NEW TECHNOLOGIES FOR CONCRETE PAVEMENT CONSTRUCTION

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ABSTRACT

New technologies for concrete pavement construction have been demonstrated on a 1750 m long access road to the freeway system in the Northern part of Jutland in Denmark during the autumn of 1995.

The new technologies refer both to the cement treated granular base (ROADBASE) and to the concrete pavement itself. The latter being the result of a Brite-EuRam project "ECOPAVE".

In the cement treated granular base 25 vol% of the materials are reused products which otherwise had to be landfilled. The reused products are old asphalt, low quality flyash and dust from cement kilns.

Due to mechanical vibration a few days after paving, a system of microcracks have been established in the baselayer. For this reason no random cracking formed. The risk for reflective cracking in an overlaying asphalt- or concrete layer therefore is minimized.

The concrete layer itself is constructed according to the ECOPAVE (ECOnomic PAVEment) principles. Active transverse cracks for every 1.5 m have been established within two days after paving, thus minimizing the crack widths and thereby eliminating the use of expensive dowels across the cracks. Due to the narrow crack width, load transfer is secured by interlocking between aggregates and rough crack surfaces.

The 8.4 m wide, 120 mm thick, ROADBASE layer as well as the 8 m wide 200 mm thick ECOPAVE layer have been paved and totally compacted in full width only using an asphalt paver. The concrete was produced at a stationary concrete mixing plant. The mixing capacity equals a paving speed between 30 and 60 m/h.

Even with a cement content as low as 260 kg/m^3, and a content of microsilica of 20 kg/m^3, the 28 days compressive cylinder strength is higher than 90 MPa. The concrete is freeze/thaw resistant, even in the presence of deicing chemicals though no air entrainment has been used.

INTRODUCTION

The traffic loads on the main roads in Europe have increased markedly during the last years. An increased amount of transported goods, and higher allowable axle loads are the main reasons for this. The increased use of super-single tires have increased the loading further, resulting in serious rutting of the asphalt pavements.

Pavements which minimize rutting, reduce energy consumption and decrease traffic noise can be produced with modern concrete technology. During the last few years new construction techniques, which in addition decrease construction costs considerably, have been developed.

Within the EU, it was foreseen in 1990, that the necessary annual maintenance cost of the roads would exceed 11,000,000,000 ECU (1) before 1996 . It is likely to be a serious underestimate, due to the marked increase in traffic loads until now. The maintenance cost in the new members of the EU will of course increase the total maintenance cost further. Furthermore, it is expected that the allowable axle load will be increased again in order to enhance the capacity on the existing roads.

On this background a strong interest for durable and almost maintenance free roads is to be expected from road authorities as well as road users and tax payers. This is the case even when construction costs are somewhat higher than for a traditional pavement.

The road construction scheme in Denmark favors rather small jobs compared to other European pavement construction jobs. The largest jobs typically is 13 km of freeway corresponding to 210,000 m^2. Even if a contractor get such a job every year, investment in large equipment such as slipform-pavers and large mobile concrete mixing plants cannot pay off. For this reason a heavy asphalt paver has been used for the development of paving technique.

During the last ten years Aalborg Portland has invested about 30 man-years and 2 million ECU on development of material and paving techniques for construction of concrete roads as well as cement treated gravel bases. A large part of this work has been carried out in cooperation with other companies, and the EU has granted research funds from the Brite-EuRam program for parts of the development.

The developments have lead to new construction techniques. Techniques which have lowered construction costs considerably and furthermore are much more economical and technical capable for smaller paving jobs than traditional concrete paving. So far approximately 150,000 m^2 have been paved by Aalborg Portland utilizing these new techniques.

Performance results to date are encouraging, and because whole life costs are being increasingly taken into account during tender evaluation, the predicted low maintenance costs and longer service life of modern concrete pavements will enhance their advantages with respect to traditional pavement types.

The present paper deals with construction of a 1750 m long, 8 m wide road, situated near the city of Hjørring in the Northern part of Jutland. Construction was carried out in October 1995 using ROADBASE (crack-controlled cement treated granular base) and ECOPAVE.

CONCRETE TECHNOLOGY

Development of suitable paveable concrete mixes for ECOPAVE has led to concrete types very much like the types used for concrete paving blocks today, and to those used for concrete pavements in the 1930's. For the cement treated granular base materials the same paveability of the mix is used.

The water/cement ratio has even been reduced compared to the concrete types mentioned above. Water/cement-ratios below 0.3, and water/powder-ratios less than 0.25 are used. The concretes are produced without air-entraining agents, since the freeze/thaw durability is obtained through these low water/cement-ratios. The concretes can be mixed in free-fall mixers as well as in paddle-pan- and pugg-mill mixers.

Since the paver is very sensitive even to very small variations in the moisture content in the concrete, all possible efforts have to be taken to avoid such variations. An acceptable limit for the variation in the free water content is normally within ± 2.5 kg/m^3. In the actual job, the variation in the amount of added water was within ± 0.3 kg/m^3.

Frost- and alkali-silica resistant types of aggregates are used. For pavements with a surface of exposed aggregates, special requirements for abrasion resistance of the aggregates have to be fulfilled.

In order to obtain the best compaction and good stability immediately after the paver, it is preferred to use aggregates with aspect ratio close to unity, the coarse aggregates preferably with a cubic particle form, and the sand with a round particle form.

PAVING TECHNOLOGY

Paving is carried out using a paver with a high-compaction screed. So far all our paving has been carried out using a crawler driven Vögele Super 2000 paver owned by Aalborg Portland. This paver is capable of paving up to 8 m wide, and 250 mm thick, pavements in one operation.

Compared to the pavers normally used for asphalt paving, this paver is equipped with a high compaction screed having extensions of fixed lengths. Due to the special properties of concrete compared to asphalt, screeds having hydraulic extensions cannot be used.

With this high compaction screed (Figure 1) precompaction of the concrete is achieved through the tamper and the screed plate. High compaction is achieved by two pressure bars, which are pressed onto the pavement surface through hydraulic rams. They remain in permanent contact with the concrete. The pressure on the concrete excerted by these pressure bars is determined by their contact surface and the hydraulic pressure, which is infinitely variable up to 130 bars. A final screed plate improves on the surface quality. Some, rather small, modifications of the screed have been made in cooperation with Vögele in order to substantially improve the quality of the paving (2).

Special care must be taken to avoid or minimize segregation of the large aggregates; the larger the aggregates, the greater the tendency for segregation. Transferring of the concrete from mixer to truck and from truck to paver has a large influence of this. Furthermore, the sizes and the positioning of the individual augers in the paver are essential to minimize segregation and to give a homogeneous surface.

In order to obtain a good result, it must be recognized that concrete and asphalt do not behave in the same way in the paving process. Therefore special attention has to be paid about training the operating crew.

The paving technique is far less man power consuming than slipformpaving. A crew of four to five technicians, including the foreman, can easily run the paver.

DESIGN OF THE ACTUAL ROAD

The road acts as an approach road to the new freeway connecting Aalborg and Hirtshals. Underneath the pavement there are a 460 mm thick layer of sand and a 120 mm thick layer of mechanical stabilized gravel.

The pavement itself has a 120 mm thick and 8.4 m wide ROADBASE-layer below a 200 mm thick, 8.0 m wide ECOPAVE concrete layer. The construction was carried out by the Danish contractor Højgaard & Schultz and Aalborg Portland in a joint-venture cooperation.

ROADBASE

The crack control in the ROADBASE-layer is obtained by weakening some of the bonds between the cementitious binder and the aggregates. This is achieved by using crushed old asphalt as a part of the coarse aggregates. In order to ensure that the weakening is active, a heavy vibratory roller is used on the hardened pavement after two days, thus breaking the weakest bonds and creating a random network of fine cracks. After 18 months, and two winter periods, no random larger cracks have appeared. Development of the ROADBASE concept has been carried out in cooperation with the Danish contractor Novejfa, who did not take part in the actual construction job..

The cementitious binder is composed of cement, dust from the electro filters of a cement plant and flyash of a low quality, which can not be used either in cement production or in normal concrete production. Use of a binder like this will in many cases reduce the materials cost, since no fines have to be added to the gravel.

As a result, approximately 25 volume percent of the ROADBASE material is reused products which otherwise had to be landfilled. The replacement of kiln dust by fly ash does not produce much variation in ROADBASE properties.

Mix design and the obtained compressive strengths [cylinders] for the ROADBASE-layer in Hjørring are shown in table 1.

The ROADBASE layer was paved with a speed of 1 m/min, corresponding to 60 m^3/hour. The layer was fully compacted by the paver in full width; 8.4 m. On previous tests the homogeneity of the layer was so good, that the standard deviation on density, measured on 30 drilled cores was approximately 1%. Besides there was a strong correlation between the density measured on drilled cores and the in situ measurements with radioactive gauges. For the latter, the standard deviation was 2.2%. For this reason, the control of the quality of the compaction on the actual road paving job was carried out only by one set of density measurements per 500 m^3 material. It was furthermore accepted, that this control be carried out solely with radioactive gauges. A standard deviation of only 2.1% was obtained.

The layer was cured with a bitumen emulsion. During the following concrete paving it showed up, that such emulsion adheres to the crawler belts giving rise to some problems. It can therefore be recommended to use a normal concrete curing instead.

ECOPAVE

The original ECOPAVE concept was a composite multi-purpose paving system, with a modified cement-bound structural layer with a controlled cracking system and surfaced with a thin bituminous wearing course.

To avoid reflective cracking in the wearing course, a close system of predetermined narrow cracks was introduced in the structural layer. Due to aggregate interlocking across these narrow cracks the load bearing capacity across the cracks are high, and the vertical movements of the individual slabs of the pavement are hindered. Thus expensive dowels are eliminated.

The ECOPAVE-system was developed between 1988 and 1992 within the European Communities' Brite-EuRam program by an Anglo-Danish consortium with five partners; Trafalgar House Technology Ltd, Research and Development Centre, UK; The Transport Research Laboratory, UK; Dansk Beton Teknik A/S, DK; The Danish Road Institute, DK and Aalborg Portland A/S, DK (3).

In parallel with the research carried out in the ECOPAVE project, further developments with regard to both concrete- and paving technology were carried out. As a result of this, an even concrete pavement with a noiseless surface texture which reduces fuel consumption can be produced.

Logically, this technique is suitable for ECOPAVE, if the intended crack system can be produced without destroying the surface texture and evenness. During the summer period of 1993, such a crack forming technique was successfully developed by Aalborg Portland and Højgaard & Schultz..

ECOPAVE CONSTRUCTION IN HJØRRING

The 8 m wide, and 200 mm thick pavement was paved and compacted in one operation. Active transverse cracks were established every 1.5 m. Two 10 mm tiebars were placed across the longitudinal crack for every 1.5 m section. The central part of these bars were epoxy coated to avoid corrosion. No bituminous wearing course was applied.

The thickness of the ECOPAVE layer was determined according to normal concrete pavement design. The higher concrete quality, and the ECOPAVE concept, might in future lead to a decrease in thickness and thereby a reduction in construction costs.

Mix design and properties of the concrete are shown in table 2.

The maximum aggregate size was 12 mm, but even better noise reduction can be achieved by using smaller aggregates, d_{max} = 8 mm (4). The main reason for this choice is, that it is very difficult to obtain the desired stability of the freshly paved concrete in 200 mm thickness with aggregates smaller than 12 mm. Aggregates with a polished stone value (PSV) of 52 was used in order to minimize abrasion of the exposed aggregates.

On the mixing plant a carefully control of the moisture content of the aggregates, the water content, the density of the fresh concrete and a visual inspection of the concrete was carried out. As a result of this, not one single batch of ROADBASE- or ECOPAVE material was rejected from a total production of 4500 m^3.

The accuracy on the mixing plant resulted in very small deviations from the planned amounts of materials in each batch. Deviations from the correct mix design are presented in Table 3
Both the ROADBASE- and the ECOPAVE-concrete were mixed at a stationary mixing plant on a 3 m^3 paddle-pan mixer. The mixing plant was situated 40 km from the site. Transport of the material was carried out on 30 tons trucks. During transport the concrete was covered under tarpaulins to protect against the elements.

The ECOPAVE layer was paved with a speed of 0.5 m/min, corresponding to 48 m^3 concrete/hour and an average daily production of 300 m pavement.

Compared to the theoretical watersaturated density, the average degree of compaction of cores taken from the pavement is 96.4%. The standard deviation on the density is only 0.7%.

Construction of the ECOPAVE-layer involved several different operations:

Paving

Paving was carried out with the Vögele paver, operated by three technicians and one foreman. A simple system for placement of the tiebars across the longitudinal joint was arranged.

Curing

- A French product, Pieri Cromofibre Retarder, which both act as a curing membrane and a retarder was used. The agent was applied almost immediately after the paver. After approximately 30 minutes the agent had dried up, and it was possible to walk and drive on the surface.

Sawing of the transverse crack guides

The transverse crack guides was cut with a Soff-Cut saw, which can make the saw cut without water. Furthermore, the saw can be used on very fresh concrete. The cracks were sawn after 7 to 8 hours with width 3 mm and depth 25 mm. A special guide was constructed to control the straight cut and the distance between the individual cut (see figure 3). With this equipment, two technicians were able to carry out 200 cuts of 8 m lengths in less than 10 hours.

Sawing of the longitudinal joint

The longitudinal joint (width 4 mm, depth 60 mm) was cut with an ordinary diamond saw as soon as possible, normally within 16 to 20 hours after paving.

Exposure of the aggregates in the surface

The aggregates were exposed by water jetting at water pressure of approximately 100 bars. This was carried out on one day old concrete after sawing the transverse and longitudinal joints.

Creating the transverse cracks

In the ECOPAVE concept it is of utmost importance, that all the transverse cracks are active from the beginning, otherwise the first natural cracks to appear will be so wide, that the load transfer due to aggregate interlocking will not function.

- Two days after paving, a heavy weight guillotine system was used to create the cracks. Before cracking a piece of azobe wood was placed on top of the crack guide, see figure 4. Visual inspection during this operation, and inspection on drilled cores later, have documented that all cracks are active.

Curing

For the final curing a bitumen emulsion has been used. This emulsion even penetrated the cracks, thereby reducing water penetration. No other sealants were used in the joints.

During the summer period crack movements on 20 cracks, randomly distributed along the road were monitored. On the day of measurement, the temperature of the black bitumen-coated surface varied from 17 °C in the morning to 33 °C in the afternoon. On the straight part of the road an average change in crack width of 0.045 mm was measured; in the outer part of the curved part of the road, the change was somewhat larger. No attempts have been made to correlate these measurements with theoretical values, since no information on temperature variation in the concrete layer is available.

Load transfer efficiency [LTE] has been measured on two sections of the road. One on the straight section and one on a curved section with a radius of 1500 m. The requirements to the LTE was fulfilled in both lanes on the straight section as well as in the inner lane in the curved section. In the outer lane in the curved section, the LTE did not fulfill the requirements. This is in agreement with the measured larger crack movements, and suggests that the crack distance ought to be reduced in curves. The measured LTE's are shown in Figure 5.

SURFACE TEXTURE

During the last years, a large amount of research has been carried out on the relation between surface texture and noise level from the traffic.

The noise is generated partly by vibrations in the tires, partly from the air pressed in front of the wheel and sucked in behind it. Therefore, the lesser the vibrations in the tires and the lesser the resistance towards movement of the air, the less the noise (5).

It is now possible to define the surface texture by a wavelength and an amplitude. In such terms, the lowest noise will arise from a surface having small amplitudes for wavelengths larger than 10 to 15 mm, and large amplitudes for wavelengths smaller than this. Such a surface will minimize vibrations in the tires, make air movement easy and further ensure quick draining of water, and thereby secure a good skid resistance under nearly all weather conditions.

On the other hand, large amplitudes for wavelengths larger than 20 to 30 mm gives rise to an increased fuel consumption (6).

A surface texture having rather high amplitudes for wavelengths below approximately 10 mm and small amplitudes for larger wavelengths, can be produced by the new paving technique. Since no rollers are used for compaction, the evenness (large wavelengths) is controlled by the paver. As long as the paver is supplied with an ample amount of suitable concrete of constant quality, the automatic leveling system is very accurate. Evenness within 1 mm on 4 m has been measured on almost all of a 6 km long pavement constructed in the western part of Norway in 1991. However, even when evenness is within such limits, a small systematic wave can be obtained, caused by the hysteresis in the automatic leveling system. Bumpcutting can eliminate this problem. However, in that case it will not be able to obtain the noise reduction caused by the exposed aggregates. It is therefore recommended to pay more attention to the accuracy of the automatic leveling equipment on the paver.

The high amplitude for wavelengths smaller than 10 mm can be produced by exposing the aggregates in the surface. The aggregates have to be smaller than 8 mm. Such a surface can be as quiet as a porous asphalt pavement according to Austrian experience (4).

CONSTRUCTION COSTS

Cost calculations on ROADBASE

The actual road construction job was not large enough to be used for a realistic judgment of construction costs. However, for the tender the costs were calculated both for a traditional cement treated granular base and for ROADBASE. These calculations indicated that ROADBASE-construction costs are some percent lower than the costs for construction of a traditional cement treated granular base.

Cost calculations on ECOPAVE

A computer-based comparative cost model has been developed by Trafalgar House Technology to identify the cost benefits of ECOPAVE against flexible, rigid and traditional composite pavements in the UK. The model is designed to combine pavement design with information on material costs and process parameters to produce an overall construction cost.

This cost modeling demonstrates that initial construction savings up to 15% can be expected with ECOPAVE when compared with traditional flexible pavements in the UK. The cost savings are expected to be made both in materials and in the construction process. Such calculations will of course be dependent of the market prices in the different countries. However, the greatest advantage of the ECOPAVE system is the saving on the whole life cost. Because maintenance costs for ECOPAVE are

anticipated to be largely independent of traffic loading, the ECOPAVE system becomes increasingly attractive at higher traffic densities, when savings are predicted to be very substantial (3).

Tenders on Danish freeway sections

During spring and summer 1993, tenders for ECOPAVE-concrete pavements on two different sections of the new Danish freeways in Jutland were submitted. 1 section on 145,000 m^2 and 1 section of 205,000 m^2. These tenders have been studied by J.C.H. Hede (7). According to this study it was concluded, that the whole life cost for ECOPAVE was lower than for asphalt, even when the bids for asphalt pavements were app. 20% lower than the ECOPAVE bids. Furthermore, old German experiences have been used in the life time modeling. This experience defines that after 7 year, 1.8% of the pavement has to be renewed every year. A part of the extra construction costs for ECOPAVE compared to traditional asphalt is caused by in situ construction of the cement treated granular base. This cost has to be included in the construction costs for the concrete pavement, but not for the asphalt pavement since cement treated granular bases so far normally not are used under asphalt pavements in Denmark. Unfortunately, the Danish Road Directorate choosed another model for calculation of life time costs, and the freeway sections were constructed with traditional asphalt pavements.

Compared to traditional slipform paving, the ECOPAVE system tends to be approximately 20% cheaper in construction.

DURABILITY

Judging durability from laboratory tests will always be somewhat empirical, since, by nature, these tests have to be accelerated.

In an attempt to improve such a durability judgment for the new concrete pavement types, a comparison between an ECOPAVE type of concrete and a 58 years old concrete taken from a road still in use, has been carried out. Freeze/thaw resistance towards deicing salts, according to the Swedish Standard SS 13 72 44, version I/1988, and microstructure characterization on thin sections, for the two concretes were compared. According to this comparison, the ECOPAVE concrete will be at least as durable as the one 58 years old.

For the actual ECOPAVE section, the acceptance criteria with regard to freeze/thaw resistance was changed compared to the Swedish Standard. The maximum allowable amount of scaled material was decreased from 1 kg/m^2 to 0.6 kg/m^2 after 56 freeze/thaw cycles. On 16 cores, 150 mm diameter, no one exceeded this value, and the mean value was 0.25 kg/m^2. On thin sections a measurement of microcracks showed about 1/10 of the acceptable amount.

CONCLUSION

The road construction job described in this paper has shown, that the new materials- and paving techniques developed during the last years can be used on large jobs. The techniques have lead to marked reductions in construction costs compared to traditional concrete paving. The paving technique is furthermore economical and technical suitable for small areas.

The new techniques will eliminate or minimize problems with rutting. The maintenance cost will thereby also decrease and fewer traffic problems caused by repair works will arise.

Durable pavement surfaces with a texture giving reduced noise level and decreased fuel consumption resulting in improvement of the environment can also be obtained using the new techniques.

TABLE LIST

TABLE 1 Mix design and properties of ROADBASE

TABLE 2 Mix design and properties of ECOPAVE concrete

TABLE 3 Accuracy of concrete mixes, kg/m^3

TABLE 1 Mix design and properties of ROADBASE

Mix Design		Mixing	
Binder	250 kg/m^3	Mixing time	60 sec
Granulated reused asphalt	350 kg/m^3	Batch Size	2.5 m^3
Gravel 0/32 mm without filler	1600 kg/m^3	Compressive strength (cylinders)	
Free water	135 kg/m^3	7 days	6 MPa
Density	2375 kg/m^3	28 days	12 MPa

TABLE 2 Mix design and properties of ECOPAVE concrete

Mix Design		Mixing	
Cement [CEM I 42.5 NA]	260 kg/m^3	Mixing time	90 sec
Flyash	55 kg/m^3	Batch size	2 m^3
Microsilica	20 kg/m^3		
Plasticiser	4.2 kg/m^3		
Sand, gravel pit, 0/2mm	673 kg/m^3		
Stone, crushed granite 4/8mm	388 kg/m^3	Compressive strength (cylinders)	
Stone, crushed granite, 8/11mm	1055 kg/m^3	1 days	29 MPa
Free water	87 kg/m^3	7 days	69 MPa
Water / Powder ratio	0.26	28 days	94 MPa

TABLE 3 Accuracy of concrete mixes, kg/m^3

	Cem.	FA	MS	Sand	4/8	8/11	Plast	Water
Maximum deviation	3.1	1.5	0.6	2.7	1.6	7.4	0.1	0.9
Mean deviation	0.8	0.1	0.1	-2.0	-0.4	-3.2	0,0	-0.1
Dispersion	0,5	0,4	0.2	0,7	0,4	2,1	0,0	0,2

FIGURE LIST

Figure 1 Heavy Compaction Screed

Figure 2 Paving of the 8 m wide, 200 mm thick ECOPAVE layer

Figure 3 Soff-Cut saw and guide system

Figure 4 Guillotine on top of a sawn crack guide.

Figure 5 Distribution of Load Transfer Efficiencies

Figure 6 Surface texture, the maximum aggregate size is 12 mm. The active transverse crack can be seen.

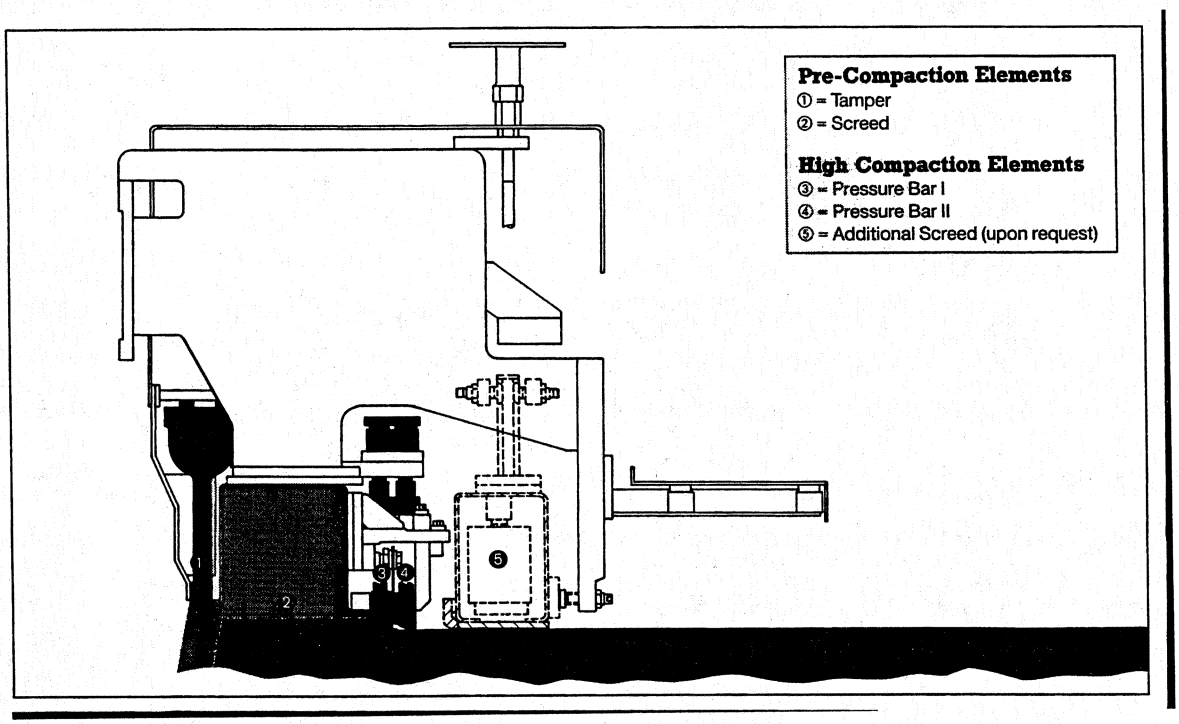


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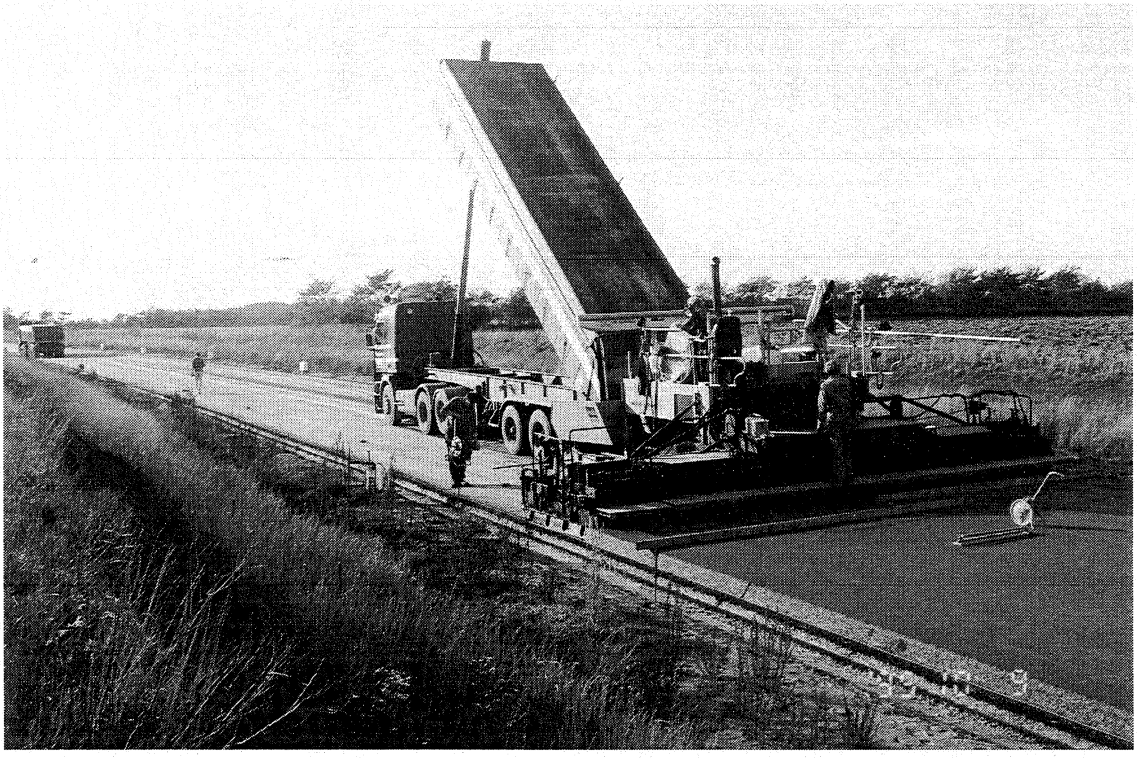


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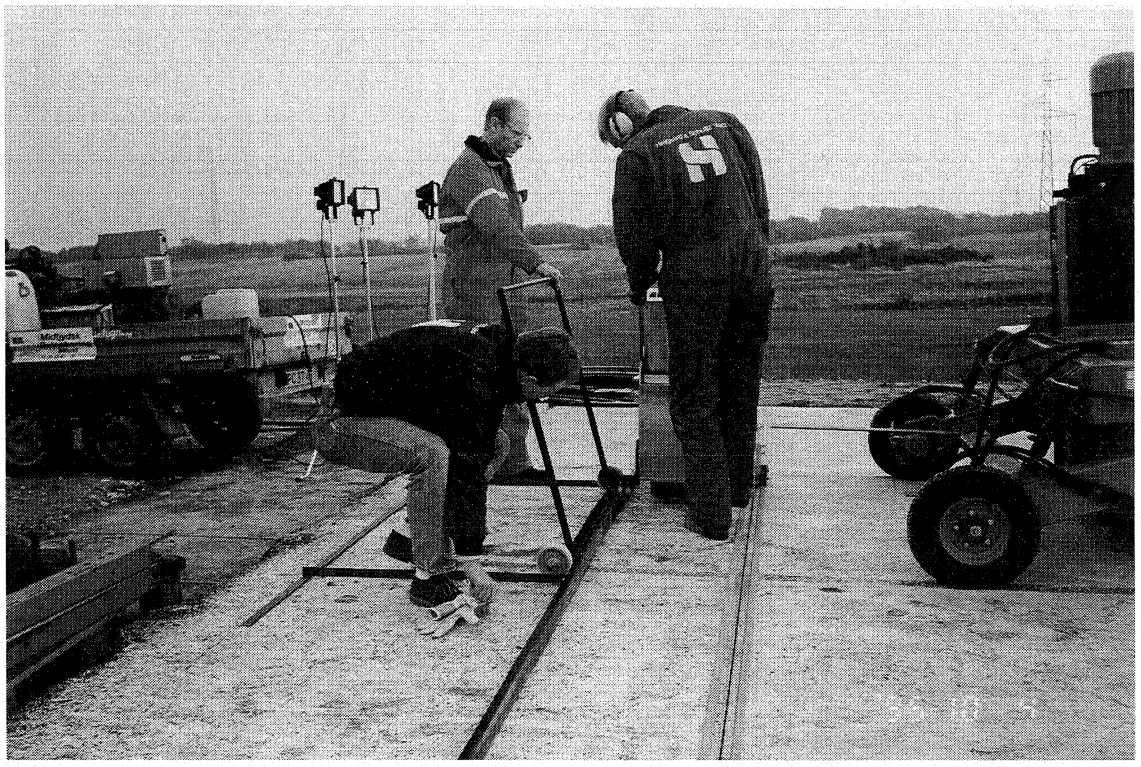


Figure 3 Soff-Cut saw and guide system

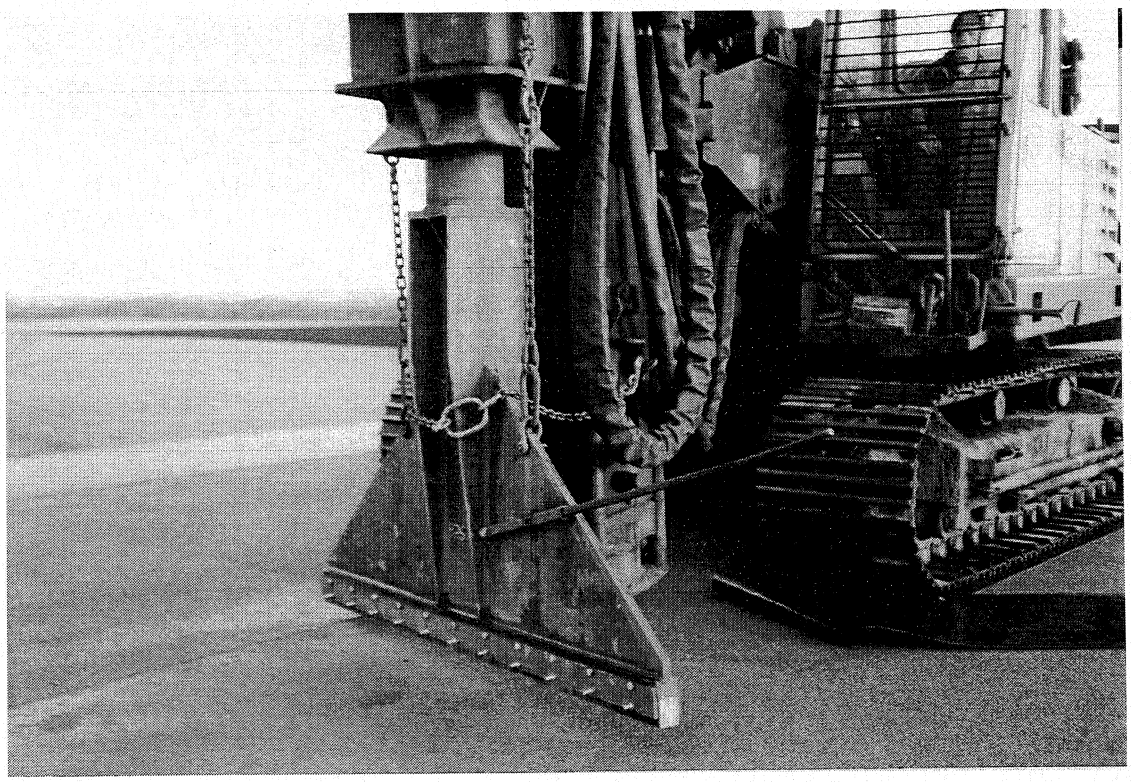


Figure 4 Guillotine on top of a sawn crack guide.

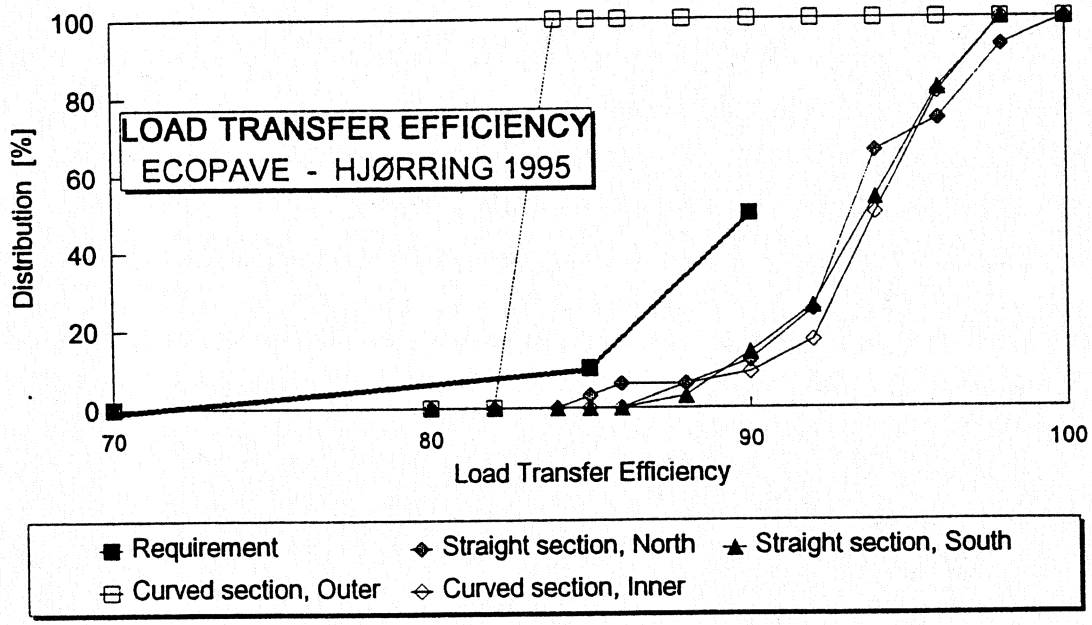


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