Rehabilitation by cracking and seating of concrete pavement optimized by FWD analysis

H. C. Korsgaard & J. P. Pedersen
Carl Bro Pavement Consultants, Kokbjerg 5, DK-6000 Kolding

M. Rasmussen
Copenhagen Municipality, Road and Park Division, Smedetoften 14, DK-2400 Copenhagen NV

S. Königsfeldt
Copenhagen Municipality, Road and Park Division, Njalsgade 13, DK-2300 Copenhagen S

ABSTRACT: One of the main roads to the town of Copenhagen was constructed in 1942 during the Second World War as a 4 lane concrete pavement. The slabs are constructed directly on the clay subgrade using a 50 mm slag material levelling layer. The pavement has, despite of a traffic load of about 150,000 10t ESAL per direction per year, functioned until today, but over the last 10 years in a very poor condition.
The preliminary investigations revealed that several of the concrete slab corners were badly supported, that the soil below the concrete had surface E moduli of down to 35 MPa, while the clay material had CBR values of down to 19 %. A preliminary design with estimated E values of 6,000 MPa for the cracked and seated concrete layer resulted in a designed asphalt overlay with a thickness of 170 mm for 6.0 mill. 10t ESAL equivalent to a design period of approx. 40 years.
In the Spring of 1999 a small test section was selected. The concrete pavement was cracked and seated and FWD measurements were carried out. The measurements resulted in design E values of the cracked and seated concrete slabs of 1,600 MPa. The redesign resulted in an asphalt overlay thickness of 200 mm for 4.8 mill. 10t ESAL equivalent to a design period of approx. 32 years.
After construction of the asphalt layer, the FWD measurements on the asphalt surface revealed that the E values of the cracked and seated concrete layer had changed to 7,000 MPa over the cracks. These results were later confirmed partly by measurements carried out one year later during the second half of the rehabilitation of the old concrete pavement, partly by measurements carried out two years after the construction.

KEYWORDS: Crack and seat, E moduli, concrete pavements, FWD (Falling Weight deflectometer), back-calculation

1. INTRODUCTION

This project is about an old concrete pavement based directly on a clay subgrade, which was successfully rehabilitated using the "crack and seat" technique. The road is one of the primary roads into Copenhagen, Gl. Køge Landevej, which in 1998 carried about 152,000 single axle loads (10 t) per year per direction (equivalent to 366,000 8t ESAL). In 1998 the pavement was in a very poor condition with corner cracks and transversal cracks of the concrete slabs and with differential settings of the different slabs.

The concrete pavement was constructed during World War II in 1942. The concrete thickness is about 200 mm and is founded directly on the subgrade using a 30-100 mm slag material as layer. The concrete pavement was constructed as an unreinforced and undowelled pavement with a slab size of approximately 3.5 m x 7.0 m.

As the subgrade contained an old sewage pipeline from about 1910, the City of Copenhagen was not interested in rehabilitation in full depth and they therefore asked for an alternative rehabilitation method.

Based on former experience with "crack and seat" techniques used on old concrete pavements it was decided to carry out preliminary testing in order to see, whether this method was suitable for the concrete pavement.

Before, during and after the rehabilitation of the road the following investigations have been carried out:

- Preliminary investigation
- Test section
- FWD screening of the entire pavement
- FWD control of the first 500 m rehabilitation carried out in 2000

The results of these investigations are described below.

2. PRELIMINARY INVESTIGATIONS

In December 1998 preliminary tests were carried out on selected representative concrete slabs of the old concrete road. The preliminary investigations involved FWD measurement of 10 slabs and material investigations of 4 slabs.

The preliminary FWD investigations revealed that generally the concrete pavement was in a relatively good condition with load transfer across the joints above 80% and with differential deformations only in one case higher than 0.050 mm as required as maximum by the Asphalt Institute, and with zero load deflections between 0 and 0.025 mm which is well below the "Carl Bro criteria" that normally requires zero load deflections less than 0.15 mm.

The results of the back-calculations (2-layer system) show concrete E values between 7,000 MPa and 33,000 MPa and subgrade E values between 37 MPa and 92 MPa.

The material investigation revealed that the slabs in the outer lane had a thickness of about 200 mm while the slabs in the inner lane had a thickness of about 160 mm.

The concrete core analyses showed that the concrete, except for the cracks, were in a relatively good condition.

The analysis of the clay subgrade material showed a clay material with a high strength (CBR-values above 19%) but in a relatively poor compaction condition (compaction degrees down to 85%).

The relatively poor compaction degree explains the differences between the back-calculated subgrade E moduli of 35-60 MPa and the CBR values higher than 19%.

The conclusion of these investigations was that the "crack and seating" solution was probably a suitable rehabilitation method in connection with this pavement.

Based on the results of the preliminary investigations, a preliminary overlay design was carried out (see table 1) based on Danish design criteria, a design period of 40 years and an annual design traffic of 139,400 ESAL (100 kN axle load) in each direction corresponding to 5,975,000 ESAL in the design period (14.5 mill. 80 kN ESAL). The material design E modulus of the cracked and seated concrete layer of 6,000 MPa is based on Carl Bro's experience.

The design resulted in an asphalt overlay design thickness of 170 mm. Further the economic and environmental calculations showed that this rehabilitation solution was much more feasible than a new construction so it was decided to carry out crack and seating on a test section of the pavement.

Table 1. Preliminary asphalt overlay thickness design

Investigation	Asphalt overlay		Cracked and seated concrete		Subgrade	Design period	Design traffic
-	Design thickness	Design E modulus	Design Thickness	Design E modulus	Design E modulus	-	100 kN axle load
-	mm	MPa	mm	MPa	MPa	Year	ESAL
Preliminary	**170**	3,820	200	6,000	35	40	6.0 mill.

3. TEST SECTION

The test section was selected in order to represent the areas with the lowest bearing capacity as found by the FWD measurement, in the preliminary investigations.

The following FWD investigations were carried out at the test section:

- Before crack and seating
- After and 5 passages of 12t steel wheel compactor
- After and 7 passages of 12t steel wheel compactor and 2 passages of 20t rubber wheel compactor
- On top of a covering layer of 60 mm asphalt base course

Each series of FWD measurements were carried out at the same points and the FWD measurements were repeated.

Figure 1: The surface of the crack and seated concrete slabs at the test section

Further settlement, crack pattern and core were investigated.

The back-calculation of the FWD was carried out using the RoSy back-calculation software. These calculations were carried out as if the cracked and seated concrete was a homogeneous layer.

The surface of the cracked and seated concrete slabs on the test section can be seen in the photo, figure 1.

The conclusion of the investigations of the test section is based on the FWD measurements that the back-calculated mean material E modulus of the concrete layer after crack and seating drops down to almost the same value and centres of the concrete slabs (about 2,150 MPa) from generally higher values before crack and seating (see table 2).

Table 2: Back-calculated E modulus of concrete layer on test section before and after crack and seating (C & S). A fixed E modulus of 3,845 MPa is applied for the 60 mm asphalt overlay

E modulus of concrete layer					
FWD measurement	Before C & S -	After C & S 5 roller passages	After C & S 7 roller passages	After C & S 9 roller passages	After C & S and 60 mm asphalt
	MPa	MPa	MPa	MPa	MPa
All Points	5,950	2,150	1,900	2,250	2,150
Slab centre	9,700	1,650	1,250	1,650	2,500
Slab joint	5,650	2,000	1,850	1,900	2,100
Slab corner	4,100	2,700	2,500	2,950	2,100

The E modulus of the cracked and seated concrete layer below the asphalt layer was calculated by fixing the asphalt E modulus at 3,845 MPa (temperature 15° C during measurements).

The surface E modulus, illustrated in fig. 2 demonstrates clearly the changes in E modulus from before the crack and seating till after the crack and seating and after the construction of the 60 mm thick asphalt layer. The highest drop in E modulus is naturally registered at the centre of the slabs, while there in some of the corner spots are improvements of the E modulus after the crack and seating and 60 mm overlay.

Furthermore, a variation in E-modulus from measuring point to measuring point can be seen, which shows the differences in the placement of the FWD close to or between the cracks from the crack and seating. This is illustrated clearly below.

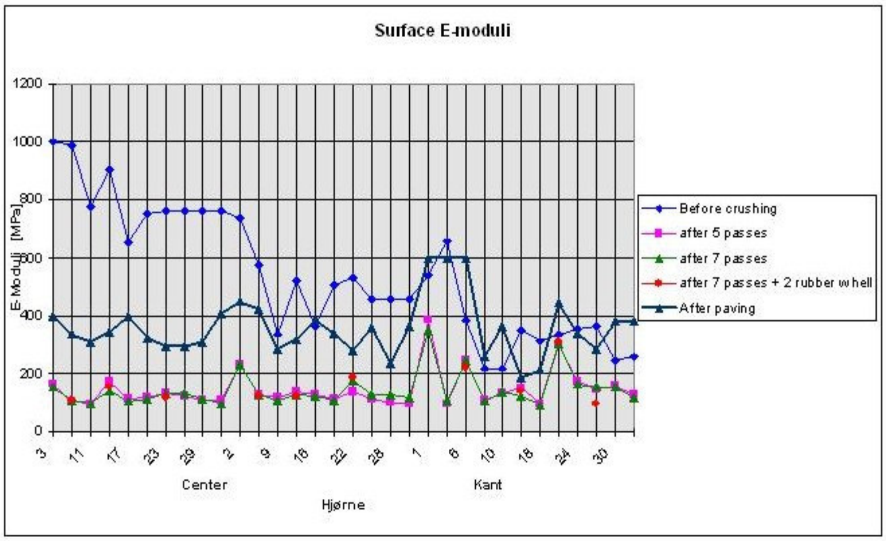

Figure 2: Surface E modulus measured on the test section.

Because of the findings of a relatively low β value of the cracked and seated concrete layer, a redesign of the thickness of the overlay was carried out, using the results from the cracked and seated test section, using an 85% reliability level.

The calculation presentation and results can be seen in table 3. Based on the characteristic β values of the subgrade and the cracked and seated concrete layer from the test section and the lower design period of 32 years accepted by the engineers from the City of Copenhagen, a 200 mm asphalt overlay thickness was calculated.

Table 3: Corrected asphalt overlay design based on findings from the test section

Investigation	Asphalt overlay		Cracked and seated concrete		Subgrade	Design period	Design traffic
-	Design thickness	Design E modulus	Design thickness	Design E modulus	Design E modulus	-	100 kN axel load
-	mm	MPa	mm	Mpa	MPa	Year	ESAL
Test section	**200**	4,000	200	1,566	55	32	4.8 mill.

The results of the crack pattern investigation and the evaluation of the cores showed that the load used for the crack and seating should be reduced and it also demonstrated that the crack and seating should be carried out using a guillotine blade.

Furthermore the conclusion of the test section was:

- Stress relieving of the concrete slabs can after some modification be carried out successfully.
- The insufficient support at some of the corners of the concrete is eliminated by the stress relieving method
- The mean settlement of the concrete was 16 mm with single values up to 30 mm after the crack and seating and compaction.
- The asphalt covering layer has a significant influence upon the improvement of the bearing capacity of the pavement having stress relived concrete slabs. 60 mm of asphalt layer increases the bearing capacity with more than 100% with regard to the FWD measured surface moduli on top of the pavement.

4. FWD SCREENING OF ALL PAVEMENTS

In order to be sure that there were no sections with lower bearing capacity than the test section, the pavement of the road was screened by carrying out 255 FWD measurements in all four lanes throughout the whole length of the road, about 1000 m in total.

The aim of these measurements was to investigate the:

- E modulus of the subgrade
- Support of the corners and the concrete slabs joints

All points measured were subjected to three load levels (6, 12 and 16 tonnes) and the deflection bowls were recorded for each load level.

Based on the measurements at the three different load levels, the "zero load deflection", (determination of the deformation by extrapolation, the working line to zero load), calculated at each measuring point. Figure 3 shows an example of these calculations.

Figure 3: Example of "Zero load deflection" calculation, from the FWD screening of the complete pavement

From the analysis of the “zero load deflection”, it could be concluded that only a few points had problems with the support of the plates, according to Carl Bro’s standard requirement that requires zero load deflection less than 0.150 mm.

Based on the back-calculated E moduli, it was concluded that the pavement generally had a better quality of concrete than the test section and that none of the plates were in such a bad condition that replacement would be necessary.

Further, it was concluded that the asphalt overlay design based on the results from the test section was a little conservative, meaning that additional structural life in the range of 0 to 10 years could be expected.

5. FWD CONTROL OF THE FIRST 500 M REHABILITATION CARRIED OUT IN YEAR 2000

The rehabilitation of the main section was divided into 2 sections of approx. 500 metres each.
The first section was rehabilitated during the summer of 2000, and was paved with 16 cm asphalt base material, with the 4 cm wearing course postponed until the summer of 2001.

During the work with the crack and seating of the concrete slabs and after the paving of the 160 mm asphalt base course FWD measurements were carried out in order to check that the strength that had been calculated during the planning was achieved.

The measurements were carried out in the outer lane in both directions. The asphalt temperature during the measurements was 18 to 21 degrees centigrade.

Figure 4: The surface of the cracked and seated surface of the old concrete pavement.

The measurements were used to calculate the surface E moduli and to back-calculate the E moduli of Asphalt + cracked concrete and the subgrade. Also analyses were performed to see the variation in E moduli of the cracked concrete.

The picture in figure 4 shows the surface of the cracked and seated surface.

Figure 5 shows the calculated surface E-modulus using the Bousinesq formula for a one-layer system and a Poisson’s ratio of 0.35.

As can be seen from figure 5, there is no reason for dividing the pavement section into smaller more uniform sections.

The results of the back-calculation using the Carl Bro RoSy back-calculation software are illustrated in figure 6. For these calculation a 2-layer system has been used, where the composite layer (the asphalt and the cracked and seated layer is regarded as the first layer and the subgrade below as the second layer.

As can be seen in figure 6 the subgrade E moduli vary between 60 and 120 MPa. While the 360 mm thick composite layer of asphalt and cracked concrete varies between 5000 and 16,000 MPa.

The variation is most likely caused by the difference in the shape of the deflection bowls depending on the position of the measurements, whether the measurements were taken over one of the cracks or in between the cracks of the cracked and seated layer.

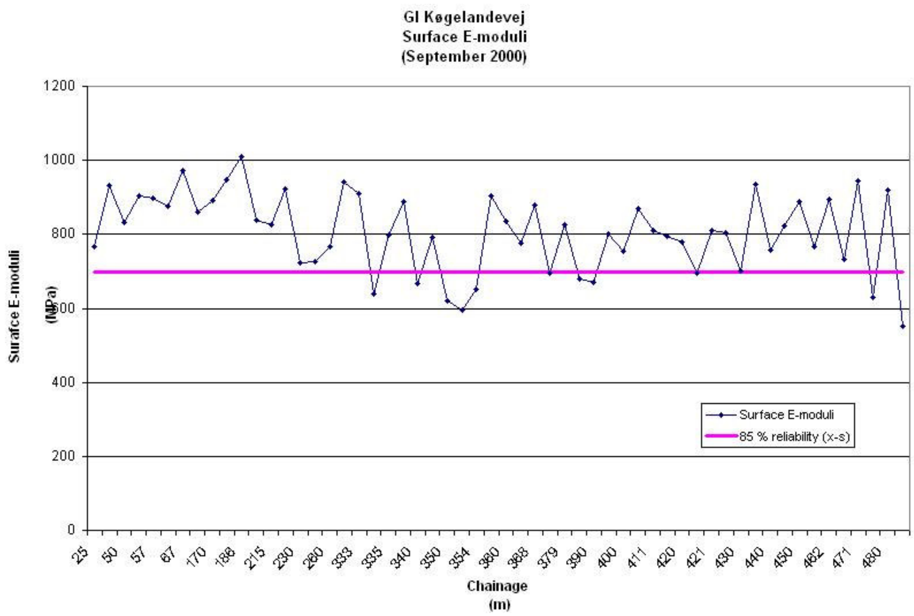

Figure 5: Surface E moduli from the FWD measurements carried out on the first 500 m rehabilitation after construction of 160 mm asphalt base course overlay.

In order to be able to calculate the E-modulus of the cracked and seated concrete layer, the results were divided into four groups depending on the size of the subgrade E modulus, which divide the road into two sections (0- 330 m offset and 330 – 490 m offset), and depending on the size of the E modulus of the composite layer (Ec).

It was decided to define measuring points with Ec higher than 10,000 MPa as points situated between cracks in the cracked concrete layer and measuring points with Ec lower than 7,000 as points situated over cracks in the cracked concrete.

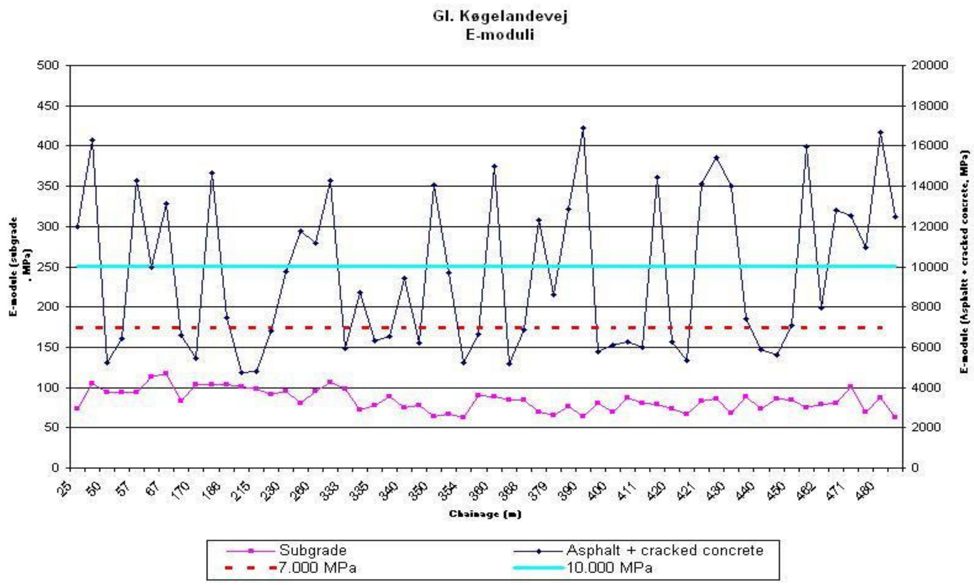

Figure 6: The back-calculated E modulus of the cracked and seated layer after construction of the 160 mm asphalt overlay.

The calculated mean E modulus of the cracked and seated concrete layer in the four groups can be seen in table 4 together with the back-calculated subgrade E modulus. The mean E modulus of the cracked and seated concrete layer is calculated using an estimated E modulus of 4,583 MPa for the Asphalt layer at the measured asphalt layer temperature of 20 degrees C.

Table 4: Back-calculated material E modulus of cracked and seated layer calculated using a fixed asphalt E modulus of 4,583 MPa (Asphalt temperature during measurement 20° C).

Grouped layer E modulus			
Section	m	0 - 330	330 - 500
E modulus of cracked and seated concrete layer measured between cracks	MPa	55,000	58,000
E modulus of cracked and seated concrete layer measured over cracks	MPa	8,500	9,300
Subgrade E modulus	MPa	97	77

From the tables appears that this calculation of the E modulus of the cracked concrete has resulted in mean E moduli between 8,500 MPa and 9,300 MPa for the measurements “over cracks” and mean E moduli between 55,000 MPa and 58,000 MPa for measurements “between cracks”.

Looking at the values for the calculation of the E modulus “between cracks”, it seems obvious that these values are too high, which is due to the reason that the theoretical E moduli for the asphalt layer are estimated at a too low level.

But changing E modulus of the asphalt layer to a higher level and consequently get lower E modulus for the cracked and seated concrete layer will result in approximately the same overlay thickness design, and as the asphalt E modulus is based on the Danish design standards, it has been decided not to change the fixed asphalt E modulus.

Table 5: Control design of the structural life of the cracked and seated concrete, based on the FWD measurements of the rehabilitated pavement before construction of the asphalt wearing course. The calculation assumes asphalt overlay thickness of 200 mm using a 85% reliability level for the design E-moduli of the cracked and seated layer and subgrade.

Investigation	Asphalt Overlay		Cracked and seated concrete		Subgrade	Design period	Design traffic
-	Design thickness	Design E modulus	Design thickness	Design E modulus	Design E modulus	-	100 kN Axel load
-	mm	MPa	mm	MPa	MPa	Year	ESAL
Section 0-330	200	4,000	200	5,800	87	**74**	**11.0 mill.**
Section 330-500	200	4,000	200	8,000	68	**63**	**9.4 mill.**

Assuming a traffic forecast of 0% increase of traffic per year on this road, the FWD control of the rehabilitated pavement shows, that the pavement should be expected to have the residual life of min. 63 years.

This is almost the double of the design life based on the result from the test section.

The results show that the thickness of the asphalt overlay has a significant influence on the E moduli of the cracked and seated layer. The thicker the overlay, the higher the design value of the cracked and seated layer.

After five years' use the road is functioning perfectly.

6. CONCLUSION

The results of the FWD measurements of cracked and seated concrete show that:

- FWD measurements can be used for control of, whether the cracking and seating is effective or not.

  Back-calculated material values show mean E moduli of the FWD measurements between the cracks of about 55,000 MPa and mean E moduli of the FWD measurements over cracks of about 9,000 MPa – in both cases measurements were carried out after construction of 200 mm overlay.

  FWD measurements over the cracks directly on the surface of the cracked and seated concrete show mean values of about 2,000 MPa.

- The interpretation of the FWD measurements also reveals that when carrying out FWD measurements on top of a pavement with a cracked and seated concrete layer as base course, it is important to distinguish between measurements over the cracks and measurements between the cracks.

- The design E moduli of the cracked and seated concrete cannot be calculated from the FWD measurements made on top of the surface of the cracked and seated concrete, while the design E moduli of the cracked and seated concrete changes significantly with the construction of the asphalt overlay.

  Design E values of the cracked and seated concrete based on the back-calculated values from the FWD measurements changes in this project from design values (85% reliability) of 5,800 to 8,000 MPa from measurements on the surface of the newly constructed 200 mm asphalt overlay. The design E moduli are in this project all calculated from measurements over the cracks.

- Furthermore, the FWD measurements show that the E moduli of the cracked and seated concrete vary with the thickness of the asphalt overlay. In this project the E moduli change from about 2,200 MPa with a 60 mm asphalt overlay to a value of about 9,000 MPa with a 200 mm asphalt overlay.

REFERENCES

Bemanian, S., 1998. Rubbilization, *Crack and Seat Effective in Nevada*. Internet presentation.

Shisheng Wu, 2002. Rujun Yin, 2002. *Evaluation of Overlay on Concrete Slab in Airport with 3D FEM*. BCRA proceedings 2002.

Pedersen, J. P., 2002. *Validation of FWD Measurements in Connection with Outsourcing Contract*. BCRA proceedings 2002.