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TUNNELS AND EXCAVATIONS

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ABSTRACT

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In these the road is returned to the normal level, which is either at or above ground level. Reinforced concrete is used as the building material. After completion, the road is beneath the groundwater level over practically the entire length of the works.

The construction of the tube and the basin ensure that no groundwater is withdrawn from the surroundings. This is in contrast to the end phase, during the implementation of which the groundwater conditions in the tunnel surroundings are indeed affected.

The cheapest building method is practically always obtained by carrying out the work in an open excavation.

It is generally advisable for the civil engineer to be aware that although he may know the geological composition of his building land, he is not always in a position to complete specific projects on the basis of his own knowledge and experience. The assistance of a geologist having specific civil engineering knowledge is frequently very important so that he can help to assess a project and the steps required for its implementation.

INTRODUCTION

Half of The Netherlands lie below sea level and the Dutch, who have long been known as hydraulic-engineering specialists, do their very best to keep the country dry and protect it against attacks by the sea. It can almost be said that The Netherlands were built by the Dutch themselves, and consist of polders, dykes, ditches, canals, rivers, etc. As the past has already proved, the civil engineer in The Netherlands will in future still have a very extensive task in order to protect this small and beautiful country against all attacks by nature and to ensure that nature is not irresponsibly violated for the sake of technology, as is all too frequently and incorrectly thought to be the case.

Attacks by natural forces are generally associated with the sea. To the geologist, the sea is a base on which he can construct his theories. The sea was there long, long ago. The seas determine new structures. The civil engineer is involved in this both directly and indirectly. In the direct form, the force of the water in all its facets springs to mind, and this necessitates skilful operations in that context. Sedimentation comes to mind as an example of the indirect form.

When a civil engineer thinks of the subsoil in The Netherlands, he is not referring to the deeper strata of the earth, from which rock salt and oil are extracted, but mainly to the top section, which is frequently of restricted load-bearing capacity. This is the area which generally forms the civil engineer's work site.

It is generally advisable for the civil engineer to be aware that although he may know the geological composition of his building land he is not always in a position to complete specific projects on the basis of his own knowledge and experience. The assistance of a geologist having specific civil engineering knowledge is frequently very important so that he can help to assess a project and the steps required for its implementation. This is true, for instance, for tunnels.

The term tunnel and the associated term excavation are quite general. Tunnels and excavations can be distinguished by use, geological situation, type of construction, and so on (Fig. 1). This paper will deal especially with tunnels and the associated excavations, giving particular attention to the groundwater problem.

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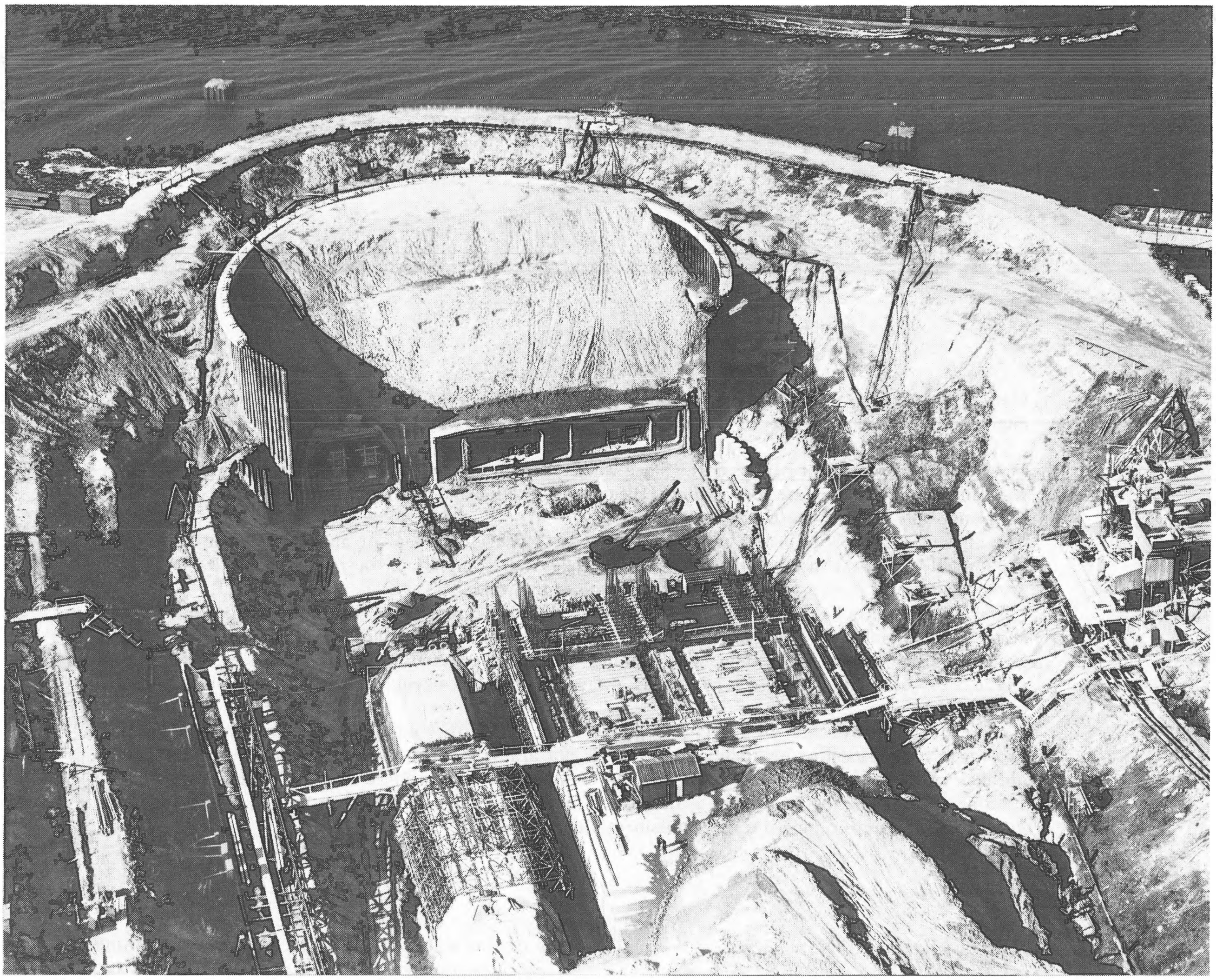


Fig. 1
Velser tunnel under construction in coverdam and open excavation. Foto KLM Aerokarto.

GENERAL DESCRIPTION OF THE TUNNEL-CONSTRUCTION METHODS IN THE NETHERLANDS

Most tunnels are formed by tubes at the place where there are large traffic intersections of waterways and/or roads. Tubes are constructed at the deepest location and basin structures consisting of a floor and walls are constructed on each side. In these the road is returned to the normal level, which is either at or above ground level. Reinforced concrete is used as the building material. After completion, the road is beneath the groundwater level over practically the entire length of the works.

At this stage there is no question of influencing the level in the surroundings. The construction of the tube and the basin ensure that no groundwater is withdrawn from the surroundings. This is in contrast to the end phase, during the implementation of which the groundwater conditions in the tunnel surroundings are indeed affected. The cheapest building method is practically always obtained by carrying out the work in an open excavation. This is shown diagrammatically in figure 2.

A dewatering system is first installed and then the open excavation is carried out. The dewatering system ensures that the water table falls to about 0.50 m beneath the bottom of the excavation so that the actual works (a reinforced concrete basin on pile foundations is shown in figure 2) can be built in the dry state. On completion the works are earthed up and the dewatering system is finished.

In principle, the same method of construction is employed for the underwater part of immersed tunnels, except that in this case the work is not carried out on the site, but elsewhere: in a dry dock. Immersion tunnel units of a length of about 120 m are prefabricated in this dry dock (a dewatered open excavation). Each unit is provided with temporary watertight bulkheads to form a sealed hollow tube, which can subsequently be floated for transportation.

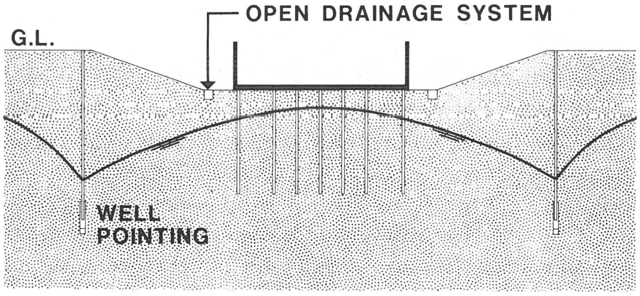


Fig. 2
Tunnel building in open excavation with well pointing.

Once all the units have been completed, dewatering is stopped, the dry dock is filled with water and an access channel is dredged from the fairway to the dock. The floating units are towed one by one to their destination and are sunk, by means of ballast, in a trench dredged in the river bed to conform with the tunnel profile.

The units are then interconnected and the trench is covered with dredging spoil until the original river bed has been restored. It is beyond the scope of this paper to describe this fairly advanced technique in detail, but it should be noted that a dewatered open excavation is again used for the construction of the tunnel units.

THE SUBSOIL

The subsoil in which the civil engineer works is generally the top strata, which in deltaic areas have limited load-bearing capacity. The properties of this soil, directly beneath the surface, must be determined from skilled soil investigation. The object of this investigation is to discover the properties of the ground in the immediate surroundings of the tunnel works, so that the work can be developed economically and be carried out safely. The strata of limited load-bearing capacity in which this work is done consist mainly of sand, clay and peat. In order to obtain rough ideas for setting up a tunnel project it is important to know what material is present and what its load-bearing capacity is.

The properties of the soil in terms of soil mechanics, such as its resistance to cone penetration, give the basis for the calculations. This is the factual basis on which the civil engineer builds.

It is probably necessary to acquire a greater feeling for the influence of the geological structure of the subsoil on the project and its implementation. Once sufficient knowledge of the subsoil has been collected, attention must be paid to the solution of the groundwater problem. Water levels, the way in which they are influenced by the works and the effect on the environment must be carefully studied.

It is important to realise that no civil-engineering works should be carried out without carefully studying and considering the indirect effects on the environment.

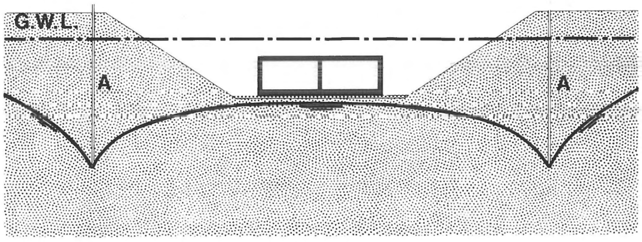


Fig. 3
Water level lowered in open excavation.

DEWATERING

Lowering of the groundwater level by dewatering

The excavations required for building structures having deep foundations, such as tunnels, sluices and weirs, can be carried out in two ways:

(1) by dredging away the soil and then dewatering the excavation;

(2) by making a dry open excavation and simultaneously lowering the water level.

Every child who has spent a day at the seaside knows that if you try to dig a trench you can only do it to the depth where the groundwater begins. If you remove the sand to a greater depth, the aqueous mass starts to flow and the equilibrium of the trench walls is disturbed. When excavations have to be carried out to below the groundwater level for civil-engineering works, then this level must generally be temporarily lowered by dewatering. The types of soil in the base and walls of a foundation well are very important with regard to the water inflow, dewatering, and the precautions required. The geological and hydrological condition of the land governs the way in which the work is carried out. Special attention must be devoted to the stability of the slope under water, during the lowering of the ground water level, and in the dry state. The equilibrium of slopes and base must be ensured in every circumstance. If the water level is to be lowered, a dewatering system must be installed of such dimensions that there will not be any disastrous consequences of a single pump breaking down. Two main geological situations can be recognized:

(1) If the geology is of a nature such that the soil consists solely of gravel and/or sand with good permeable properties, then dewatering is carried out in an open aquifer. Characteristic differences can be assumed in connection with the dewatering of open and other excavations. If, for some reason, the dewatering system breaks down, the disadvantage is that the open excavation slowly becomes immersed (Fig. 3).

(2) If, however, the soil profile contains an impervious aquiclude, underlain by an aquifer containing water under artesian pressure, then this pressure must be relieved in order

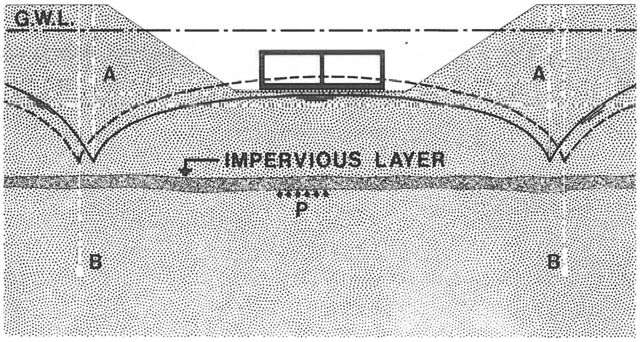


Fig. 4
Well pointing during the building of the tunnel structure, with deep water impervious strata in the subsoil.

to prevent the soil bursting open during excavation and building of the tunnel structure. The pressure P under the watertight stratum must always be less than the weight of the soil above (Fig. 4).

If this is not done, breakdown of the dewatering system is disastrous and the excavation soil may break open.

The possible consequences of dewatering to the environment

The – temporary – lowering of the groundwater level in the surroundings of the excavation may result in:
(1) damage to houses and buildings;
(2) damage to agriculture and horticulture;
(3) damage to natural and leisure areas;
(4) reduction of the amount of groundwater available for use as drinking water, because the pumped water is drained away as surface water and hence is lost to the drinking water potential;
(5) harmful consequences to agriculture, horticulture and stockbreeding, because pumped water which is brackish or otherwise unsuitable is drained into ditches, polder reservoirs, and so on.

Regarding damage to houses and buildings (1) this may occur if lowering the groundwater level results in a considerable subsidence of the soil. If such subsidence is uniform, it need not necessarily be important, but it may result in cracking particularly in the case of uneven settlement within a building.

With reference to damage to agriculture and horticulture (2) a distinction should be made between the events occurring during dewatering. If the soil and crops are sensitive to dewatering, there may be a shortage of water during the growing season, and this will reduce crops. When dewatering is stopped, the ground level may have undergone compaction, so that the difference between ditch level and ground level has become so small that reduced crops must be expected permanently, unless this effect is counteracted by adjusting the ditch level (under-dewatering). Although this sounds paradoxical, the situation can be improved as compared with the situation before dewatering if the ground level was initially 'too high' with respect to the ditch level.

The above list of possible damage should be read in the light of the fact that in very many cases there is only limited damage or no damage at all. It cannot be overstressed that the possible occurrence of damage and its extent are determined completely by the amount of dewatering, the nature of the soil, and the use made of the soil and groundwater.

Recharge well pointing system and infiltration

In principle there are two possible ways of returning the pumped water back to the soil: by infiltration from the ground level; and by a recharge well pointing system.

(1) For infiltration from ground level, in which the water sinks away into the sub-soil from, for example, ditches and trenches usually dug specially for this purpose, a (sandy) soil with good permeable properties should be present beneath the ditch soil. Although sand piles are used for discharge to deeper aquifers, sealing of the trench soil may have a very disadvantageous effect. Infiltration via ditches and trenches is usually more suitable for limited quantities, while the quality of the water and the permeability of the soil will play an important part.

(2) In the case of the recharge well pointing system, the well-outlet pipes are connected to vertical well-discharge pipes with screens in the ground to which the groundwater is to be 'returned'. An accurately controlled excess pressure causes the water to penetrate into the subsoil where the well screens are located.

If these systems work properly – and this is not possible in every case – they can provide an attractive technical solution to a number of problems, but the cost aspect must not be underestimated.

As an example reference may be made to the installation of a structure in an area where the groundwater is extracted for drinking water supplies. The pumped water is then not drained into the surface water and it is not lost to the waterworks. The method can also be used if the pumped water is highly polluted (e.g. by a high chloride content) and must not therefore be drained into the surface water, in view of use for agriculture, horticulture and stock-breeding. It will be apparent that only recharge well pointing systems may be used in that case, and not surface infiltration, because the qualitatively poor water must be returned to the deeper strata from which it comes.

Another application (possibly in combination with the objectives referred to earlier) is to restrict subsidence or drying-out in the surroundings. The recharge well pointing system etc. is in that case situated between the dewatering system and the 'object' requiring to be protected. By siting

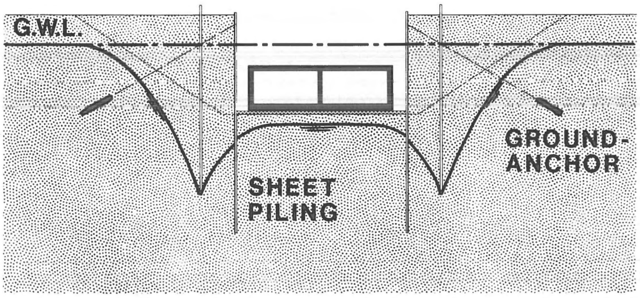


Fig. 5
Excavation with sheet piling.

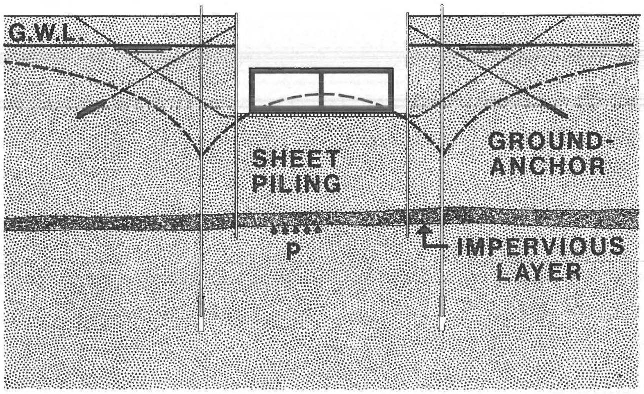


Fig. 6
Impervious layer, sheet piling and well pointing.

the system in this way the groundwater can be retained at its original or almost original level, at the place where the object is situated. Depending upon the circumstances, these recharge points can be placed around the entire work, or else just locally for a specific object.

EXCAVATIONS FOR TUNNEL BUILDING

An excavation may be carried out in the dry or wet state. Bucket dredgers, cutter suction dredgers, or draglines will be used depending on circumstances. There may be certain disadvantages to the environment in constructing an open excavation.

(1) The large installation width of the open excavation is much larger (see figure 2) than the width of the final structure. This may give rise to difficulties in respect to existing built-up areas, roads, etc., certainly in an urban area. If possible at all, these drawbacks can only be overcome at high cost by making, for example, vertical sheet pile walls. This method of construction may even offer advantages if there is an impervious layer. The figures 5 and 6 clearly show the effect on dewatering, for example. The examples to be given later will show its significance in tunnel construction.

(2) To make an open excavation in one operation over the full length may be difficult in respect of intersecting roads, sewers, cables, pipelines and so on. Although this building method is often the cheapest, it is not always feasible technically, and the open excavation and hence the tunnel building must be carried out in sections.

(3) The groundwater level will be lowered by dewatering during building.

(4) Any excavation results in a quantity of spoil requiring storage space. Such space is scarce in The Netherlands. Good soils generally do not give rise to any problems, but it is difficult to process and store the poorer soils. Apart from storage there is also the transportation of the material. To carry sand spoil via conveyor pipes is ideal, but transporting mud over busy roads frequently encounters opposition.

It should be emphasized that these difficulties *may* exist, but that they need not necessarily occur. They are all governed by local conditions, including the nature of the environment, the nature of the soil, and the nature of the civil engineering works.

The excavations may be *temporary*, during the building of the civil engineering works, but they may also have a *permanent* character, so that the excavation has a permanent function. A very important part in this distinction is played, of course, by the building method, by geography, hydrology, and particularly by the geological structure of the subsoil. A picture of how tunnels can be built will be given in the following section by reference to a number of practical examples. In this paper it is not possible to describe building methods in full detail; the reader should consult the bibliography for further information.

EXAMPLES OF OPEN EXCAVATIONS AND TUNNELS CARRIED OUT

Building docks

Building docks or dry docks have been dug for various tunnels in the west of The Netherlands and are re-used for the construction of new tunnels. The effect on the environment has been practically nil as a result of the very favourable situation of these building docks and the good condition of the soil. The three best-known examples are:

(1) The *Barendrecht dry dock*, in which the immersion tunnel units of the Heinenoord tunnel, the pipeline tunnels beneath the Hollandsch Diep and the Oude Maas, the Drecht tunnel and the Kil tunnel were built (Fig. 7). The dimensions of the dock are about 400 × 120 m. The dock bed is about 10 metres below N.A.L. Some 26 deep-well pumps are disposed around this dock to keep it dry during the building of the various tunnels.

(2) The *Madroel dock*, in Rotterdam (Fig. 8), in which the immersion tunnel units of the Benelux tunnel and the Botlek tunnel were built. The dock dimensions are about 400 × 100 m and the depth is 10 metres below N.A.L. This dock is also

Fig. 7
The Barendrecht dry dock with the immersion tunnel units of the Drecht tunnel and the Kil tunnel.

kept dry by dewatering.

(3) The *Amsterdam Noord dry dock.* The immersion tunnel units of the IJ tunnel, the Coen tunnel and the Hem railway tunnel were built in this dock. Originally it consisted of two smaller docks which were combined to one large dock for the construction of the Hem tunnel immersion units, and this was done by removing the bulkhead between these two docks (Fig. 9). The concrete immersion units of this railway tunnel had a length of 268 metres. Nothing like this had been known anywhere in the world before.

Dry docks enclosed by dykes

It is interesting to review the Haringvliet operation, to see what has been learned from this work. The first task was to make a ring dyke for the dock which was to be excavated for the construction of the Haringvliet locks. There was no previous experience of building a ring dyke of such dimensions. The part of the western Schelde tunnel requiring to be immersed under water will also be constructed in the Western Scheldt within a ring dyke, in a dry dock which is to be constructed in the river (Fig. 10). All this will draw on the previous experience of the Haringvliet locks.

The Drecht tunnel

The 8-lane tunnel on the A-16 highway beneath the Oude Maas is in the built-up area of the towns of Zwijndrecht and Dordrecht. Combined with the fact that the subsoil is sensitive to subsidence (it includes clay and peat strata), it was clear that dewatering, which would lower the groundwater to below 15 m below N.A.L. at the deepest point, should be avoided. This did not give rise to any problem for the section beneath the river. It was possible to make the immersion units in the Barendrecht dock (Fig. 7), which is at a distance of about 11.5 km. A land section was built on each bank and

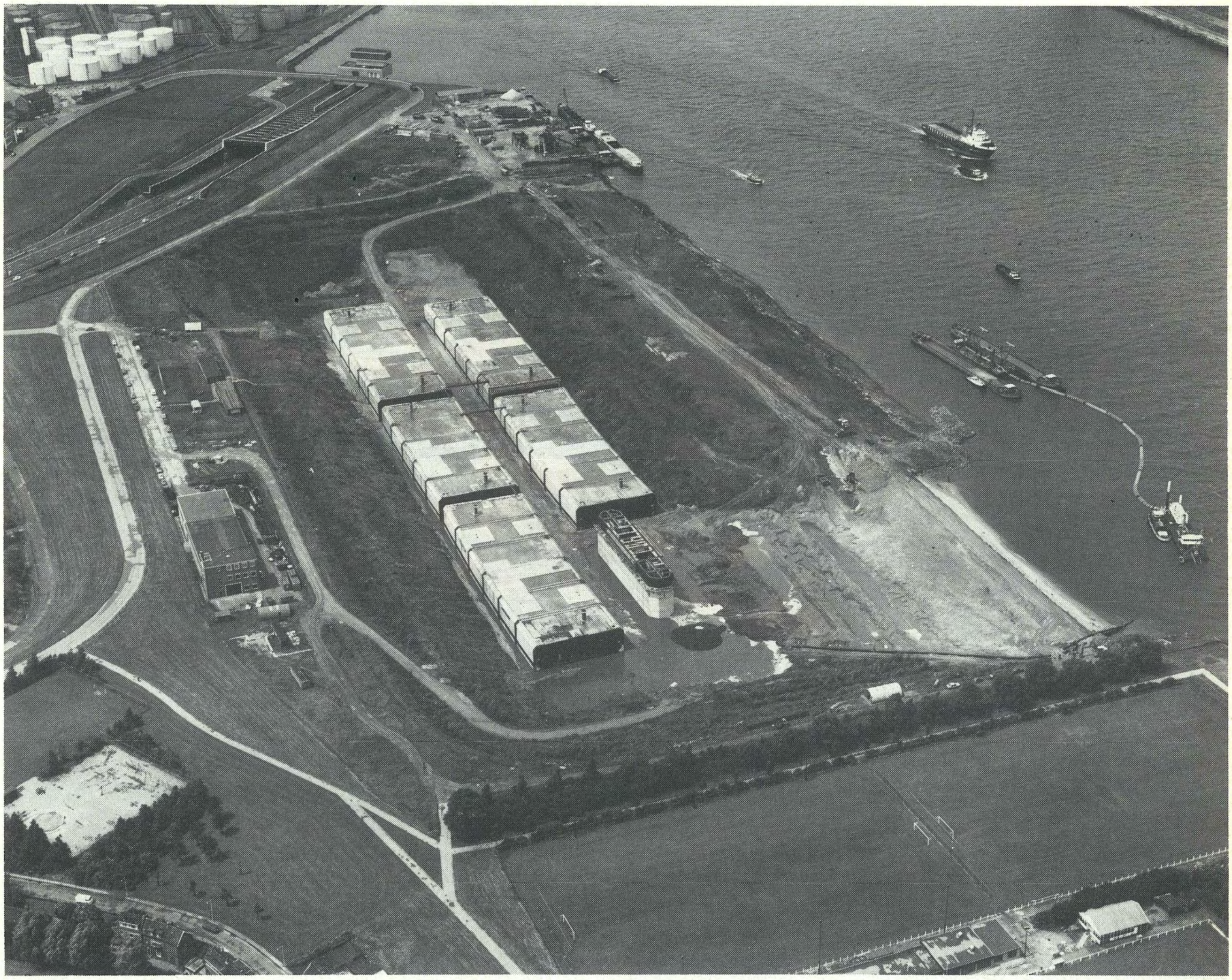


Fig. 8
The Madroel dry dock with the immersion tunnel units of the Botlek tunnel. In the left top corner the south entrance of the Benelux tunnel.

consisted of a closed portion about 110 m in length and an open approach 151 m in length on the Dordrecht side and 102 m on the Zwijndrecht side.

In this open approach the road passes through a cutting which gradually increases in depth and the road level of which falls from the level of the adjacent road body to the level in the closed tunnel. The dam is formed by three elements: a horizontal impervious clay layer beneath the road surface, with the top at about 23 to 25 m below N.A.L. (the Kedichem Formation), and the two sheet piling walls driven in on both sides of the cutting (see figure 11). The top of these walls is on the verge of the slope and is situated above the groundwater level, while the bottom is driven in as far as the clay layer. In this way it is possible to lower the groundwater level beneath the road surface without influencing the situation in the environment. A drainage system ensures that rainwater and any seepage water are discharged and thus keeps the groundwater level within the 'invisible basin' at the required level beneath the road surface. The open excavation is in this case a permanent one, because it forms the excavation in which the road is situated.

The construction was possible because of the favourable nature of the soil (depth, thickness and quality of the clay layer and the capillary rise of the aquifer). However, this is not an exceptional situation in The Netherlands. The higher portion of the eastern approach of the Kil tunnel is also constructed in that way, while the same construction is now being used for a 280 m long civil-engineering construction (an underpass with approaches) beneath the A-7 road at Drachten.

This impervious clay layer was also utilized for the closed sections of the Drecht tunnel, which are constructed on the banks. Reinforced concrete diaphragm walls were used here instead of sheet piling (see figure 12). The 'wall-roof' method was used in this case.

Diaphragm walls of a width of 0.8 m and a depth of 28 m were first made from ground level and extended as far as the

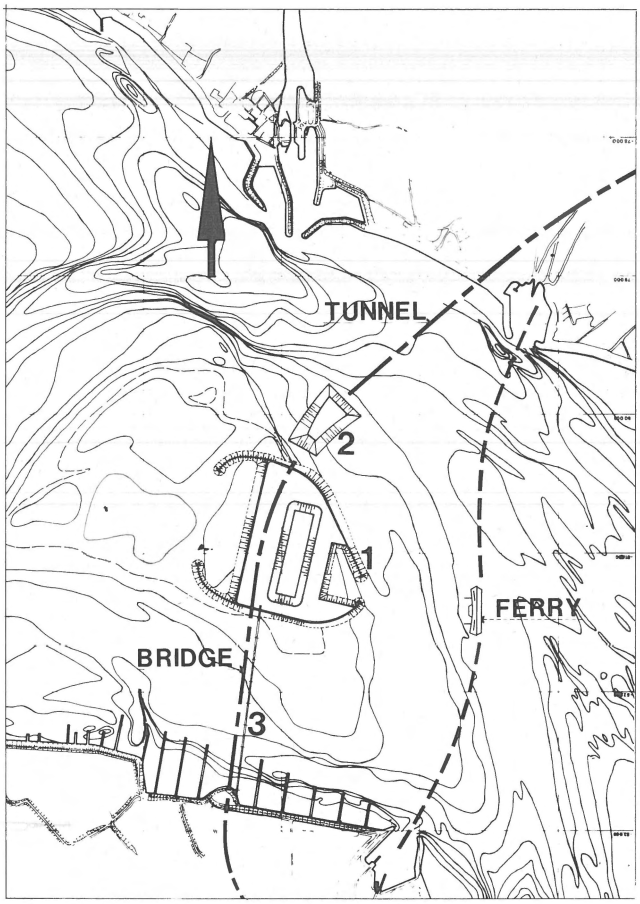
Fig. 9.
The Amsterdam Noord dry dock with the immersion tunnel units of the Hem railway tunnel.

impervious clay layer. At the same time, concrete piles were driven in where the future walls were to be located between the carriageway tubes. The reinforced concrete roof slab was then cast, just below ground level. At this stage the walls and roof were ready and the road level could again be used for intersecting roads and railways. This early return to use of the ground above the tunnel is one of the advantages of the wall-roof method.

Beneath the roof and between the walls the excavation was then carried out to a level at which struts were fitted between the outer walls. These permanent struts were required to counteract the forces on the diaphragm walls due to soil and water pressures. The excavation was then continued to the level where the concrete floor and road surface are situated. Here again the sealing of the diaphragm walls and the clay layer, together with a drainage system, ensured that no water pressures built up beneath the concrete floor. The wall-roof method is widely applied throughout the world, particularly for underground railway tunnels because of its advantages during short-term activities at the overlying road level, its restricted excavation width, and its construction without lowering the groundwater level.

Many modifications to this method are possible. For example, sheet piling can be used instead of diaphragm walls (this has been done, for example, in the case of a short section of the East Line underground railway in Amsterdam). In the case of the Drecht tunnel, possible groundwater problems were restricted because of the presence of the clay layer. In the original design of the wall-roof method an increased air pressure was applied beneath the roof and between the walls so that the groundwater level falls and it was possible to excavate and install the reinforced concrete floor. In the final stage the damming function is provided by the floor and the positive air pressure was no longer required.

The open approach and the closed tunnel section have so far been treated as separate elements, but in reality they gradually



1 ARTIFICIAL ISLAND
2 EXPERIMENTAL SINKING GROOVE
3 AUXILIARY BRIDGE

Fig. 10
Island with dry dock used for the Western Schelde tunnel.

pass into one another. The sheet piling wall of the open approach connects up with the diaphragm wall of the tunnel, so that a continuous dam is obtained around the entire structure on one bank.

When the sheet piling walls were driven, some of the planking was found to have moved out of the trench. An important cause of this was the presence of obstacles at a relatively considerable depth in the subsoil.

It is interesting to note how unexpected conditions may locally be found at considerable depths despite exhaustive soil investigation. For example, in the case of the Drecht tunnel a very hard 'sandstone layer' was discovered locally at a depth of 15 m below N.A.L., and this was found to be formed from guano residues. A warehouse for imported guano was located at the site of the present tunnel on the bank at Zwijndrecht in the middle of the 19th century. Residues of this had sunk to form an impenetrable layer. The moisture from the guano, together with the sand present there, had formed a kind of sandstone.

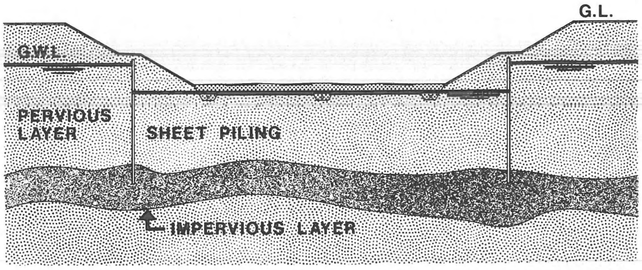


Fig. 11
Open approach Drecht tunnel.

This had to be removed with explosives. This obstacle was not discovered during the conventional, relatively detailed soil investigation. In view of the fact that such obstacles were not detected in the subsoil during conventional soil investigation, an extensive supplementary investigation has been arranged for the future Drachten underpass mentioned above. For this investigation a drilling tube has been vibrated into the soil every 3.50 m on the line of the sheet piled wall.

The Kil tunnel

The Kil tunnel on secondary road 43 between 's-Gravendeel and Dordrecht was built for the Stichting Tunnel Dordtse Kil (Fig. 13). The planning authority, the Locks and Weirs Division of the National Public Works Department, encountered a difficult problem on the west bank, for the approach was projected in the catchment area of the 'Hoekse Waard' spring waterworks. In addition, the built-up area of 's-Gravendeel was a relatively short distance away from the work, while the composition of the subsoil was such that, if extensive dewatering were carried out, fairly extensive damage must be expected. The situation on the west bank required a method of construction with dewatering restricted as much as possible.

In this case the design could utilize the relatively favourable structure of the soil. From the ground level to about 8-12 m below N.A.L. the subsoil consisted of clay and peat layers of poor permeability, with intercalated sand banks. A coarse

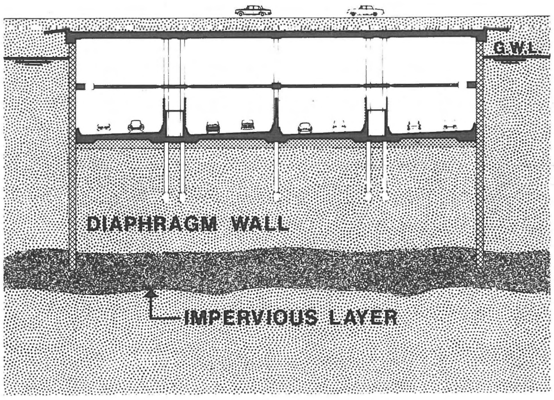


Fig. 12
Cross section cut and cover part Drecht tunnel.

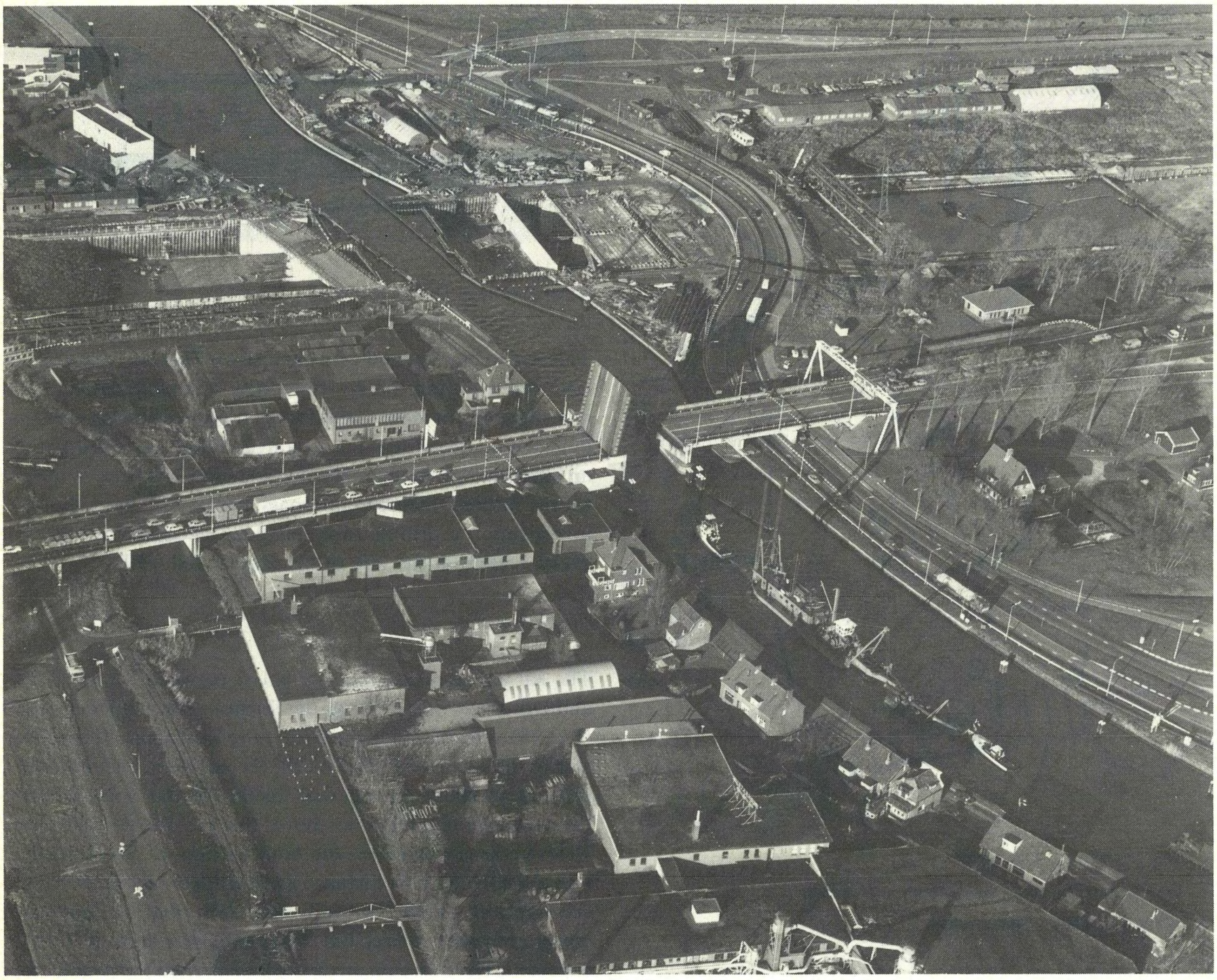


Fig. 13
The Kil tunnel between 's-Gravendeel and Dordrecht. The onland-built part under construction.

aquifer in the form of a sand layer occurred at 17 to 20 m below N.A.L., followed by a clay layer of poor permeability to about 28 m below N.A.L., with a second sandy aquifer, 7-10 m thick, beneath. Figure 14 shows this structure diagrammatically. The water penetration to the open excavation was therefore expected primarily via the first sand layer (between 8 to 12 m below and 17 to 20 m below N.A.L.). Consequently, a sheet piling wall was driven around the entire excavation from the ground level to the poor-permeability clay layer beneath the first sand layer, to a depth of 22 m below N.A.L. The penetration to the open excavation, the deepest point of which was 14.70 m below N.A.L., was considerably restricted in this way (the sheet piling wall was driven in before excavation was started).

Precautions had to be taken in respect of the capillary rise in the second sand layer. If this were left unchanged, the water pressure in that layer would cause the clay layer situated between the first and second sand layers to burst open, undoubtedly if the excavation were made to a depth of 14.70 m below N.A.L. Vertical equilibrium required that the water pressure beneath the clay layer should be less than the weight of that layer plus the remaining weight of the first overlying sand layer after excavation. This vertical equilibrium made it necessary for the capillary rise of the water in the second sand layer to be lowered during construction from the normal N.A.L. level to 3.50 m below it. For this purpose, two deep-well pumps had to be provided with the filter in the second sand layer (about 28 m^3 of water per hour were pumped by this in practice). In order to loose the minimum amount of water, the discharge pipes were connected to the pipe system of the 'Hoeksche Waard' spring waterworks. In this way a total of some 220,000 m^3 of water were supplied to the drinking waterworks. The foregoing might give the impression that the installation and performance were carried out independently by the engineers, but conditions were quite different in reality. The entire work was possible only by the greatest possible co-operation with the waterworks. However, a lot more had to be done than lowering the capillary rise in the second sand layer. As already stated before, a clay layer of low permeability was located between the first and second sand layers, so that the layer was not absolutely watertight; some water oozed upwards through this layer towards the open excavation. There was also water penetration via some leaks in the sheet piling wall. Consequently, two deep-well pumps and some vacuum pumps were provided in the sheet piling wall in the first sand layer.

Comparison of the complete project with work carried out in an open excavation with the normal dewatering system shows that the total water yield was many times smaller. This is perhaps best seen by comparing the lowering of the capillary rise to 3.5 m below N.A.L. with what would have been necessary if the sheet piling walls had not been installed (the water level in the first sand layer would then have had to be lowered to about 0.5 m beneath the bed of the excavation, i.e. to 15.2 m below N.A.L.). The amount of water that would have had to be pumped in that case has not been calculated because it was established from the outset that there should be minimum withdrawal, particularly for water-production purposes.

The consequences in respect to the surroundings at ground level were also minimal. The capillary rise in the second sand layer was lowered only to 3.50 m below N.A.L. at the site of the open excavation, while at some distance from this it was much less. It is perhaps interesting to point out that before driving the sheet piling walls they were chlorinated in order to prevent any bacterial contamination with the ground water in the catchment area.

The sheet piling wall, which had only a temporary function, was withdrawn where possible after the open excavation had been earthed in. Finally, it should be noted that fairly considerable sums were involved with the extra precautions to restrict dewatering.

Similar precautions were taken on the east bank as well, at least at the deepest part of the approach, while construction without dewatering was chosen for the higher section.

The Gouwe aquaduct

With the Gouwe aquaduct (Fig. 15) on the A-12 road, the Locks and Weirs Division again were faced with the problem that dewatering was not permissible. Very soft layers, containing a considerable amount of peat, generally occur here from ground level to 12.5 m below N.A.L. The peat, which has a specific gravity of barely more than 1.0, is very sensitive to the withdrawal of water. Dewatering would result in inadmissible subsidence in the surroundings (quite apart from the damage to the Gouwe embankments and the built-up area in the event of an artificial lake forming as a result around the tunnel after completion of dewatering).

There was a sand bank below 12.5 m below N.A.L. In contrast to the Drecht tunnel, no impervious layer was found beneath the sand layer, at least not at a depth which was economically still 'useful'. This layer therefore had to be created during the performance of the work. In this case it was in the form of an underwater concrete floor (Fig. 16).

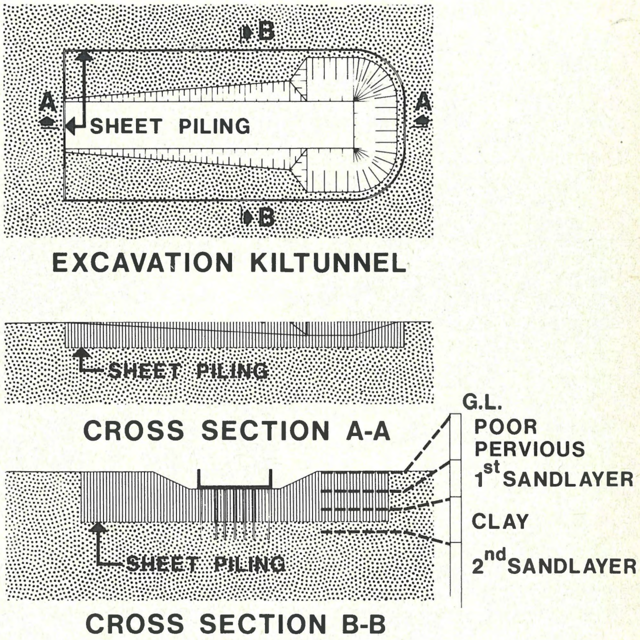


Fig. 14
The excavation of the on-land-built part of the Kil tunnel, with cross sections.

The sheet piling was first driven in, the walls being anchored with grouted anchors. From the pit limited in this way the soil was removed wet as far as the bottom of the underwater concrete floor which would be installed subsequently. Piles were driven through the water into the subsoil from a gantry, movable longitudinally over the entire pit. A crane track on foundation piles was constructed over the entire length of the work on both sides of the construction basin for the movement of the gantry. The pile driver scaffolding can move transversely of the basin on the gantry, so that a pile can be driven anywhere in the basin.

The pile heads are left to project from the excavated bed of the pit. An underwater concrete floor is then cast between the sheet piling walls to a thickness of not less than 1.10 m. After setting, the basin can be pumped dry. The removal of the weight of the water from the floor causes the piles to have to deal with a fairly considerable tensile force (capillary rise of the groundwater minus the actual weight of the underwater concrete floor). To be able to transmit the shear stresses required for this purpose, the sides of the piles have a corrugated profile – at least insofar as they are received in the underwater concrete – on two sides, while the other two sides have granular surfaces.

A final tank profile of reinforced concrete is then made in the basin (and a closed structure at the point of intersection with the Gouwe). The reinforcement of the pile heads projecting from above the underwater concrete is accommodated in the concrete floor after stripping the pile heads.

Fig. 15
The Gouwe aquaduct on the A-12 highway, under construction.

Only the principles of construction of the Gouwe aquaduct have been described above. The actual construction was more complicated, partly because of the longitudinal phasing of the works required (e.g. re-laying of the various intersecting roads and partial diversion of the Gouwe).

The Hem tunnel

The Hem railway tunnel is built under the Noordzeekanaal for the new Hem railway line. The underwater part, consisting of 7 tunnel units of lengths of 134 and 268 metres, was built in the Amsterdam Noord dry dock, which has already been mentioned (Fig. 9). Because of the very considerable length of the section requiring to be immersed, it is more economic to make the total length as large as possible, in order to avoid working in very deep open excavations with extensive dewatering.

Consequently, the tunnel is sunk to a length past the future banks, and dredging has to be carried out that far. Temporary or new water dams have to be installed for this purpose. The approaches are constructed in open excavations with banks (Fig. 17). Because of the long immersed section of the tunnel, the open excavations are restricted in extent and

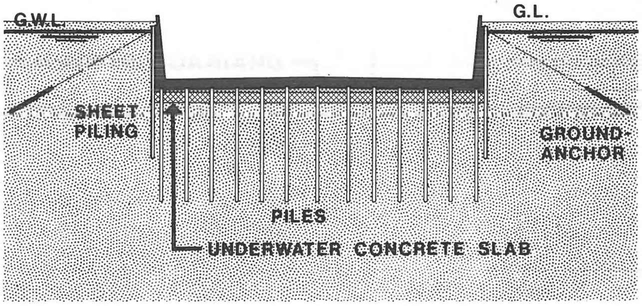


Fig. 16
Cross section Gouwe aquaduct.

Fig. 17
South approach of the Hem railway tunnel.

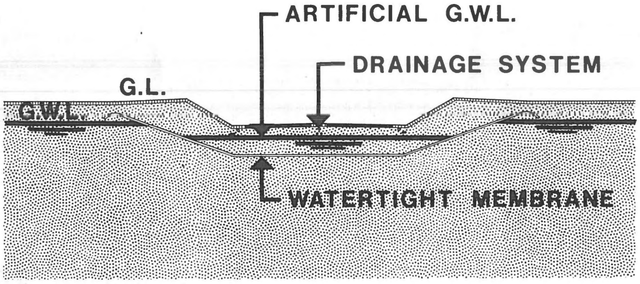


Fig. 18
Cross section of the Hem railway tunnel.

depth: to about 12 m below N.A.L. at the water cellars. A considerable additional advantage is that the dewatering capacity can be limited (limitation of the reduction of the groundwater level in the surroundings and hence reduction of the risk of damage). Underwater pumps were installed in up to 26 wells for the North and South open excavations, to prevent the soil from bursting open.

Open dewatering removes the surface water. The open approaches have foundations in the form of tension piles formed in the ground and compression piles as far as the load-bearing strata. Construction in an open excavation with dewatering was freely usable here because the work was relatively far away from the built-up area and there was no risk of any great damage to the surroundings (Fig. 18).

A considerable problem with this tunnel was the spoil from the immersion trench, the approaches and the building dock. Since a fairly considerable amount of elevating work has to be carried out in the surroundings for the purpose of roads required, most of the spoil could be sold to the surrounding municipalities.

The good topsoils were used for the railway covering. Unsuitable spoil was dumped in an old sand pit.

The tunnel in the Schiphol line beneath the airport

The impervious layer of part of the tunnel in the Schiphol line beneath the airport (Nederlandse Spoorwegen, Betonbouw) is formed by injecting the (sand) soil between the sheet piling walls over a thickness of about 1.5 m as shown in figure 19. Sufficient weight of soil to prevent bursting open still rests on the impervious layer when excavation is carried out between the sheet piling walls. The actual reinforced concrete tunnel is built in the dry state inside this basin. The depth of the injected layer is also governed by the requirement that the tension piles fitted after excavation should not perforate the layer and hence cause leakage. The provision of an injected layer is also one of the options available in the wall-roof method.

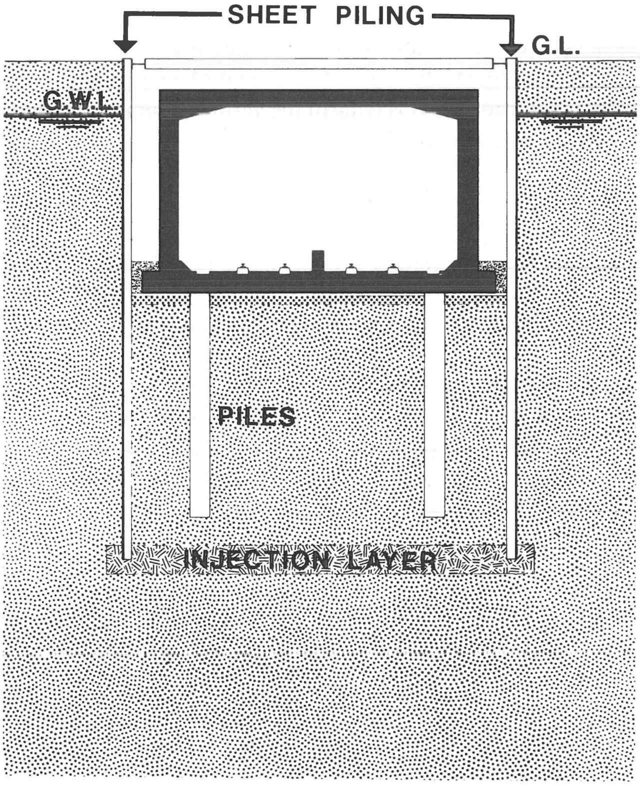


Fig. 19
Cross section of the Schiphol tunnel.

SUMMARY

In the foregoing an attempt has been made to give a picture of how tunnels are built in The Netherlands and of the associated specific design and construction problems. The emphasis has been laid on excavation and dewatering. The following comments are generally applicable.

(1) A tunnel can be built in an open excavation with dewatering. This is usually the cheapest solution.
(2) If the presence of impervious layers in the subsoil can be used, it is generally rational and cheap to use these naturally present strata.
(3) If dewatering results in serious damage to the surroundings, then as far as possible an attempt must be made to find a building method (if necessary without injecting layers of soil) in order to avoid dewatering.
(4) It is impracticable to give standard solutions for constructing tunnels and sunken roads.
(5) It is desirable for the tunnel builder to be in possession of very reliable and detailed data relating to the subsoil at an early stage of the project. Skilled geologists, familiar with this matter, are required for this purpose and new techniques will probably have to be evolved.

Considerable knowledge of tunnel building has been acquired in The Netherlands and this knowledge can be used for future projects. The Netherlands continue to be a specialist in hydraulic engineering, and fortunately still have a good reputation throughout the world.

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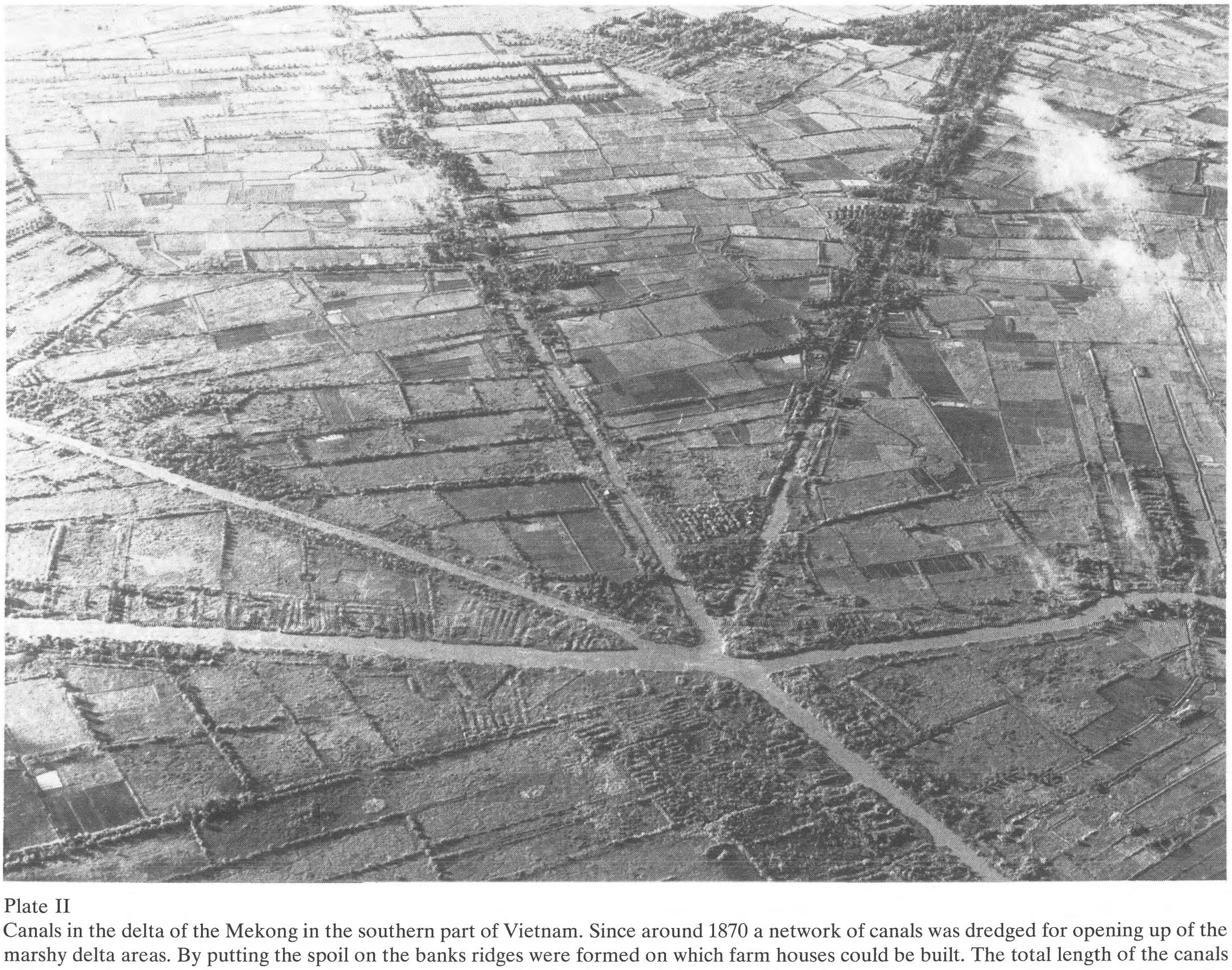

Plate II

Canals in the delta of the Mekong in the southern part of Vietnam. Since around 1870 a network of canals was dredged for opening up of the marshy delta areas. By putting the spoil on the banks ridges were formed on which farm houses could be built. The total length of the canals wider than 6 m is 4000 km. They are in open connection with the rivers and the sea and by tidal level variation offer limited possibilities for drainage and irrigation.

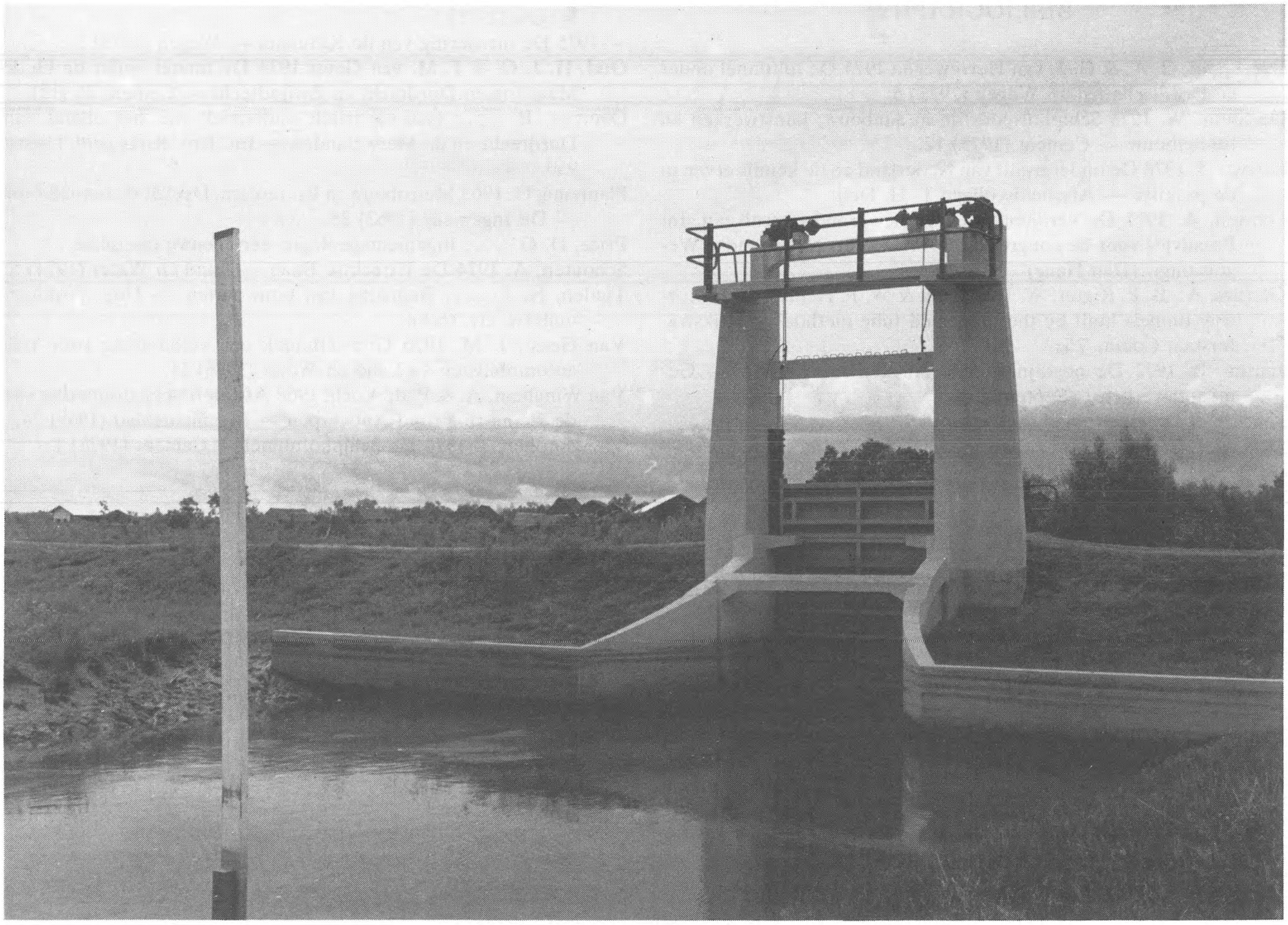

Plate III
Modern drainage sluice for removal at low tide of excess water from low-lying coastal polders in Malaysia (Tanjong Jurong). The light-weight gates consist of aluminium.