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The Wind Barrier along the Caland Canal near Rotterdam

Pare-vents en bordure du Calandkanaal, près de Rotterdam

Der Windschirm am Calandkanal bei Rotterdam

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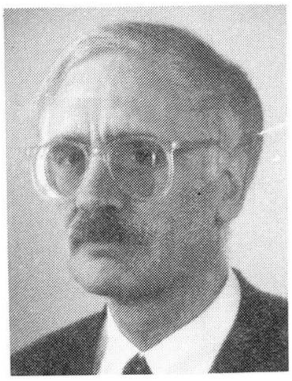

Joop Schilperoord, born in 1939, completed his studies in 1959 at the Rotterdam College of Technology. In 1983 he graduated in general economics at the Erasmus University in Rotterdam. The focus of his work is in the design and preparation of special constructions.

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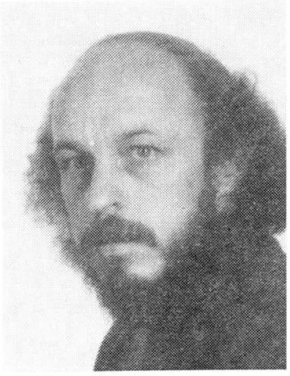

Maarten Struijs, born in 1946, trained as an architect at the Rotterdam Academy for Architecture. Since 1971 he has been practising as an architect. The scope of his work lies in the design of public buildings and artefacts, with emphasis on theoretical premises.

SUMMARY
This publication gives and insight into the design process for the wind barrier along the Caland Canal, near Rotterdam. The aim of this structure is to reduce the wind pressure on passing ships. The design involved a close collaboration between the three parties involved, the architect, the (wind-engineering) advisor and the designer. A finite element method program was used for calculating the details of the concrete barrier. A characteristic feature of the barrier is the employment of semi-circular shells.

RÉSUMÉ
Cet article présente la réalisation d'un pare-vents en bordure du Calandkanaal, près de Rotterdam. Cet ouvrage d'art contribuera, par sa présence, à réduire l'impact des vents sur le trafic fluvial. La réalisation de ce projet a été marquée par un esprit d'étroite collaboration entre les différentes parties concernées : l'architecte, le conseiller (spécialiste des vents) et le constructeur. Le développement de l'ouvrage en béton, caractérisé par une composition d'écrans cintrés, a été conduit à l'aide d'un programme d'éléments finis.

ZUSAMMENFASSUNG
Es wird ein Einblick in den Entwurf des Windschirms am Calandkanal bei Rotterdam vermittelt. Zweck dieses Bauwerkes ist die Verminderung des Winddrucks auf vorbeifahrende Schiffe. Beim Entwurf gab es eine enge Zusammenarbeit zwischen den drei am Projekt Beteiligten : dem Architekten, dem (windtechnischen) Berater und dem Konstrukteur. Bei der Bemessung der Betonabschirmung wurde vom Finite-Elemente-Programm Gebrauch gemacht. Die Verwendung halbrunder Schalen ist ein charakteristisches Merkmal der Abschirmung.

1. INTRODUCTION

1.1 Geography

The port and industrial area, also known as Europoort, situated between Rotterdam and the North Sea, is in its present form a product of a 30-year evolution. It is a narrow strip of ground, bounded by Nieuwe Waterweg, the shipping communication with Rotterdam, and a scenic area formed by the Brielse Maas with adjacent built-up (residential) areas. In this area is found a lot of (petro-)chemical industry, in addition to (container) transshipment firms and oil storage. A prerequisite for all this industry is good communications with the hinterland by means of rail and road links (fig. 1).

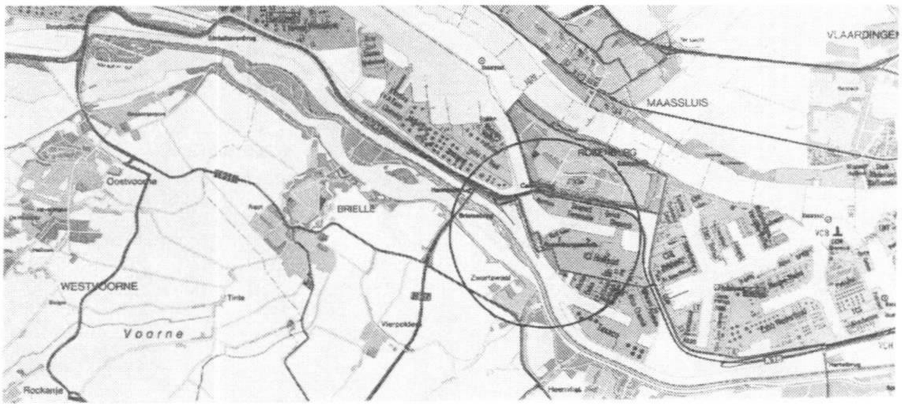

Fig. 1 The Europoort area, Brittanniëhaven is indicated by a circle.

1.2 Changed environmental requirements

These roads were constructed during the very first phase of the development of the Europoort region. At this time, it was envisaged that almost only petrochemical companies would be established, but times have changed.
About half-way along the Europoort area, right next to the residential district of Rozenburg, is Brittanniëhaven. This harbour was designed on the implicit assumption that petrochemical industry would be established around it (see fig. 2). This conviction was so strong that the Caland Bridge, which enables road and rail traffic to cross the Caland Canal (the link between Nieuwe Waterweg and Brittanniëhaven), was dimensioned such that only relatively small ships could pass this bridge without problem on their way to Brittanniëhaven.

1.3 Shift in use of Brittanniëhaven

With the emergence of container transport and car transhipment (Ro-Ro), a possibility emerged to give this harbour an environmentally safe use. In 1981 Quick Dispatch established itself with a car terminal on the northern side of the harbour. In addition, Seaport started up a new multi-purpose terminal. These companies frequently receive ships with a large windage.
Practice has shown that these ships cannot pass the Caland Bridge without problem under all conditions. Beyond a certain wind strength, these ships were therefore not allowed to pass the bridge in order to reduce the risk of damaging it to a minimum.

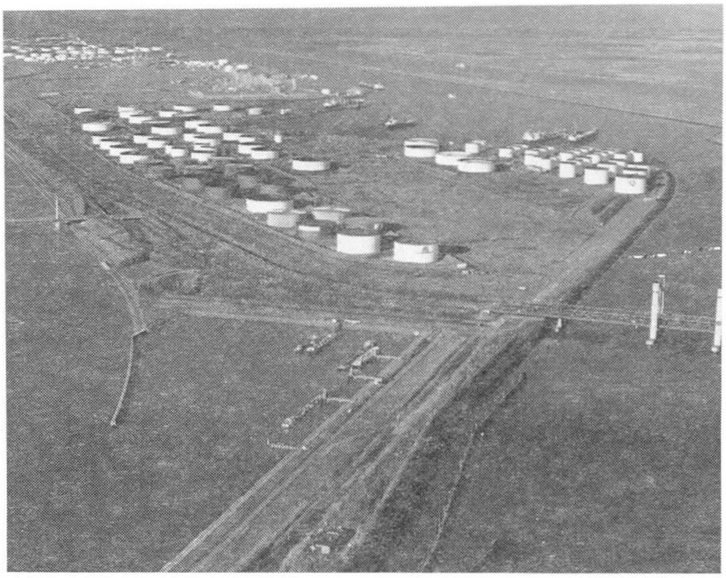

Fig. 2 The situation before 1985.
In front the Caland Bridge.
photo: Bart Hofmeester

This restriction resulted in waiting times, which was a nuisance for the companies in question. The infrastructure would have to be changed if Brittanniëhaven was to remain economically attractive. The most obvious solutions, such as widenening the bridge passage or even replacing the bridge by a tunnel, were out of the question on financial grounds.

1.4 Necessity for improving wind climate

The only remaining solution was the erection of a structure to change the wind climate, especially at the Caland Bridge to such an extent that there would be no significant waiting times.
The management of the port area, the Municipal Port Authority, requested TNO to carry out wind tunnel research in order to determine how these requirements could best be met.

2. ARCHITECTURE OF THE WIND BARRIER

2.1 Architect's contribution necessary

As the project developed, people began to realize just how great the impact on the landscape would be. The Port Authority then asked Public Works to put the further elaboration of the barrier in the hands of an architect, with the additional request that a number of models be developed in order to provide a choice. Since no comparable projects had been undertaken anywhere else in the world, reference could not be made to existing models.

2.2 Architectural design process

The architectural design process began with an investigation into the architectural means. Preliminary wind research had first of all examined the fine meshed "seive model". But it also appeared possible to consider the barrier as a series of large-scale elements with relatively large gaps between them. Bearing these two possibilities in mind, the architect developed four models by approaching the wind barrier from four different architectural design starting points.
The development of a number of architectural variants is based on a theoretical model developed by Maarten Struijs and which has been described in a number of publications. This model is based on the assumption that architecture is a specific form of knowledge.
The field of knowledge opens out into three directions:

* The empirical direction, this takes "experience" as its starting point
* The rationalistic direction, takes a discipline of science as starting point
* The idealistic direction takes an ideal picture as starting point

A specific category of knowledge is characterised by two structures, viz. the internal and the external structure. Ideas based on the internal structure - how does the discipline itself work - are called "autonomous" ideas. Realistic ideas are those based on the external structure: how is the discipline related to other knowledge and experience. They are based on a different reality than the discipline itself.
From the model for knowledge in general, viz. the empirical, rationalistic and idealistic fields of knowledge on the one hand, and the model for a specific field of knowledge (knowledge category, discipline) viz. the autonomous and the realistic ideas, on the other, arises the specific knowledge model for the discipline of architecture.

* Autonomous architecture ideas
* Empirical-realistic architecture ideas
* Rationalistic-realistic architecture ideas
* Idealistic-realistic architecture ideas

In order to arrive at the various architectural models, it was decided to develop an ordering principle from each idea (see fig. 3). The models developed from this were considered from the wind-technology, constructional engineering and cost points of view.

In addition, the models were submitted to the municipality of Rozenburg, the Urban Development Department and the Rotterdam Building Inspectorate. The almost unanimous opinion was that the design now implemented the empirical order model, was the best choice from among the models presented.

2.3 Wind barrier design

Figure 4 shows the completed wind barrier. The characteristic feature of the barrier is the use of semi-circular shells 25 m high, having a radius of 9 m at the southern side and placed every 12 m. The central part consists of half shells with an internal radius of 2 m and a separation of 1.33 m. The design of the central part was made in close collaboration with the sculptor Frans de Wit. The presence of road intersections meant that it was not possible for the central section to extend to ground level at all points. A heavy torsion-resisting bridging beam was therefore employed over the entire length of this section in which the shells are anchored at road intersections.

The convex sides of the shells are directed towards the water, the most effective orientation from the wind point of view.

The third, northernmost barrier section is a combination of a 15 m high, wind-breaking embankment, on top of which are 10 m high wind-breaking flat slabs.

The division of the barrier into three sections, which was in fact made necessary by local conditions, meant that the overpowering and massive character of the structure could be toned down. The final result of these architectural efforts is one of the few examples in The Netherlands of an entirely architect-designed civil engineering project. It has an enormous impact on the landscape, a post-modern architectural monument.

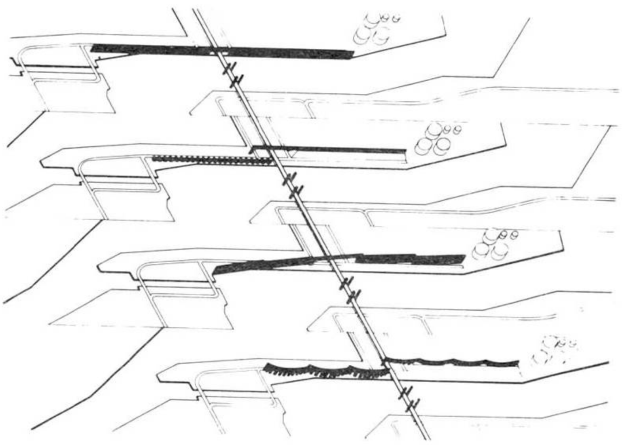

Fig. 3 The 4 models considered.

Fig. 4 Situation nowadays.
photo: Bart Hofmeester

3. CONSTRUCTION OF THE WIND BARRIER

3.1 Wind tunnel research

The wind tunnel research was carried out in two phases. The TNO research first of all concentrated on an approximate determination of the optimum barrier height and also looked at the effect of the permeability. This exploratory research showed that a 25 m high barrier with a 25% permeability would be the best solution to the Port Authority's requirement in respect of the reduction of the wind pressure, measured at the navigation line.

On a basis of these rough starting points, the architect determined the exact shape. The final choice was for semi-cylindrical shells with 25% permeability,

which was achieved by spacing the shells. The three sections of the barrier (southern, central and northern part) partly overlap each other.
The length of this overlapping part was determined empirically.
The choice for the semi-cylindrical shape was made primarily on architectural grounds, but also had definite wind-effect advantages. The measurements made by TNO showed that the half shells were so effective that their separation, which had originally been put at 6 m, could be increased to 12 m.

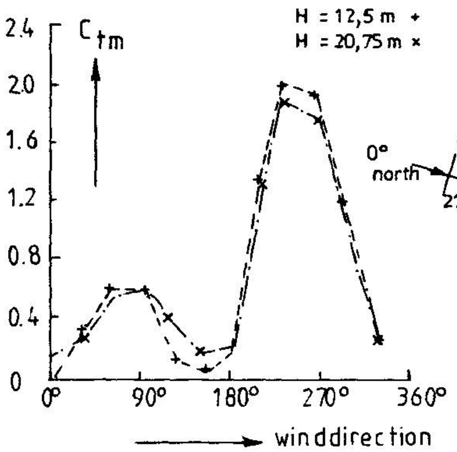

Fig. 5 The C_t value as a function of the wind direction.

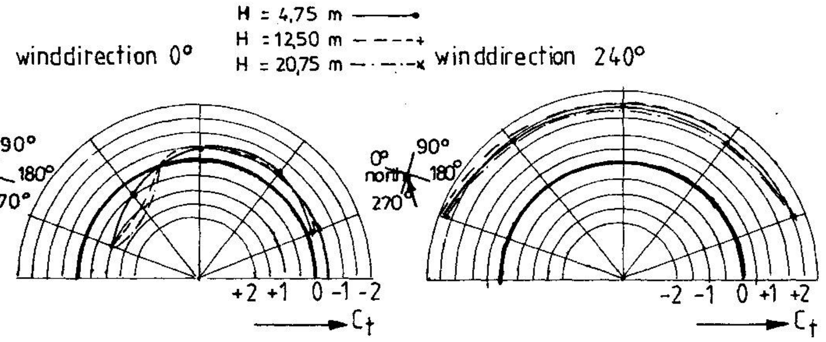

Fig. 6 The detailed wind distribution for two significant wind directions (0° and 240°).

The effectiveness was determined in a second series of wind tunnel tests, in which a part of the barrier (southern part) was measured. Thirty Pitôt tubes were positioned both at the inside and the outside of the scale model (1 : 250), which enabled the total C_t value of one shell to be determined as a function of the wind direction.

3.2 Some constructional aspects of the southern barrier section

The shape of the shell is ideal from the constructional point of view: maximum rigidity for a minimum of material used. The choice of concrete for the material was never really in question.
Thanks to the great rigidity of the structure, tensile forces are only very localised and not too great and can easily be coped with by mild steel reinforcing.
Each shell is built on foundations consisting of 11 pre-stressed prefabricated piles. The centre of gravity of the pile arrangement coincides with the centre of gravity of the shell, so that no uneven pile loading will occur for resting load. Locating the piles as far as possible from the centre of gravity produced a maximum rigidity (for a minimum number of piles). The thickness of the shell was fixed at 250 mm, determined mainly by the casting aspects (sliding shuttering, double reinforcing mesh).
Due to the boundary conditions, or rather due to their absence (no constraint, no thickened edge, no through shell), it was not possible to calculate the structure purely theoretically. Calculation of a discretised structure and the structure itself was the most that could be hoped for. It was therefore decided to calculate the structure with the aid of the finite element method. For some time now, Rotterdam Public Works has at its disposal the DIANA program developed by TNO-IBBC.
This extremely advanced program can draw from a wide range of element types, including the super-parametric, double-curved shell element with 40 degrees of freedom (CQ40S), which was used in this case. It can accommodate bending, perpendicular and transverse forces, as well as twisting forces. At the bottom

of the shell, the piles were inserted as triple two-node elements, resilient in the three major axis directions. This enabled the shell behaviour as a result of a wind load varying over the surface, to be accurately determined.
The importance of this research became evident when it was found that large movements could arise locally (near the top angles) as a result of the wind load which increased strongly towards the tips. This was only discovered after the second series of wind tunnel tests had been carried out.
As the constructional work had already been started, it was no longer possible to thicken the shell further. The only solution for reducing the bending moments in the top cross section was to fit a tension joint at the top of the shell. In the determination of the wind load, the dynamic aspect was translated into the allowance factor φ_1 calculated as a function of the lowest Eigenfrequency. This was about 0.7 Hz (see fig. 7), which resulted in an allowance factor $\varphi_1 = 1.15$. The critical wind velocity for the shell is $V = (1/s) . f D_m$.
In case of complete working of the shell (which is brought about by the tension connection), D_m can be taken as 18 m. Given the factor S (Strouhal number) which can be taken as 0.02 for this type of construction, the critical wind velocity is 60.3 m/sec. Only at this speed there is a risk of the construction being excited at its lowest Eigenfrequency. This value is far above the design velocity of 40 m/sec (145 km/h).
The design wind loads varied between 0.3 and 3.1 kN/m^2, depending on wind direction and point on the shell surface.

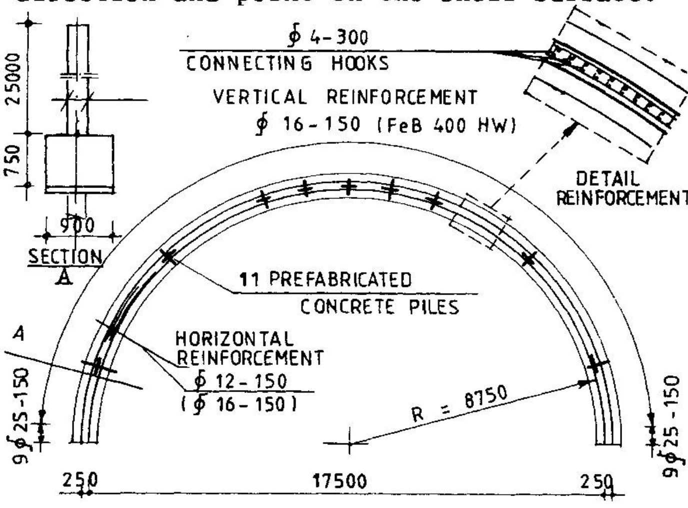

Fig. 7 Horizontal cross-section over southern shell.

The shells are reinforced with a double crossing mesh ϕ12-150 Feb 400 HW, locally thickened to ϕ16-150. The horizontal rods are situated in the outer layer.
To prevent the reinforcing from springing apart, the two meshes are linked to each other by "bacon hooks". A 40 mm coating of concrete was employed in order to reduce the risk of corrosion (see fig. 8).
Particular attention was paid to the concrete mixture, especially the fine fraction. To this end, fly-ash was added. Since the cracking moment would only be exceeded at an exceptionally high wind load, a surface coating was not applied.

4. CONCLUSION

The wind barrier along the Caland Canal is clearly an example of an amalgamation of engineering and aesthetics leading to an optimum result. The architect's demands could be met almost completely, and this was thanks in no small part to the facilities available to the designer, comprising a sophisticated computer program (DIANA finite element method), which enabled model research to be performed as it were without additional costs. As Public Works always had this program (implemented on a Geminix/Microdutch microcomputer) at its disposal, it was possible by means of "fine tuning" to put the design fully in the architect's hands. In addition, it was also possible to achieve an economic design, since the required reinforcing could be determined precisely. The possibilities open to the architect were considerably enhanced by the computer, while there was also more scope for the designer, since he did not always have to turn down a seemingly extravagant request by the architect. The wind barrier will certainly not be the last project to be realized in consequence of this trend.