavement surface to about 30ºC above ambient temperature.

Construction and instrumentation of test section. The original Modieslab test section at the LINTRACK test area consisted of 4 slabs, each 5 m wide and 3.5 m in length and 380 mm thick (310 mm reinforced concrete plus 55 mm coarse graded porous concrete plus 15 mm fine graded porous concrete). Figure 4 gives an overview of the original LINTRACK test section, including the location and codes of the longitudinal strain gauges that were installed at the bottom side of the central slabs 2 and 3 and the location of the two wheel tracks that were subjected to LINTRACK loadings.

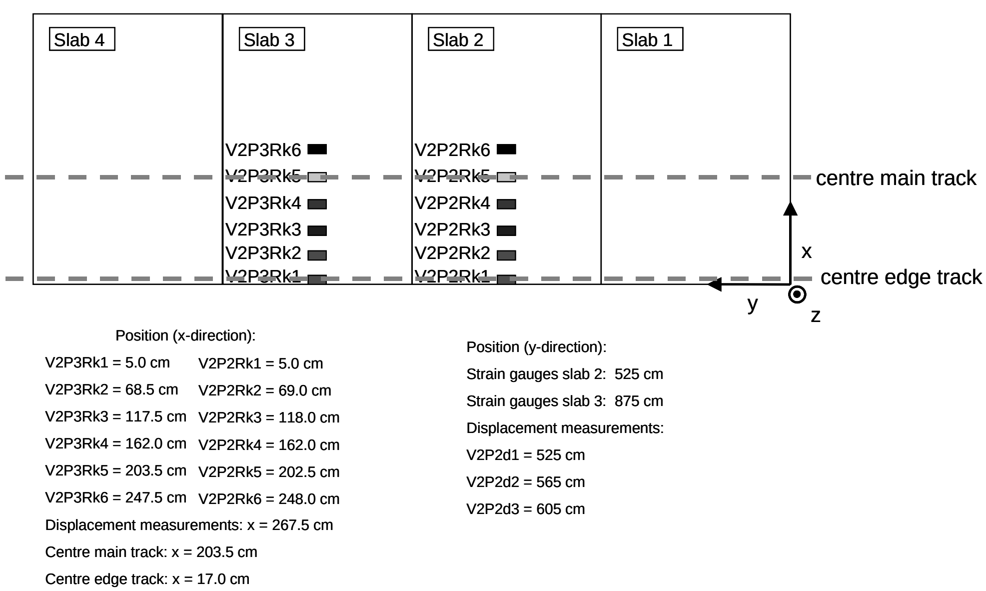


Figure 4. Locations and codes of strain gauges and wheel tracks on the original Modieslab test section.

Figure 5 gives an impression of the construction of the LINTRACK test section. In the left photograph the 5 supporting crossbeams have been installed in the existing settlement-free sand subgrade. In the right photograph one of the 4 slabs is placed onto the crossbeams.

Figure 5. Construction of the original Modieslab test section.

During the LINTRACK-testing the original Modieslab test section appeared to be very stiff and strong indeed (see test results ahead). Therefore it was decided after the first loading period (see table 2) to replace the original slab 3 (see figure 4) by a two-layer slab, i.e. a bottom slab (thickness 260 mm in the central part and 185 mm near the supporting crossbeams) and a reinforced upper slab (thickness 175 mm including 70 mm porous concrete). The gap of 20 mm between the bottom slab and upper slab was later filled with grout (figure 6). The bottom and upper slab are connected to each other and to the underlying crossbeams in a similar way as the original structure, and in addition the bottom and upper slabs are connected by a prestressed anchor in the middle of the two-layered slab). The two-layer system simulates an overlay (upper slab) on an old pavement, e.g. a damaged concrete pavement (represented by the bottom slab).

In total 10 strain gauges were installed on the two-layer slab 3. Their locations and directions are given in figure 7.

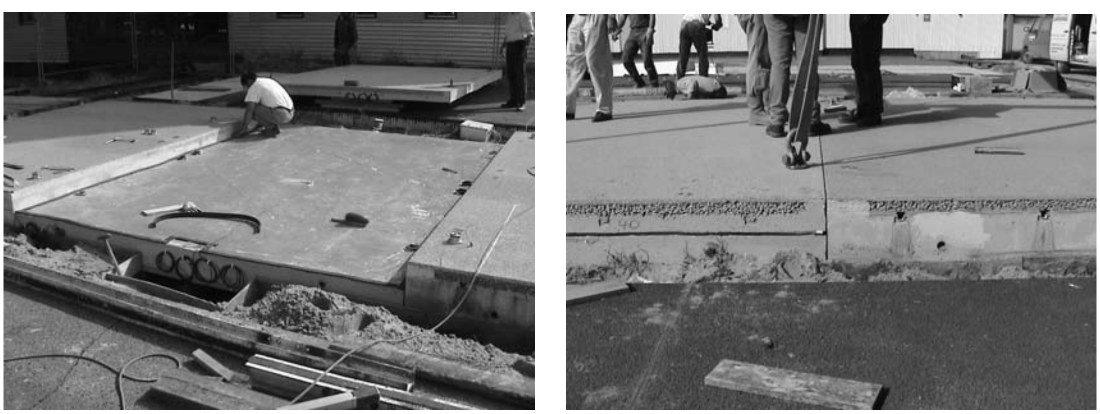
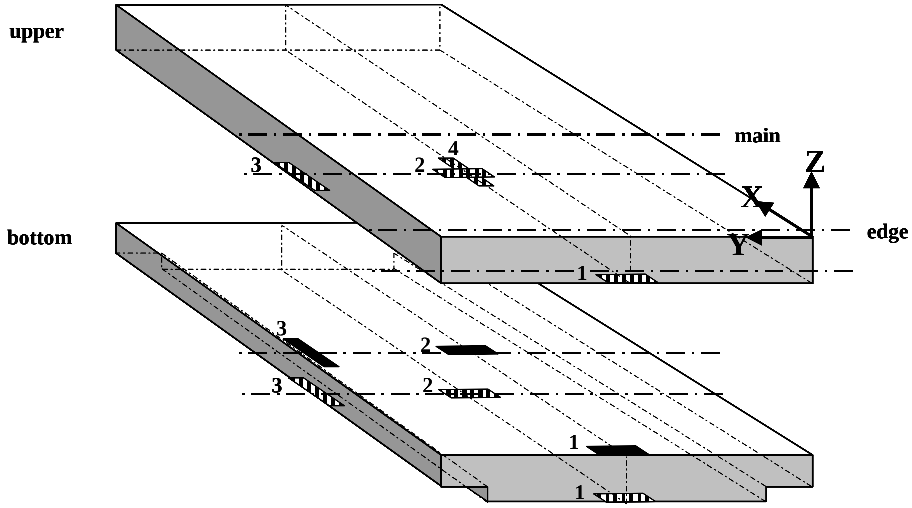


Figure 6. Installation of the two-layer slab 3 on the LINTRACK test section.



Gauges 1: V2bpo1: x = 0 cm, y = 175 cm, z = 17.5 cm
V2opb1: x = 0 cm, y = 175 cm, z = 19.5 cm
V2opo1: x = 0 cm, y = 175 cm, z = 45.5 cm
Gauges 2: V2bpo2: x = 203.5 cm, y = 175 cm, z = 17.5 cm
V2opb2: x = 203.5 cm, y = 175 cm, z = 19.5 cm
V2opo2: x = 203.5 cm, y = 175 cm, z = 45.5 cm
Gauges 3: V2bpo3: x = 203.5 cm, y = 350 cm, z = 17.5 cm
V2opb3: x = 203.5 cm, y = 350 cm, z = 19.5 cm
V2opo3: x = 203.5 cm, y = 350 cm, z = 38 cm
Gauge 4: V2bpo4: x = 203.5 cm, y = 175 cm, z = 17.5 cm

Figure 7. Scheme of the two-layer slab 3 with the location, direction and code of the 10 strain gauges.

Loading and measuring program. Two wheel tracks on the Modieslab test section have been subjected to Accelerated Load Testing (see figure 4 and figure 7).

The main wheel track is considered to be representative for practice. Therefore on this wheel track a realistic simulation of lateral wander of truck traffic has been applied, i.e. a (truncated) Laplace distribution with a standard deviation of 0.19 m and the maximum distance of the tire centre to the wheel track centre line was 0.30 m (Van Dommelen and Houben, 1999).

The edge wheel track potentially is the most critical. In practice the pavement edge is however not intensively loaded. Therefore only a limited number of load repetitions was applied on the edge wheel track without lateral wander, so channelized traffic loadings.

In the research on the Modieslab test section only one type of tire was involved, i.e. a standard wide base tire (385/65 R 22.5) for trailer axles. The tire load was always 75 kN (simulating heavily overloaded axles of 150 kN) while the tire pressure was constantly 0.9 MPa.

The greater part of the Accelerated Pavement Testing of both wheel tracks has been done at a constant pavement surface temperature of 40ºC (representative for summer conditions in the Netherlands and realised through the LINTRACK heating system), the remaining load repetitions were applied at (not controllable, so variable) Dutch winter conditions.

The applied number of load repetitions per wheel track, per instrumented slab and per temperature condition is given in table 2. Slab 2 has been subjected to 500,000 load repetitions on the main wheel track and 20,000 load repetitions on the edge wheel track. Both for the original and for the two-layer slab 3 these numbers reduce to 50%.

Table 2. Applied number of 75 kN wide base tire load repetitions in the wheel tracks of the LINTRACK test section.

Wheel track	Temperature at pavement surface					
	Controlled (July-August 2002)		Controlled (October 2003)		Uncontrolled (November-December 2003)	
	40ºC		40ºC		0ºC - 10ºC	
	slab 2	original slab 3	slab 2	two-layer slab 3	slab 2	two-layer slab 3
Main track (with lateral wander)	250,000	250,000	125,000	125,000	125,000	125,000
Edge track (without lateral wander)	10,000	10,000	5,000	5,000	5,000	5,000

The measurement program included:

- Scan measurements, performed prior and after the Accelerated Load Testing of both the original and the two-layer test section. In a scan measurement all strain gauge signals are registered when the LINTRACK tire subsequently runs over the test section at different X-positions (see figure 4 and figure 7). Three tire loads have been applied (25, 50 and 75 kN), in all cases with the tire pressure 0.9 MPa (9 bar).
- Response measurements, regularly done during the Accelerated Load Testing of both test sections. During a response measurement the LINTRACK tire (75 kN load) runs one time from the beginning to the end of the test section, either in the main wheel track or in the edge wheel track. During this loading the signals of all strain gauges are registered as well as the signals of 3 displacement transducers, mounted below slab 2.
- Visual inspection and measurement of material loss from the porous concrete wearing course, regularly done during the Accelerated Load Testing of both test sections.

In this paper only some characteristic measured (and calculated) strains during the response measurements in the main wheel track on the original test section will be presented. Very extensive information concerning all the measurements on only the original test section can be found in (Houben et al., 2004-1), while some information concerning the measurements on both test sections can be found in (Houben et al., 2004-2).

Measured concrete strains in main wheel track of original test section. Figure 8 shows the development of the maximum longitudinal strain due to the 75 kN wide base tire load as measured in the centre of the main wheel track with strain gauge V2P2Rk5 (see Figure 4) at the bottom of the (original) slab 2 during the 500,000 load repetitions. It is remarked that the maximum strains in the original slab 3 during the first 250,000 load repetitions differed maximum 5% from those in slab 2.

Figure 8 shows that the maximum strain remains quite constant. The strains at 40ºC (22 to 27 μm/m) are somewhat greater than those under winter conditions (15 to 21 μm/m), but all strains are far below the flexural tensile strain at break (that is estimated as around 175 μm/m on average). After the first 250,000 load repetitions it was therefore decided to replace the original slab 3 by the two-layer slab 3.

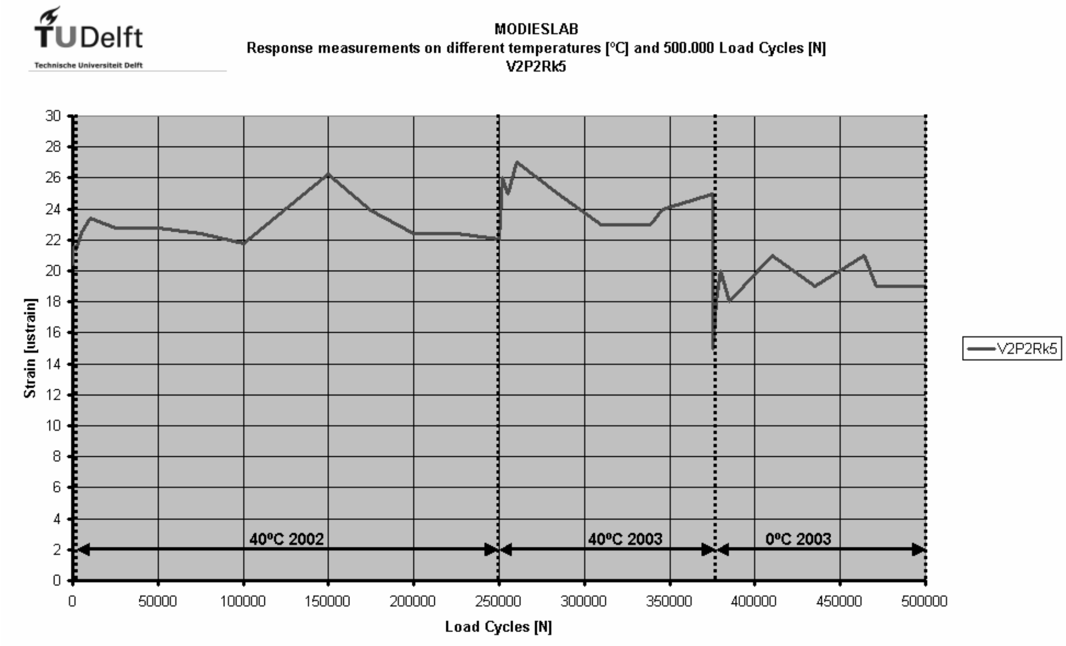


Figure 8. Response measurements in main wheel track on slab 2 between 0 and 500,000 load repetitions: maximum flexural tensile strain (μm/m) of gauge V2P2Rk5 (see figure 4).

CAPA-3D finite element analyses

Three finite element models of the Modieslab test pavement structures have been made with the CAPA-3D package:

1. a global model of the original pavement structure
2. a global model of the two-layer pavement structure
3. a local model of the upper part of the pavement that is the same for both structures.

In the next paragraphs only the models 1 and 3 are briefly discussed. Also some characteristic calculation results will be given and (for model 1) compared with measurement results. Some characteristic results for model 2 can be found in (Houben et al., 2004-2).

Global model of original structure. The global model of the original Modieslab pavement structure consists of the following structural components (from bottom to top):

- crossbeams supporting the concrete slabs; the crossbeams are placed on a Winkler foundation;
- prestressed anchors and sliding plates between the crossbeams and the slabs;
- slabs consisting of high quality concrete (including two reinforcement grids), a coarse graded porous concrete layer and finally a fine graded porous concrete wearing course.

Figure 9 gives two overall views of the global model, where different colors indicate different materials. The global model contains 3 slabs, enabling interaction between slabs. The central slab is modeled in greatest detail and the most accurate calculation results are therefore obtained for this slab. The outer slabs only determine the boundary conditions for the central slab and are modeled in lesser detail. A more detailed description of the model geometry and material properties used in the calculations can be found in (Houben et al., 2004-1).

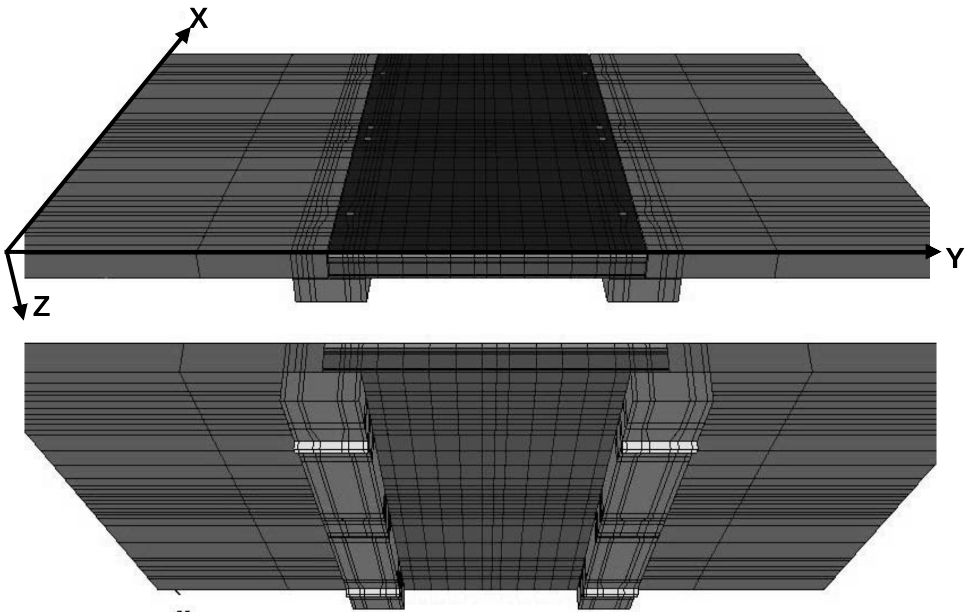


Figure 9. Overall views of the global model of the original Modieslab pavement structure; at the top: view from above, at the bottom: view from below.

The load used in the calculations is equal to the standard wide base tire load (75 kN, tire pressure 0.9 MPa) applied in the Accelerated Load Testing of the Modieslab test sections. Calculations were done for 6 load positions (figure 10) divided over the 2 wheel tracks of the test section to enable a comparison between the calculated and measured strains.

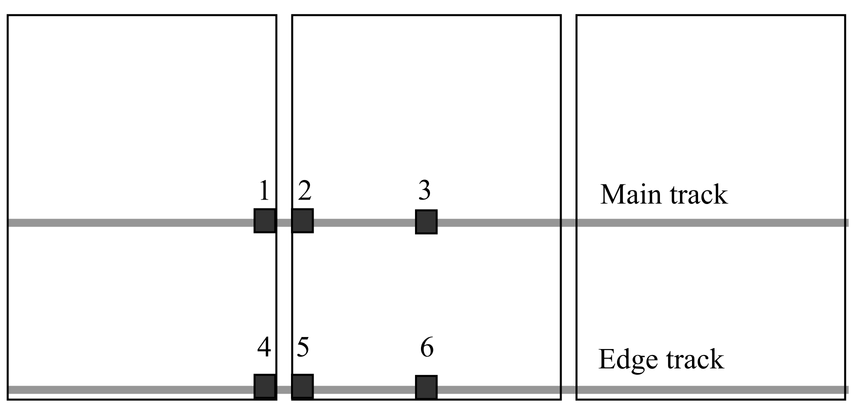


Figure 10. Tire load positions in the calculations with the global model of the original Modieslab pavement structure.

One typical calculation result is shown in figure 11. The curve shows, for load position 3 (see figure 10), the calculated strains in longitudinal Y-direction at the bottom of the central slab in the transverse section through the load positions 3 and 6. This transverse section contains the strain gauges in the slabs 2 and 3 of the original test section (see figure 4). Therefore figure 11 also includes data-points representing, for both (original) slabs 2 and 3, all measured maximum strains during the first

250,000 load repetitions in the main wheel track at 40ºC. Over the whole transverse section the calculated strain distribution falls within the small range of measured strains.

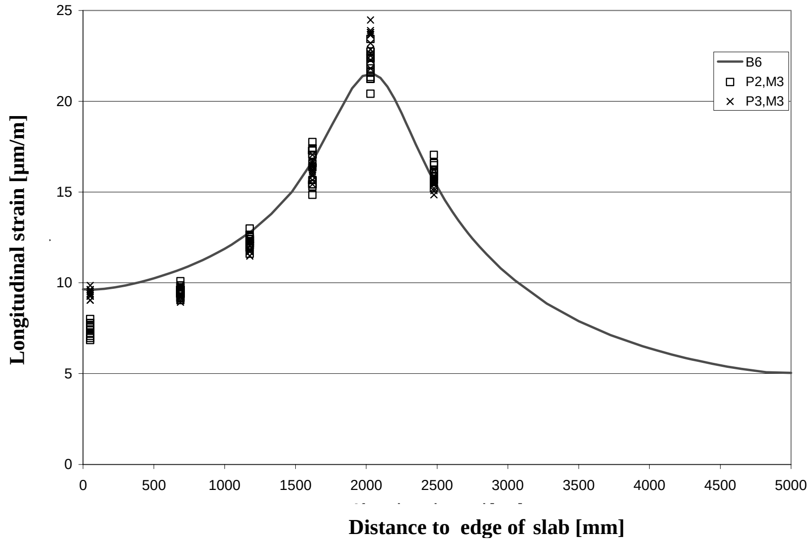


Figure 11. Calculated longitudinal strains on central cross section for load position 3 and comparison with measured strains.

Although not included in figure 11, also the measured strains on slab 3 during the last 250,000 load repetitions (see figure 8) agree reasonably well with the calculated ones. The strains measured at 40ºC are slightly greater and those measured at winter conditions are somewhat smaller than the calculated ones.

More calculation results and comparisons with measurement results can be found in (Houben et al., 2004-1).

Local model of upper part of structures. The local model was developed to obtain detailed information about the stresses and strains occurring in the most critical upper part of the Modieslab pavement structures under heavy (simulated) traffic loadings. The model concentrates on the two porous concrete layers and the upper part of the underlying concrete, including the gutters that are present there for the discharge of penetrated rainwater. The model includes two gutters and has a rigid support.

Figure 12 gives an overall view of the local model, where different colors indicate different materials. More detailed information on the model geometry and the material properties can be found in (Houben et al., 2004-1).

The calculations have been done for one type of tire load. The width and length of the contact area are 300 and 278 mm respectively. The vertical contact pressure is 0.9 MPa, which results in a total vertical load of 75 kN (equal to the LINTRACK tire load). However also a horizontal contact pressure of 0.9 MPa was applied (in contrast to the rolling LINTRACK tire). In fact the calculations with the local model simulate a heavily breaking overloaded truck axle on a dry pavement surface.

Three load positions along the model edge are distinguished (figure 13), i.e. the tire just past a gutter (position 1), the backside of the tire in the middle of the gutter (position 2) and the center of the tire exactly over the middle of the gutter (position 3).

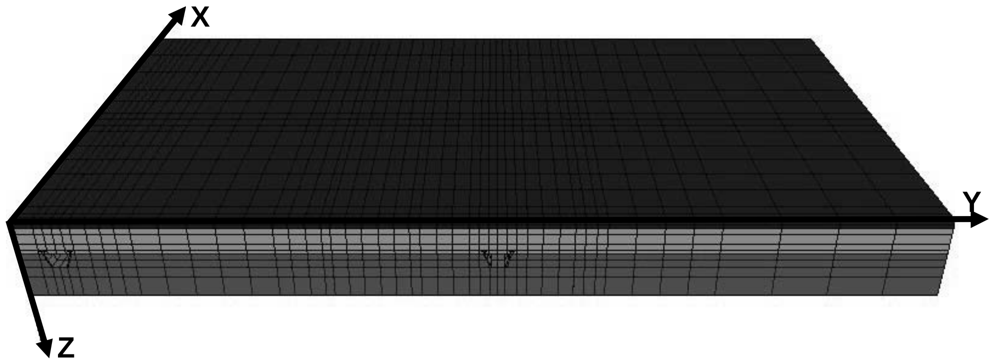


Figure 12. Overall view of the local model of the Modieslab pavement structures.

Figure 13. Distinguished tire load positions in the calculations with the local model.

Figure 14 shows, for the 3 positions of the modeled braking tire, the distribution of the longitudinal stresses (the deformations are enlarged with a factor 2500). In all cases compressive stresses are found in front of the tire and tensile stresses (up to about 3 MPa, which seems quite high for porous concrete with about 25% of air voids) at the backside of the tire. Validation of these calculated stresses is not possible as on the test section no strains were measured in the porous concrete.

Material research on porous concrete

Within the framework of the LINTRACK Accelerated Load test it was the intention to also perform some materials research, i.e.:

- Leutner shear tests on the interface between the fine graded porous concrete and the coarse graded porous concrete; beforehand this interface was considered to be weaker than the interface between the coarse graded porous concrete and the underlying normal concrete;
- 4-point beam bending tests on both the fine graded porous concrete and the coarse graded porous concrete to obtain the stiffness modulus for various loading times and temperatures.

The Leutner shear tests on cylindrical specimens could not be performed as it appeared to be impossible to obtain cores out of a Modieslab slab with undamaged porous concrete layers. Manufacturing cylindrical specimens in the laboratory

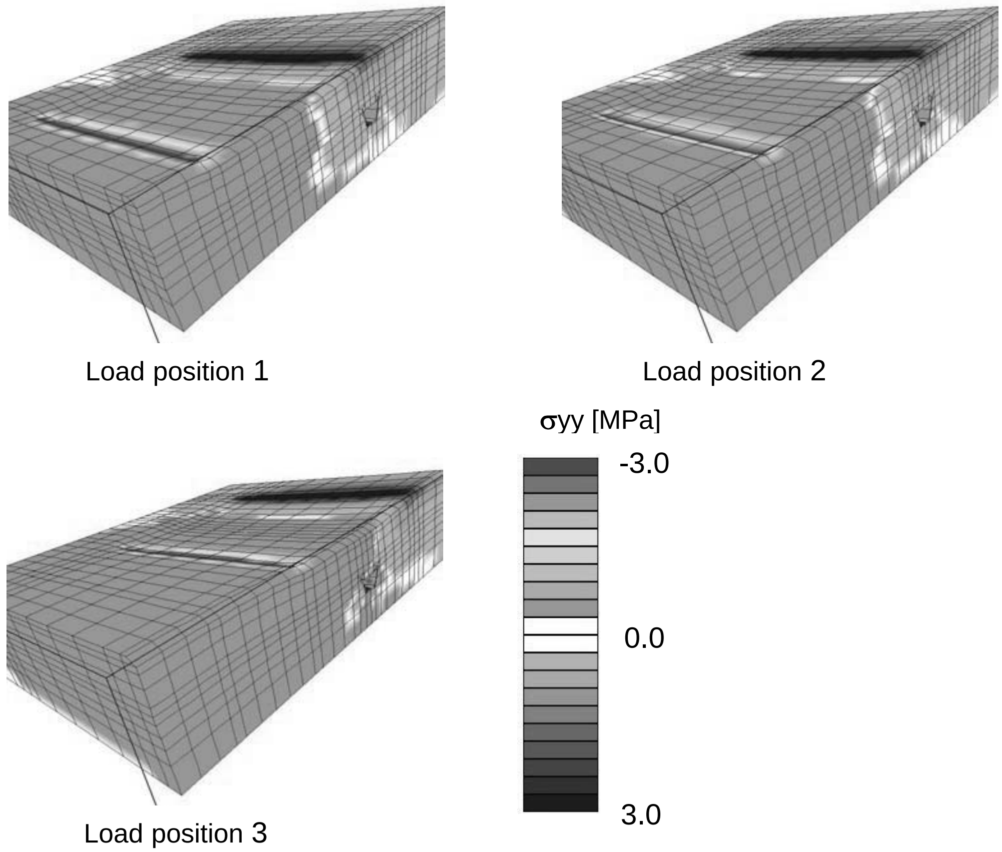


Figure 14. Calculated longitudinal stresses for 3 load positions.

(consisting from bottom to top of normal concrete, coarse and fine graded porous concrete) was considered to be not representative for the Modieslab slab.

To obtain the beams for the stiffness tests, in the laboratory small slabs (500*700 mm) were made consisting from bottom to top of 75 mm normal concrete and either 75 mm coarse graded porous concrete or 75 mm fine graded concrete. These slabs were manufactured in the same way as the real Modieslab slabs, i.e. upside down.

By means of sawing it appeared to be possible to obtain really undamaged beams of either coarse or fine graded porous concrete. The dimensions of a beam were l*w*h = 400*60*50 mm. Three beams of each type of porous concrete have been tested under the following conditions:

- displacement-controlled tests, strain level 50 μm/m (which is the order of magnitude of the strains that occurred in the LINTRACK test section);
- load frequency 0.5, 1, 2, 4 and 8 Hz (loading time 2000, 1000, 500, 250 and 125 ms respectively);
- temperature 5, 10, 15, 20, 25, 30, 35 and 40 ºC.

The average measured stiffness values for the fine graded porous concrete are shown in figure 15 and for the coarse graded porous concrete they are shown in figure 16. It appears from the figures 15 and 16 that the stiffness of porous concrete is somewhat dependent on the loading frequency (loading time) and clearly dependent on the temperature. This illustrates the presence of polymers in the binder of both types of porous concrete.

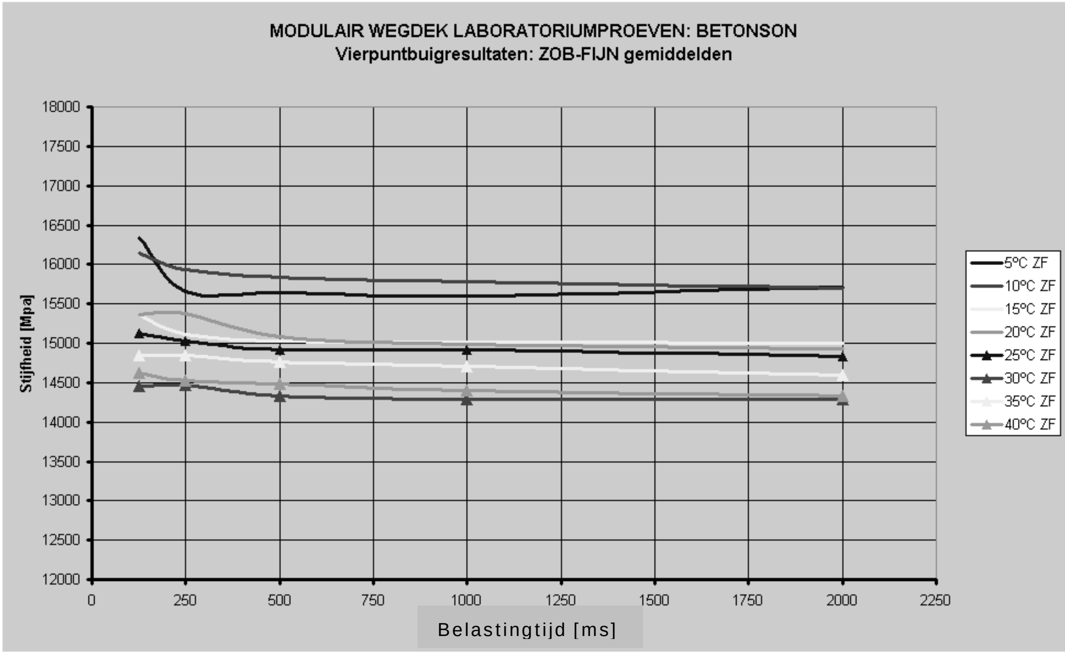


Figure 15. Average (of 3 tested beams) stiffness modulus of fine graded porous concrete as a function of the loading time and the temperature.

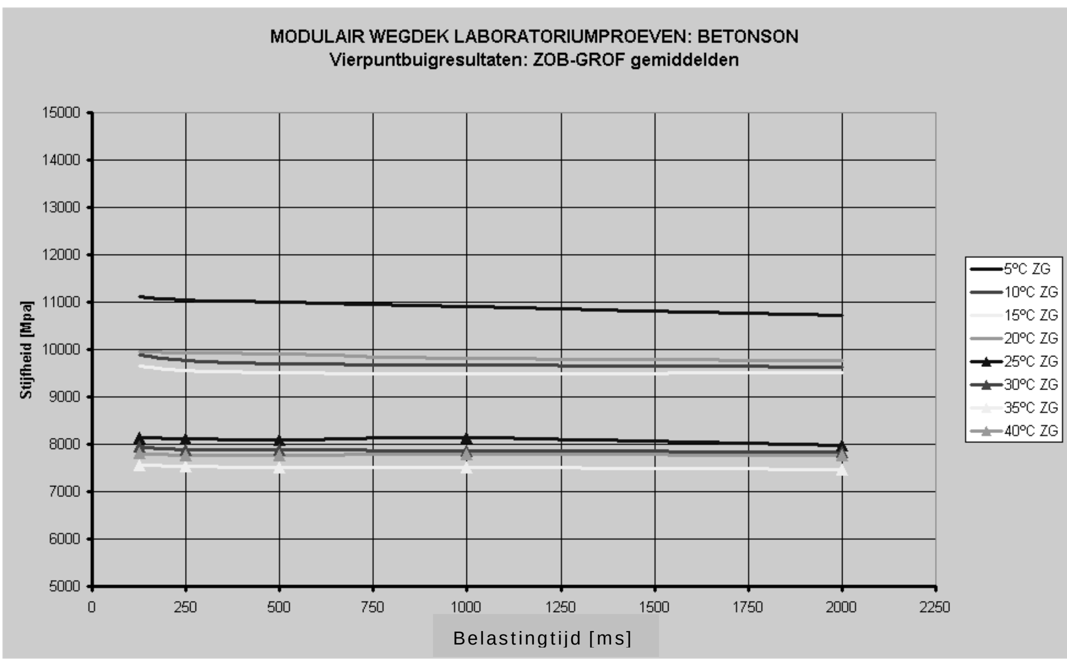


Figure 16. Average (of 3 tested beams) stiffness modulus of coarse graded porous concrete as a function of the loading time and the temperature.

The stiffness value of the fine graded porous concrete ranges from rougly 14300 MPa till 16300 MPa, on average around 15000 MPa. The stiffness value of the coarse graded porous concrete is substantially lower and ranges from 7500 MPa till 11000 MPa, on average around 9000 MPa.

Near future implementation

After the research into mainly the functional properties on the (low-risk) test section along the motorway A50, the research into the structural capacity on the LINTRACK test section and some material research it was concluded that, from a technical point of view, the innovative Modieslab pavement structure can be applied on in-service motorways, provided that the shortcomings with respect to the raveling and skid resistance are solved.

As already indicated in table 1, some slabs on the test section along the motorway A50 exhibited raveling while the skid resistance on that test section was inadequate. Also the two-layer slab, installed in the LINTRACK test section during the Accelerated Load Testing, suffered much more from raveling than the original slabs. These defects indicate that the composition of the porous concrete was not yet optimal and that was the reason that the manufacturer did further research to improve the quality of especially the fine graded porous concrete wearing course.

It was found that early raveling occurred due to either a mortar that was too dry, or a handling time that was too long (resulting in drying out of the concrete mix) or an extremely high percentage of air voids (sometimes more than 30%) due to a too thin bonding layer around the aggregates. Therefore in future the thickness of this bonding layer will be increased such that the percentage of air voids goes down to 20%. Laboratory experiments have shown that in this case the resistance against raveling is substantially increased while the reduction of traffic noise is maintained.

On the test section along the motorway A50 also some de-bonding between the fine graded porous concrete wearing course and the underlying coarse graded porous concrete was observed as a result of the 3 above-mentioned shortcomings during the manufacturing of the slabs. To resolve this, in future the thickness of the fine graded porous concrete wearing course will increase from 15 to 30 mm and it will be taken care of that the two porous concrete mixes are wet enough when producing the slabs upside down.

It is also indicated in table 1 that the skid resistance on the test section along the motorway A50 was inadequate. This was caused by the fact that the cement skin at the road surface did not wear off by the action of traffic.

Therefore, first in the laboratory and later on the test section along the motorway A50 (figure 17-left), it was tried to remove the cement skin by means of sanding the road surface. This treatment appeared to be successfully as SRT-measurements (figure 17-right) showed a substantially greater skid resistance. The

Figure 17. Sanding on the test section along the motorway A50 (left) and skid resistance measurement by means of the SRT device (right).

sanding should however be done with great care to prevent that fine aggregate is pulled out of the porous concrete wearing course that would initiate the raveling process.

It is also indicated in table 1 that the longitudinal evenness of the test section along the motorway A50 was not optimal; in the transverse direction the evenness was satisfying. Therefore in future the orientation of the Modieslab slabs is changed for 90º, which means that the length of the slabs (in the direction of the road axis) will be 5 m, while the width of the slabs is limited to 3.6 m (the width of a traffic lane). The advantage of this (besides a better longitudinal evenness) is that in case of replacement of a slab only one traffic lane (and not a whole carriageway) has to be closed, the disadvantage is a lower speed of construction and replacement of the slabs.

In addition to all the technical research a cost-effectiveness study was performed (Van Dommelen et al., 2004). This study consisted of a comparison with a standard porous asphalt wearing course with a life cycle of 35 years with maintenance at 10, 16, 25 and 35 years. The calculations were based on a number of assumptions (30% faster construction and replacement, 10%-20% higher durability due to pre-manufacturing) and included cost of traffic management during construction/maintenance and cost of reduction of traffic noise (the reference structure will require sound screens for this). In general these calculations showed that the Modieslab pavement structure is viable and can be cost-effective relative to traditional road construction and maintenance.

Given the rather positive experiences, both from a technical and an economical point of view, it was decided to actually realize an in-service road section of the innovative Modieslab pavement structure, and this is going to happen in 2005 or 2006.

The most probable project will be a 500 to 1000 m long section in a new secondary road that should be connected to the motorway A12 near Utrecht in the centre of the Netherlands. At that location the subsoil consists of 10 to 15 m of very weak peat and clay layers, with CBR-values of 1% to 2%. Due to a traditional pavement structure extreme settlements will occur. So it will be clear that the Modielab pavement structure has to be founded on piles. Currently it is investigated whether the slabs can be directly connected to these foundation piles without applying the crossbeams (see figures 2 and 5) that were used until now. Such a solution obviously reduces the investment costs.

Conclusions

The project described in this paper has shown that in a time span of only 4 to 5 years a design of a radically innovative concrete pavement concept became available for practical application on vital sections of the road network. This was only possible due to several parallel running technical (and economical) researches:

- a low-risk in-service test section for determination of the functional properties and for research on construction and maintenance (replacement) techniques,
- Accelerated Load Testing on a test section for determination of the structural integrity,

- analyses of the structural behavior of the pavement concept on the basis of advanced modeling,
- materials research that concentrated on the surface characteristics of the porous concrete wearing course.

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