Steel-fibre-reinforced concrete road on piles

Pouring the concrete slab.

In the green heart of the Dutch Randstad a new road is being built. The road runs through the swampy territory between the villages of Nieuwkoop and Woerdense Verlaat. The existing road had shown defects over time. In order to be able to repair these defects a number of innovations have been applied and the construction of the new road differs completely from the original.

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The construction of the existing road followed a common method: embankment, granulated material and finally asphalt. Below the embankment lies a layer of peat about 8–9m thick, which falls within the category 'thick water'. This means that the material will undergo large and prolonged deformation in the event of a minor change in load.

By constructing a common road structure the extra load of the road and its foundation increase the stress in the peat layer, causing the material to compress. The compression of the peat is a lengthy process as the water migrates out very slowly but over time the road will subside. Consequently, the road maintenance authority will apply a new layer of asphalt to the structure in order to prevent the road from subsiding below groundwater level. As a result, the load increases again and the process of subsidence is accelerated. In short, roads like this are expensive and progressive maintenance is required.

Piles below the road

The installation of piles below the road, founded into sand, appeared to be a solution. This way the load is transferred from the road to the piles and not from the road through the foundation to the peat below. As a result, the road practically retains its original height.

In order to transfer the load from the traffic to the pile, several solutions are possible; but this usually comes down to a choice of two – a heavy continuously reinforced concrete slab or a layered embankment of geotextile and mixed granulate.

The traditionally reinforced concrete slab is a common and logical solution for the building of a structure. This kind of slab usually contains at least 150kg/m^3 of bar reinforcement. However, the length of time for construction and inconvenience to the surrounding area precluded the use of this method.

A geotextile plied embankment on the other hand

Below left: Pile is placed in a hole within the asphalt layer. Below middle: Drilling the holes in the asphalt. Below right: Upcoming groundwater in the hole before the pour (the bottom of the concrete road is around groundwater level).



Another view of the concrete slab pour.

may be constructed relatively quickly. Several layers of geotextile and granulated material are piled on top of each other. This system has a number of disadvantages. The main disadvantage is the required thickness of the structure, say, 1 to 1.5m. This is unfavourable for the following reasons:

- an excavation would have to be made, which can hardly be kept dry in this kind of soil
- accessibility for local residents would be limited during construction
- the removal of unwanted material – in the case of Nieuwkoop, tar-containing asphalt and foundation
- many services eg. cables and ducts in the longitudinal direction, need to be accommodated.

Steel-fibre-reinforced concrete slab

In order to achieve an economically attractive structure that could be constructed quickly, a steel-fibre-reinforced concrete slab was selected. The slab is placed directly onto the piles and so facilitated the pouring of the concrete in phases. Following placement of the piles, formwork is constructed and subsequently the steel-fibre concrete poured. This way the inconvenience for the surrounding area was limited.

In the past, steel-fibre-reinforced roads were only applied in structures founded directly on the soil. However, in the case of a road on piles the situation is completely different. The bending moments on the structure are much greater, because the loads from the design axes have to be transferred over a much larger distance. This makes greater thickness necessary. However, by optimisation of the pile pattern, the slab thickness could be limited to 350mm. That is why this innovative alternative is attractive from a financial and constructional point of view. In addition, the risk could be kept to a minimum.

Design of the structure

The structure was placed on prefabricated piles. The piles were made with different load-bearing capacity, in line with the admissible disturbance and vibrations (pile driving transmits vibrations to the surrounding area). Therefore piles with lower load-bearing capacity were placed in the vicinity of houses at relatively close centres in order to limit disturbance. Piles with greater load-bearing capacity could be driven deeper and placed further apart.

The design of the piles was very detailed and precise due to their proximity to adjacent buildings. A relatively fine grid was used but in locations that were variable, the grid was made even finer. The result was a highly varied pile plan with many different pile founding levels. This meant that pile driving was very light, so that they could be driven at high speed keeping vibration disturbance to a minimum.

The concrete structure was calculated according to Eurocode and the relevant CUR (Dutch Standards) recommendations. According to this Standard, the structure has to meet relatively high requirements.

Finite-element calculations were used to minimise the number of piles below the road as much as possible. The piles were treated as non-linear supports and the pile rigidity was calculated non-linearly according to the calculated pile load-bearing capacity. This means that near the maximum geotechnical load-bearing capacity of the pile the deformation will increase to a relatively large extent. Where the load-bearing capacity is exceeded, the deformation will increase further without increase in capacity. This effect was taken account of in the calculations, so that piles with greater loads react less rigidly and as a result, the slab distributes the loads to surrounding piles. The admissible load-bearing capacity of the individual piles is reduced accordingly. Therefore the slab has to distribute the loads over a greater distance and consequently the moments will increase.

This calculation method cannot be used without adverse effects. After all, piles can be overloaded, which would result in plastic deformation. Over time this could result in increasingly large deformations of the piles due to traffic impact. These deformations have been checked and it was

Newly applied concrete slab.

Crack found in the concrete slab.

determined that for the standard serviceability limit state (SLS) no plastic deformations would occur in and below the piles.

For the SLS calculation it is permitted to use so-called load schedules similar to real traffic. Weights of 63 tonnes are distributed between five axes, the axes being spread apart, so that the loads are distributed over more piles. This allowed the piles not to be plastically loaded. In this situation the slab does not have to span forces to surrounding piles hence stress within the slab is very low. In addition, crack formation due to restrained shrinkage was taken into account in the SLS scenario.

The structure is also detailed to control restrained deformations. Contrary to typical reinforced concrete roads, the steel-fibre structure was built without joints. In general, a steel-fibre structure has insufficient capacity to be able to accommodate shrinkage cracks. This is because the fibre-reinforced concrete section has less capacity after cracking than before. This means that movement of the connecting road section is mainly manifested in a single dominant cracks wide spacing.

Calculations show that the structure is subjected to stress due to restrained deformation and therefore will crack. Pouring schedules were detailed in advance and were relatively favourable to minimising restraint. The high steel-fibre dosage prevented the crack from becoming too wide. In advance it was estimated that the structure would highly likely be subject to cracking every 150m, with a total of 12 cracks. Cracks wider than 0.5mm were to be injected; this prevents the structure from becoming too weak. An alternative would be to insert joints in the structure, but this was considered to be unfavourable.

Execution of pile driving

During pile driving, vibration was measured by placing accelerometers on the most critical premises, prior to the pile-driving activities. The vibrations were less than the values determined by the control measurements.

Concrete pour

All parties concerned were consulted with regard to the concrete and the process was attuned to quality requirements. The concrete differs from common mixtures: a high dosage of steel fibre from Metal Products was used; and due to the large quantity of fibre, more paste was required in the mixture. Simply increasing the cement dosage is not advisable as this will only result in increased shrinkage. The required quantity of fines in the concrete was obtained from fly ash. The concrete consistence class was F3 to F4 for ease of placement.

After pouring, the slabs were covered with an insulation canvas, so that the heat of hydration partly remained within the concrete, maintaining the strength development despite the low temperatures. The insulation canvas was also required for the next phases, so it was removed after a couple of days but as a consequence a number of floor sections cracked during a cold night. These cracks had to be injected at a later date in accordance with the design. Furthermore, the concrete slab was provisionally protected by a layer of bitumen containing stone chippings. In the spring the asphalt will be applied, after which the road will once again be fully trafficable. ■

Groene Hart Road N463, The Netherlands	
Client	Province of South Holland
Contractor	Dura Vermeer
Design of structure	ABT
Design of road profile	Advin
Supplier fibre material	Metal Products Horst
Supplier concrete	Theo Pouw Utrecht

Driving piles through the existing road.