Rapid Rehabilitation Techniques with Cement Concrete Applied to Combatting Rutting and Rippling in Flexible Pavements

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Summary

In the Netherlands asphaltic roads are far more common than concrete road surfaces. As a result ruts and ripple formation on waiting lanes at intersections occur very frequently. This means that regular repair work has to be carried out at certain intervals, depending on the prevailing traffic load. Often the induction straps for the electronic traffic control have to be replaced too. The need to maintain these road sections places a significant and recurrent financial burden on road managing authorities. Moreover, repair techniques of this type often cause serious traffic disruption due to the excessively large volume of traffic presently using Dutch roads. A more permanent solution is replacing the affected area with a concrete surface. The advantages of an extended service life must be weighed against the considerable time required for the concrete to harden. However, it is unacceptable for a traffic lane to be out of order for a lenghty period.

At present two contractors are offering two new techniques which reduce the construction time to such an extent that it seems possible now to install cement concrete road surfaces between two consecutive rush hour peaks. One of these techniques uses doweled prefabricated slabs which are connected to each other. The second technique is based on the use of a high-quality concrete that hardens quickly and that is given a vacuum treatment after it has been applied. As little experience exist with these techniques two test sections were built. This paper describes the construction of these two test sections and deals with the results

Introduction

Since relatively few cement concrete roads have been constructed in the Netherlands, rapid repair techniques based on this type of material have only been applied on a limited scale. However, these techniques also have the potential to be used on asphaltic concrete road surfaces, which are far more common. One application currently being considered for cement concrete is the combating of ruts and ripple formation on waiting lanes at intersections.

Formation of ruts and ripples (corrugation) tends to develop at these locations because of the inherent visco-elasticity of asphaltic concrete (figure 1).

This means that regular repair work has to be carried out at certain intervals, depending on the prevailing traffic load. The need to maintain these road sections places a significant and recurrent financial burden on road managing authorities.

figure 1: Corrugation at a waiting lane

Moreover, repair activities of this type often cause serious traffic disruption due to the excessively large volume of traffic presently using Dutch roads.

A more permanent solution to rutting and ripple damage on asphaltic roads can be obtained by replacing the affected area with a concrete surface. However, the advantages of an extended service life must be weighed against the considerable time required for the concrete to harden. It is unacceptable for a traffic lane to be out of use for a lenghty period, because this would result in a severe disruption of the traffic flow. Moreover, it is often impractical to divert the traffic in such situations because of the large number of vehicles involved

In the past tests have been carried out to reduce the hardening time by using superplasticized concrete and rapid hardening cement. The results of these tests showed that a considerable amount of time can be gained. Still the time it takes before the road can be used again exceeds the period between two consecutive rush hour peaks. A further reduction of the hardening time though, may lead to significant reduction of the concrete quality.

At present, contractors are offering two new techniques that reduce the construction time required to such an extent that it seems possible now to install cement concrete road surfaces between two consecutive rush hour peaks without the quality of the concrete being affected.

One of these techniques avoids the problems caused by having to wait for in situ concrete to harden, by using prefabricated slabs. These slabs are already fully hardened before they are transported to the site. The other method is based on the use of high-quality concrete that hardens quickly and that is given a vacuum treatment after it has been applied.
With the vacuum treatment the start of the hardening proces can be put forward for several hours.

The salient features of both techniques are outlined below.

Prefabricated cement concrete slabs

The dimensions of the slabs are selected to comply, wherever possible, with existing road building practice. A standard length of approximately 5 m is usually employed while the width of the slab normally matches that of the traffic lane (figure 2).

The thickness of the slabs varies between 18 and 22 cm and can be adapted to the site conditions. The slabs are provided with a double reinforcement system to allow them to be transported. This reinforcement contributes for a considerable part to the strength of the surface during the operational period. Because of the weight of these slabs, which is about 9 tons, they must be lifted

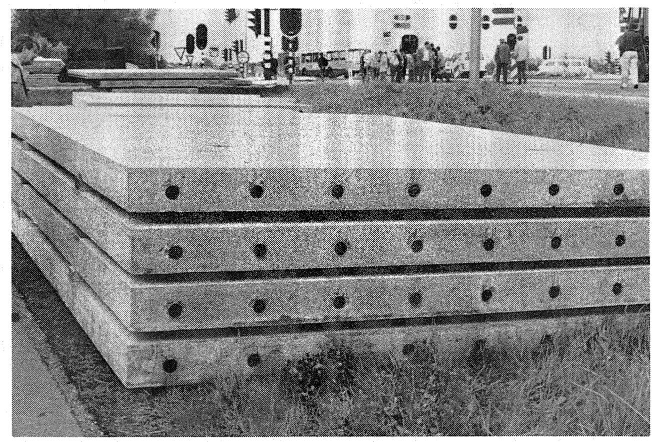

figure 2: Prefabricated concrete slabs

with a large crane. Four mounted picklocks at the surface of the slabs allow lifting them into position.

The slabs are supported on a foundation of lean concrete, which must be applied very evenly. The composition of this material is such that it can sustain the traffic loads without deforming, immediatly after it has been laid. Therefore no extra water is added to the mixture. At this stage there is no hydraulic binding yet. The cement is just as a filling substance, part of the mixture. After a while the hardening will start and eventually lead to a type of foundation that is highly resistant to climatic influences such as erosion.

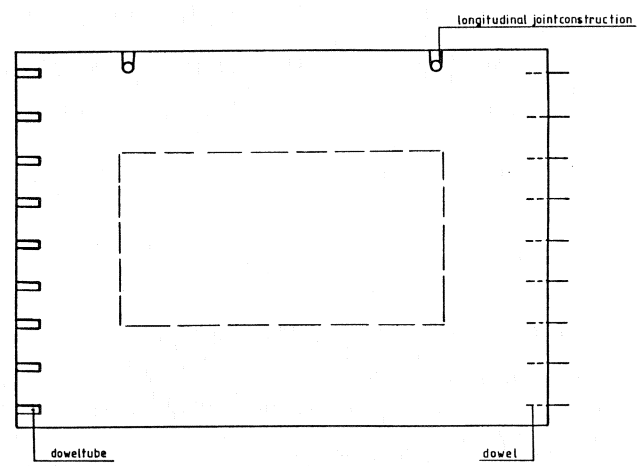

figure 3: Prefabricated concrete slab

The foundation is applied with equipment that is normally used for applying asphalt. Depending on the situation the thickness varies, however, it should not be less than ca. 12 cm in connection with the possibility of compaction.

The slabs have a special dowel construction built-in, that fits at the transverse joints to achieve proper load transfer. The jointing system is designed in such a way that the dowels projecting from one side of the slab fit into locating tubes that have been cast in place in the adjoining slab (figure 3)

The dimensions of the dowels are similar to those that are traditionally used in the Netherlands (figure 4).
The positioning of the slabs requires special caution. Because of the small space between dowel and dowel tube they are lowered into position only a few centimeters above the lean concrete surface.

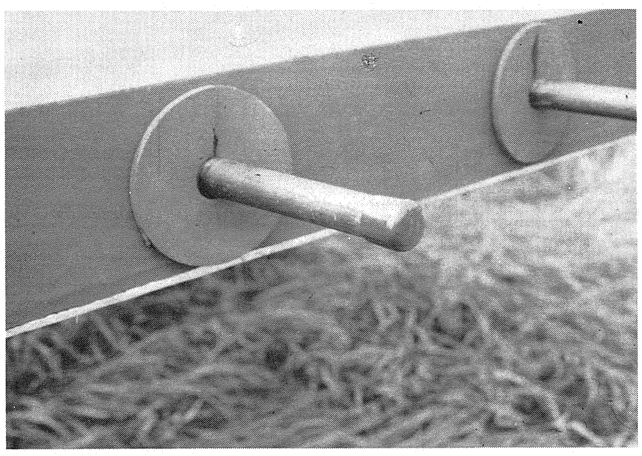

figure 4: Dowel

After the slab has been placed correctly the space between the dowels and the locating tubes is filled with a rapid-curing synthetic resin (figure 5). This is achieved by injecting the resin into small tubes positioned in the pavement surface, and which are connected with the underlaying cavities (figure 6).

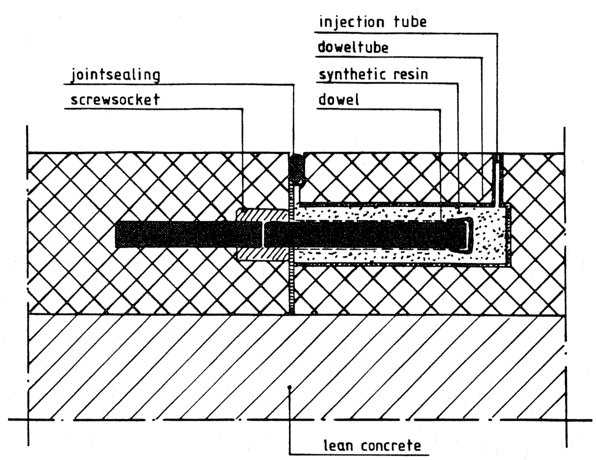

figure 5: Transverse joint constructure

To avoid the resin floating into the joints, the cavities are covered with an elastic synthetic ring.

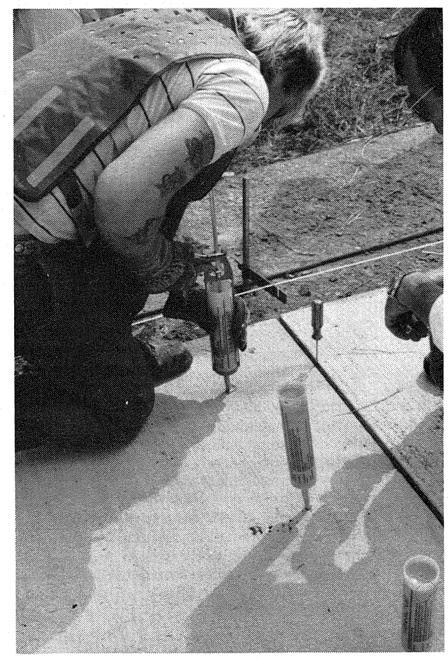

figure 6: Injection of the doweltube

In case two traffic lanes with prefabricated slabs are built side by side, a longitudinal load transfer is also possible. Therefore, two cavities are made in the slab. After the slabs have been placed, an iron clasp is put into these cavities. The remaining space is filled with a rapid-hardening synthetic resin as well (figure 7).

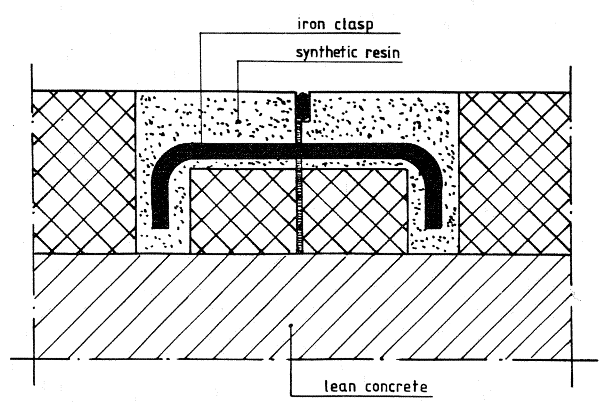

figure 7: Longitudinal joint construction

At the transverse joints the slabs are constructed with a groove on top of them in which a joint sealing compound can be placed to avoid water penetrating into the foundation.

With the prefabricated slabs it is also possible to adjust the tranverse and longitudinal gradient to local conditions. Curved roads can be built as well by deviating from the rectangular sizes of the slabs.

Vacuum treatment of concrete

The amount of water in concrete mortar, needed to facilitate the transport and placement, is far in excess of the amount required for the chemical reaction to generate concrete hardening. The purpose of vacuum processing is to remove that surplus of water. In this way a concrete mortar with a low water/cement ratio is acquired which normally could not be compacted with traditional compaction means. Besides an advanced hardening process, the removal of water provides a higher density and concrete quality.

The removal of water from the mortar is achieved by creating a vacuum within the concrete and thus allowing the atmopheric pressure to press down onto the concrete surface. Therefore a suction mat is placed upon the surface of the wet concrete, which is connected to a vacuum pump through a hose (figure 8).

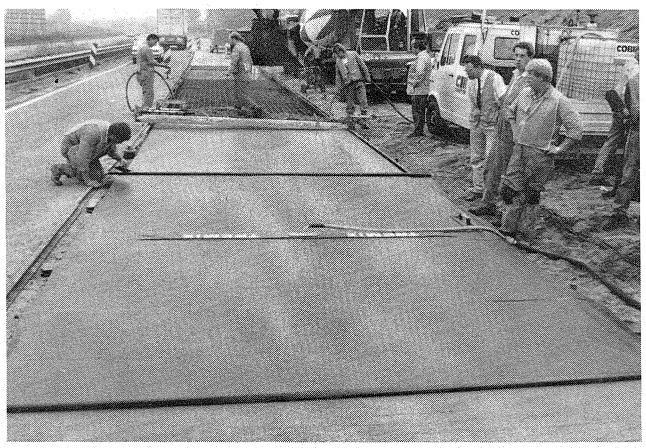

figure 8: Suction mat is placed

The suction mat consists of a top cover and filter pads. The top cover seals against wet concrete at the borders. The filter pads under the top cover from an air chamber between the tight edges of the top cover and the concrete surface. If the air between the top cover and the filter pads is evacuated, then atmosferic pressure is exerted upon the concrete via the top cover.

If the air pressure under the top cover and the top part of concrete is reduced to 20 % (80 % of possible vacuum), the concrete mass will be subjected to a pressure of 8000 kg/m² (figure 9).

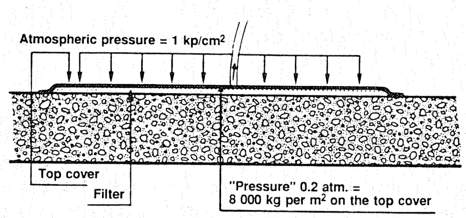

figure 9: Principle of vacuum dewatering

During the vacuum treatment, which normally takes 20-30 minutes (rule of thumb: 1 minute per cm slab thickness) the surplus water from the concrete will be squeezed towards the surface and out of the concrete. Afterwards the concrete will be so stiff that one can walk on the concrete surface without causing imprints of shoes.
To achieve the right evenness the concrete surface needs a finishing operation by floating with a skimfloater provided with a disc (figure 10).

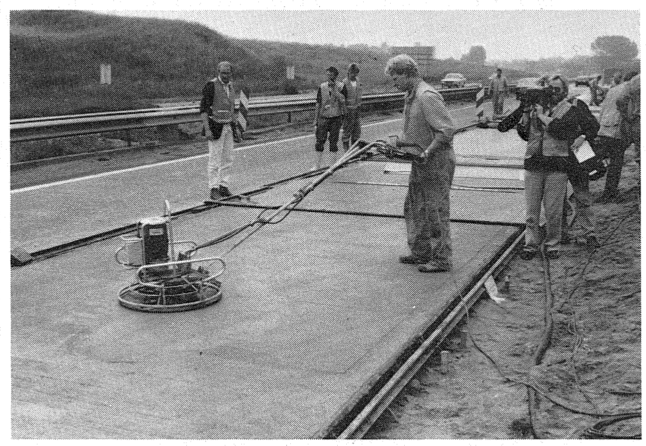

figure 10: Skimfloater

By choosing the right concrete mixture, using rapid hardening types of concrete, high quality standards (high density, high compressive strength and an eminent wear resistancy) are maintained. In the present case a mixture of 350 kg/m³ rapid hardening cement was used, partly in combination with a superplasticizer.
In order to lower the risk of shrinkage cracks and to raise the strength during the critical first hours after applying the concrete, an experiment was carried out by adding 0.9 kg/m³ polypropylene fibres, with a length of 19 mm, to the mixture. The fibres were added by mixing in plant. To allow for a comparison with a steal reinforcement, a traditional reinforcement to reduce shrinkage was also installed.

Test sections

As little experience exists with these techniques, it was decided to construct two test sections to allow for the different methods to be assessed. A test section made up of prefabricated slabs and a similar stretch based on the vacuum concrete system were installed in July 1987 and June 1988 respectively.

A location was chosen where, even in case of complete failure of the two techniques, minimum disruption of traffic could be expected. Therefore, the test sections were not chosen on a waiting lane at an intersection. The test sections were constructed at the A-59 Motorway near Waalwijk, as part of a concrete road which was built in the early sixties and needed urgent repair.

In both cases the old concrete surface was removed and the foundation of sand and a tar/chalk stabilization was repaired. The old surface was significantly damaged, both the longitudinal and transverse gradient needed to be restored. At each section, both traffic lanes of the existing road surface were replaced over a length of 50 m (figures 11 and 12).

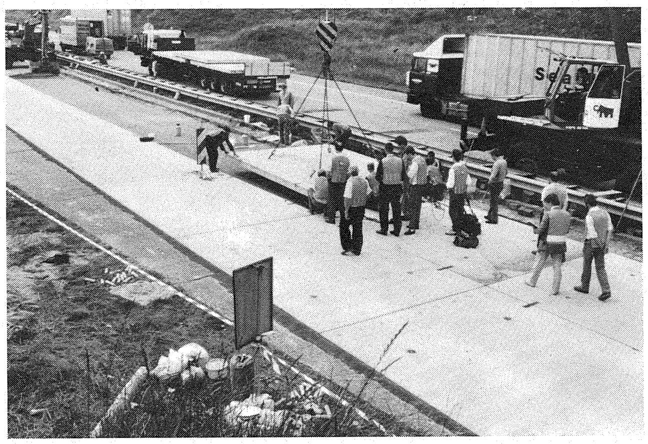

figure 11: A prefabricated slab is placed into position

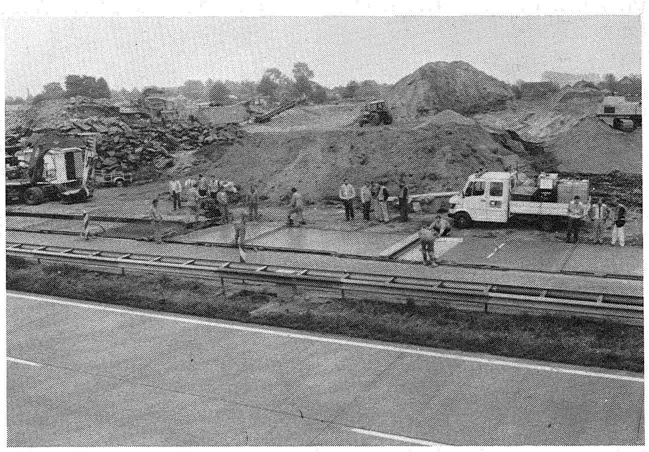

figure 12: Vieuw at the test section with the vacuum treatment

Both sections were located in a curve with a radius of ca. 1400 m. By replacing the two traffic lanes on separate days, one lane could be kept open for vehicles throughout the construction phase.

The tests sections were designed to enable both the organizational and structural engineering aspects of the two repair systems to be evaluated. A comprehensive series of measurements was therefore made before, during and after the actual construction period. In particular, a thorough investigation of the test location was conducted prior to construction by carrying out borings and static cone penetration tests. Furthermore, an extensive feasibility study was undertaken to determine the suitability of the materials employed.

In the case of the prefabricated slabs ample attention was paid to the composition of the lean concrete. This led to a comprehensive series of tests concerning compressive strength and density to prove the suitability of this mixture. Also, a lot of attention was paid to the special dowel construction, specimen were used to experiment with the injection of the dowel tubes and the hardening time of the rapid curing epoxy resin.

Because of the curved alignment specially fabricated trapezodial shaped slabs, with different sizes for the traffic- and overtaking lane, were used on the test section. Restoring the longitudial and transversal gradient in a curved road made the measuring, needed before positioning the slabs, extremely difficult. Therefore, a test was carried out beforehand on the contractors' working site in which all the slabs were placed in their 'final' position (figure 13).

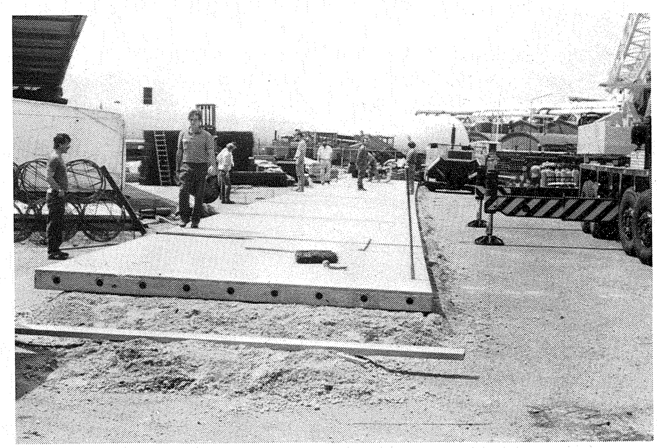

figure 13: Beforehand all the slabs were placed on the contracters' working site

The slabs were laid on a sand/coarse foundation which was made especially for this purpose and which had the same horizontal and vertical gradient as the test section. The experience gained with this exercise proved to be very useful during the actual construction period.

While the work at the test section was in progress various control tests were carried out with regard to the evenness and the density of the lean concrete road base. After completion of the concrete surface the effect of the dowel construction was tested by measuring the transverse load transfer using a slowly moving heavy vehicle.

At the vacuum treatment test section, special attention was paid to determine the developing strength of the concrete during the first hours after the mortar had been applied. Because the usual test methods to determine the compressive strength (e.g. using concrete cubes) were not possible, alternative test methods like measuring the sound-velocity in the concrete and using pull-out tests (figure 14) were used. The first gives information about the start and end of the hydraulic binding process of the mortar, the second about the hardening process itself and coorelates well with the first.

figure 14: LOK-test

Besides the initial strength, the compressive strength after 7 and 28 days (including the density of the concrete) was determined. Due to the several variants, which were built in, a great number of feasibility tests were carried out. In all 5 different types of slabs were built:

- normal mixture / without vacuum treatment
- normal mixture / with vacuum treatment
- mixture with polypropylene fibres / without vacuum treatment
- mixture with polypropylene fibres / with vacuum treatment
- normal mixture with steel reinforcement/ with vacuum treatment

In this manner, the effect of the vacuum treatment and that of the fibres on a possible advanced strength could be demonstrated.

During the construction of this test section the temperatures of the mortar were registred. The decreasing water/cement ratio during the vacuum treatment was determined by measering the amount of water withdrawn.

After construction of both test sections general aspects ,mainly involving properties such as skid resistance, evenness, texture depth, etc. were determined. Due consideration was also given to aspects of costs.

Evaluations

The results of the test program, including the experiences during applying both concrete surfaces and practical behaviour for several months, are now available and discussed below. Because the performance of the test sections will continue to be monitored for several years this can not be a final judgement.

Prefabricated concrete slabs

The prefabricated slabs had not been put into practice in the past yet. Still, on the bases of the experiences and the results of the measurements which have been carried out, it is concluded that this technique is technically viable. This in spite of the fact that the site conditions at the test location were relatively difficult, and even required special demands as far as measurement activities were concerned.

Compared with other concrete road building techniques (which are using in situ concrete) considerable construction time could be gained, the vacuum technique not included.
However, a critical point has to be made regarding the quality of the lean concrete foundation which did not comply with the compaction requirements. This was caused partly by the thin base layer, the high phreatic level, and the old concrete beams which were situated under the transverse joints of the old concrete pavement and which were not withdrawn. As a result the compaction energy could not transmit optimally to the lean concrete mixture.
Also the former evaporation of water from the mixture, due to a slight stagnation during the construction phase, had a negative influence. Nevertheless, in view of the results of the feasibility study, the required degree of compaction could be achieved.

With the slabs, a concrete road surface was built with a satisfactory evenness. On only a few spots, height differences of some mm could be measured between two adjoining slabs. Moreover this did not effect driver comfort.
Borings into the road surface, directly on the transverse joint construction, showed that the injection of the dowel tubes functioned very well (figure 15).

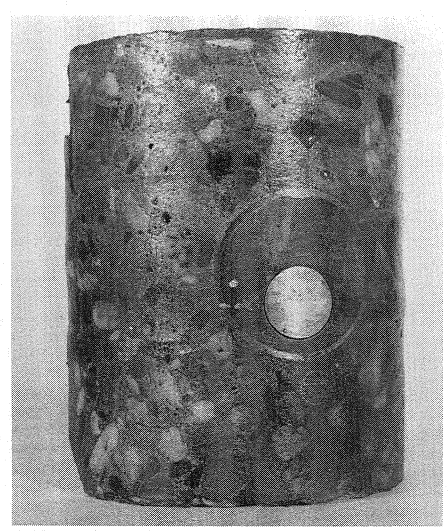

figure 15: Boring at a transverse joint construction

This was confirmed by the results of the load transfer tests. The longitudinal jointing construction performed well.

Vacuum treatment

The vacuum treatment had been used in the past, nevertheless the determined construction time was never that short. The construction of the test section proceeded without delays and problems with shrinkage cracks did not occur. With the chosen composition of the concrete mortar a road surface with the required evenness was built. The compressive strength was found to be between 55 and 65 MN/m² and complied with the requirements for the minimal strength of 45 MN/m².

The strength over time of the fresh mortar, measured with pull-out tests (LOK-test), is shown in figure 16.

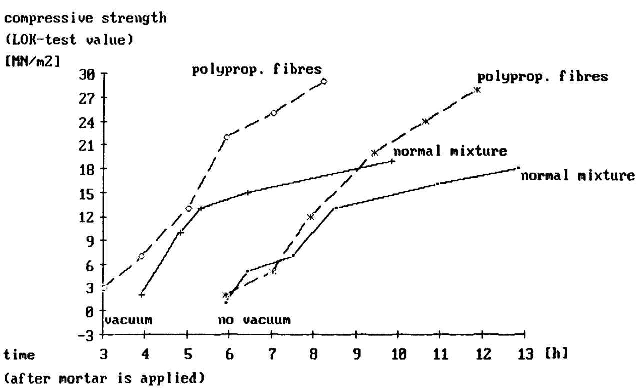

figure 16: Strength development

In figure 5 the vacuum treatment accelerates the gain in strength by several hours. At a strength level of ca. 13 MN/m² and more, the positive influence of the polypropylene fibres becomes significant. It is this strength level, between ca. 15 and 20 MN/m², that will be required at the opening of the rehabilitated pavement to traffic. By adding the fibres to the mixture an extra factor of safety is achieved, with regard to pavement damage from heavy axle loads. After 10 hours the strength of a vacuum treated mixture with fibres is over twice as high as the normal plain mixture. However, the positive effect of the fibres, with regard to the compressive strength, is no longer present in strength after 28 days.

Sand patch tests showed that the texture depth of various vacuum treated slabs was not satisfactory. Obviously the surface of the mortar was too compacted by the vacuum treatment and the skim floating process to realise a sufficient texture depth with a standard texture broom (suited with soft synthetic hair). Skid resistance measurements confirmed insufficient roughness of the pavement surface. It is expected that these difficulties can be avoided by using a broom with steel hair.

Conclusions

On the basis of the above-mentioned experiences during the construction phase and the results of the measurements which were carried out, the conclusion can be drawn that it is justified to rehabilitate waiting lanes at intersections with both techniques. In the case of the prefabricated concrete slabs, it is necessary to pay close attention to the compaction of the lean concrete road base. In case of the vacuum treatment more effort during surface texturing should ensure the right texture depth.

The answer to the question of which technique is most suitable must be weighed by surveying the specific qualities of each method. The tentative expectation of the service life of the prefabricated slabs is about 10 to 15 years and can not fully comply with that of an in situ placed concrete road surface (including the vacuum treatment). When using prefabricated slabs extra effort is required to construct a plane and well compacted road base. This action needs extra time and is, in case of the vacuum treatment, not necessary.
Because the prefabricated slabs are made in a concrete factory under optimal conditions and the placement of the slabs is relatively unsusceptible to weather conditions this method is very reliable. Especially when the pavement is to be opened to traffic in a minimum time.

On the other hand, with the vacuum treatment it is easy to make every possible form, which can be a great advantage. The concrete mortar, used with the vacuum treatment, is very sensitive to factors which can affect the hardening process (e.g. temperature).

The price of the two rehabilitation techniques (construction costs, without maintenance) is 2.0 - 2.5 as high as a comparable solution in asphaltic concrete, depending on local conditions. As far as the construction time is concerned both methods require about the same time, assuming that there are not any delays to be dealt with.

The main goal of building the two test sections was to assess both methods and conduct a comprehensive series of tests. This naturally slowed the construction process. Before a real estimation can be made on how many concrete slabs can be replaced within the proposed time period, it is necessary to apply both techniques under realistic conditions

Therefore it is expected that in the near future an intersection will be rehabilitated, between two consecutive rush hour peaks, using the doweled prefabricated concrete slabs as well as vacuum treated in situ concrete.