

# Design of the Storm Surge Barrier Ramspol, The Netherlands

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## **Abstract**

The north-western part of the province Overijssel is subjected to the risk of flooding due to high waters from Lake IJsselmeer and Lake Ketelmeer.

To protect this area an inflatable storm surge barrier will be provided. The scheme is presently under development and partly under construction.

Once completed the dam will be the largest of its kind. The dam consists of a nylon reinforced rubber sheet, anchored by clamps into a reinforced concrete foundation. Design conditions are extreme: the overall probability of failure should be  $3.5 * 10^{-4}$ /year.

To analyse the expected stresses in the rubber sheet extensive finite element runs had to be performed in combination with scale model tests in a hydraulic laboratory. The FEM calculation required a significant amendment of calculation procedures due to the phenomenon of large strains and the non-linearity of material properties and geometry.

Also the capacity tests appeared to be complex. FEM calculations were required to conclude the capacity of the tested sample. The developed models appeared strong tools to optimise geometry and as such to avoid unnecessary stress concentrations.

## **1. Introduction**

The province of Overijssel is located in the north-east of the Netherlands. Although mainly surrounded by land, the north-western part of the province is exposed to the risk of flooding

due to high waters from Lake IJsselmeer and Lake Ketelmeer. To protect this part of the province a storm surge barrier will be provided.

The barrier, presently under development and partly under construction, consists of inflatable rubber dams. In total three dams, interconnected by dikes, will be provided. The dam will be unique in terms of size, application as storm surge barrier and design conditions. Contrary to previous applications the dam will be filled with both water and air. This has been chosen to minimise dimensions and to optimise the inflation/deflation procedure of the dam. The rubber sheet is armoured with nylon inlays.

The project has been tendered as a design-construct project. The Client, local water authority Groot Salland, awarded the contract to Hollandsche Beton- en Waterbouw [HBW], an operating company of Hollandsche Beton Groep [HBG]. The Engineering Department of HBW provided the tender design and carries out detailed design.

## 2. Brief description of the project

The storm surge barrier Ramspol is located near the city of Kampen in the north-west of the province Overijssel. Under storm conditions, two waterways shall be closed: both the Ramsdiep and the Ramsgeul. The Ramsgeul will be closed by two dams [fig. 1]

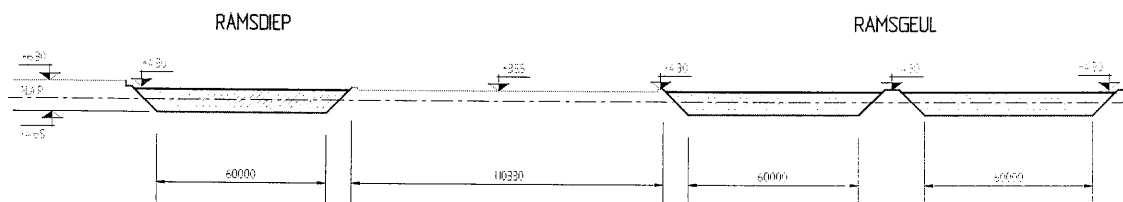


fig. 1 Elevation of the storm surge barrier

Each dam is 75 m long, 13 m wide and has a design height of 8.35 m. The waterhead is 4.4 m. These conditions are based on the design requirements that extreme hydraulic circumstances should be used with a probability of occurrence of once in 10 000 years.

Under normal conditions the dam is deflated and stored in the sill [fig. 2]. When the water level reaches the alarm level of NAP +0.5 m, the inflation procedure starts.

Pipelines in between the upstream water and the interior of the dam are opened and simultaneously compressors blow air from both edges near the dikes in the dam. This will result in an interior air overpressure of 0.1 – 0.2 bar.

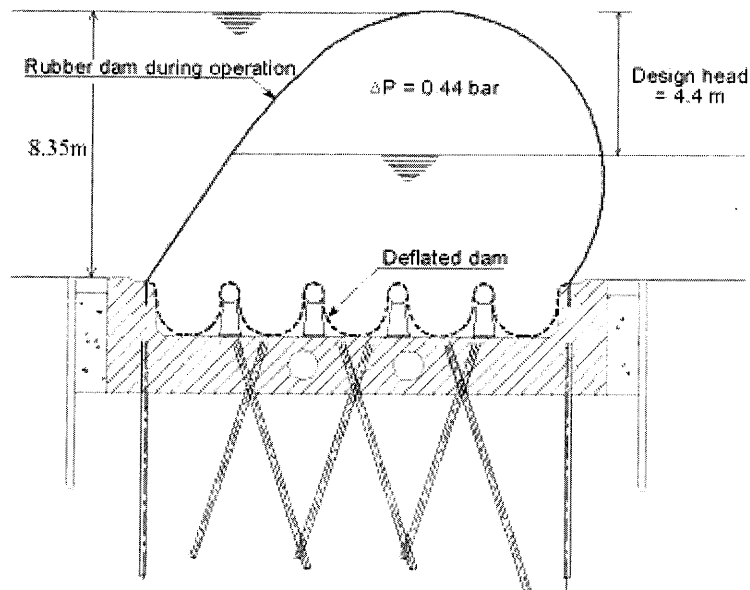


Fig. 2 Typical cross section

The waterhead difference between free water outside the dam and the interior, together with the increased interior volume, let water freely flow into the interior while the compressors continue to pump volumes of air into the dam. Upon completion of the inflation procedure the air valves are closed. The internal overpressure of air is 0.2 – 0.3 bar and the crest of the dam is above the upstream water level.

Under these conditions the waterhead is relatively low [ $< 1$  m]. When the upstream water level is rising [fig. 2 and 3] the dam will be further deformed because of higher loads. As a consequence the air overpressure will also increase and will automatically reach the required overpressure of 0.44 bar to withstand the extreme hydraulic conditions. As such a self regulating system has been achieved.

After the storm the dam will be deflated by starting the water pumps and opening the air valves simultaneously. To allow safe storage of the sheet when the dam is not in use, a specific configuration of the sill has been designed and provided with rollers. The configuration allows full storage of the sheet. The rollers are required to move the sheet equally over the width of the sill [fig. 4].

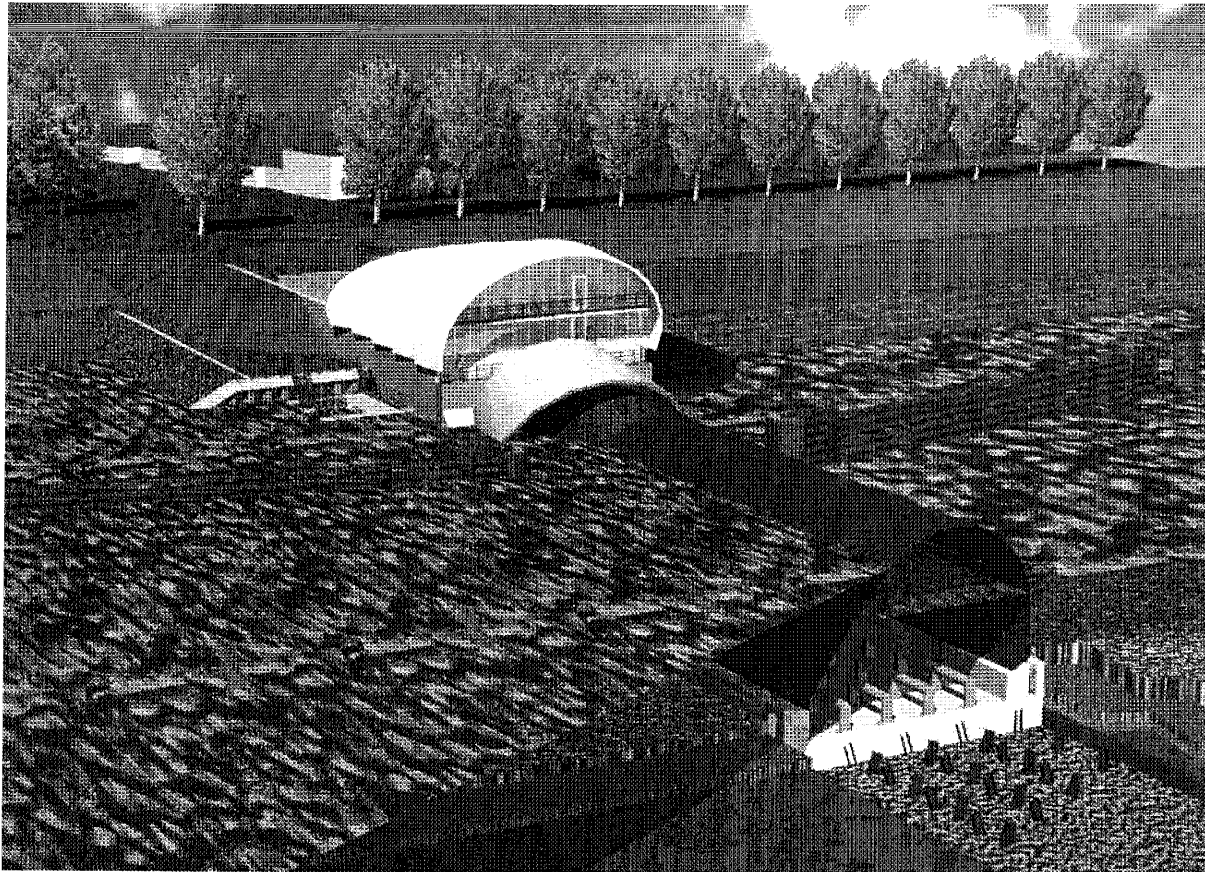


Fig. 3 Bird's eye view of the inflated storm surge barrier

### 3. Abutment slopes

Near the abutment the sill is provided with a slope [fig. 1]. Also on the slopes the rubber sheet shall be completely stored in the concrete structure of the slopes. Therefore the slopes have the same cross section as the sill [fig. 2], although tapered in plan view towards the abutment.

To meet requirements regarding crest levels after inflation and to be completely stored after deflation results in a required overlength of rubber sheet along the slope compared to the straight length of such slope. To create this overlength the slope is provided with small waves so that the developed length equals the required length of the sheet including overlength [fig. 5].

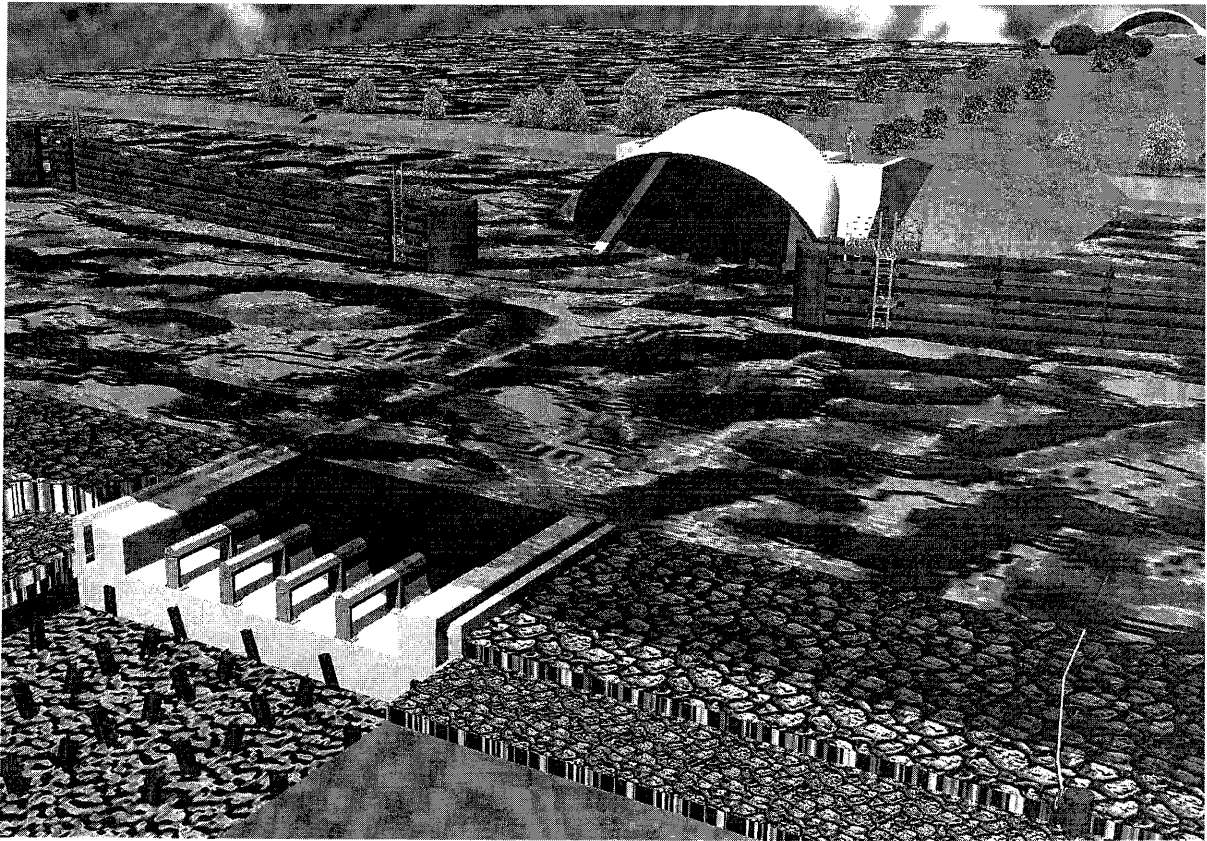


Fig. 4 Bird's Eye view of the deflated storm surge barrier

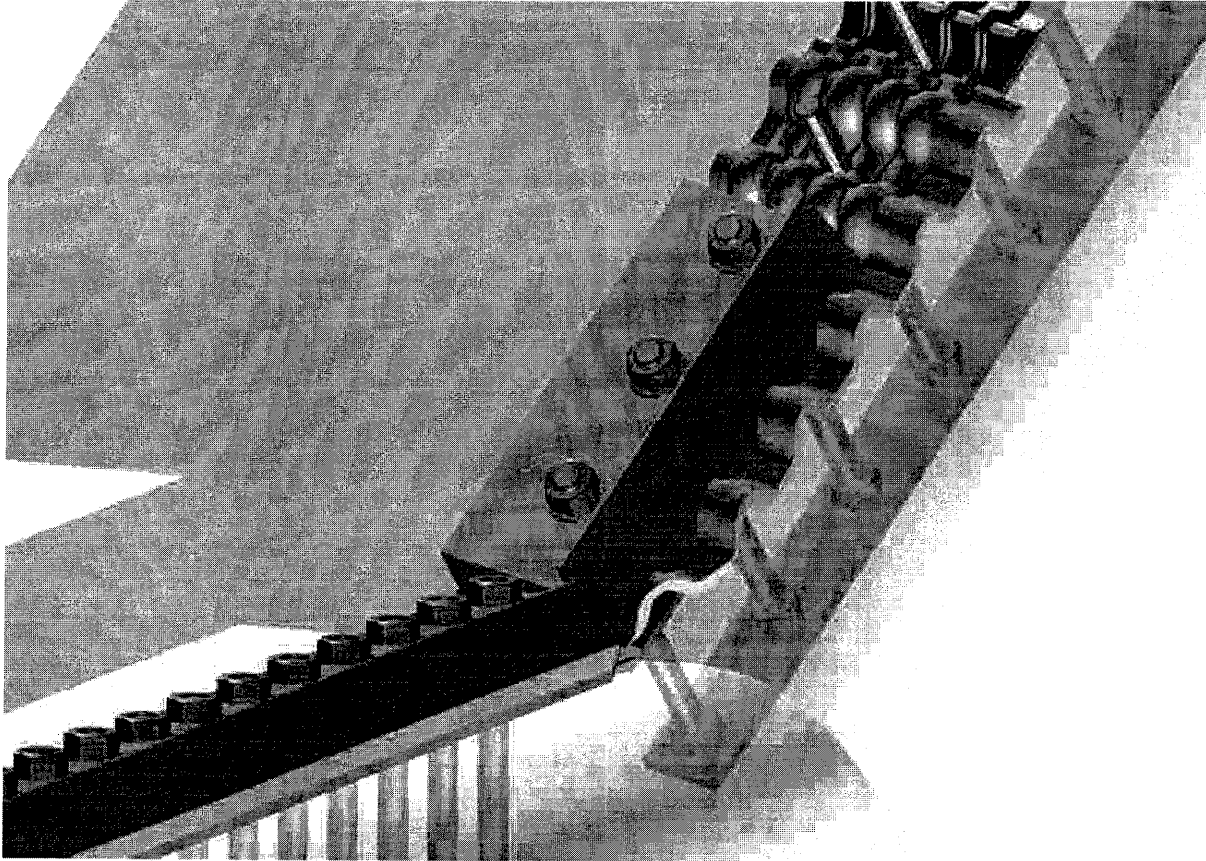


Fig. 5 Typical detail of small waves near the abutment

#### 4. **General design approach**

World wide approximately 2000 inflatable rubber dams have been constructed, predominantly in Japan [approx. 90%]. This might explain why only in Japan design codes for this concept could be found. The Japanese code requires an overall safety factor of 8 between initial tensile strength and static load calculated for a two dimensional cross section. Such overall factor should cover influences and uncertainties, among others: wave loading, stress concentration, ageing, fatigues and water saturation.

Given the extrapolated size of the dam and the use as storm surge barrier it was decided that a more fundamental investigation was required.

A wide variety of scale models and analysis techniques have been used to develop, step by step, insight and understanding relative to the inflation/deflation procedure and the performance of the dam. Models and techniques developed from simple to highly sophisticated.

The matured tools, in the end, consisted of scale models in the hydraulic laboratory, advanced finite element calculations and full scale model tests of the rubber sheet in the clamps. For a typical section of the clamp reference is made to fig. 6.

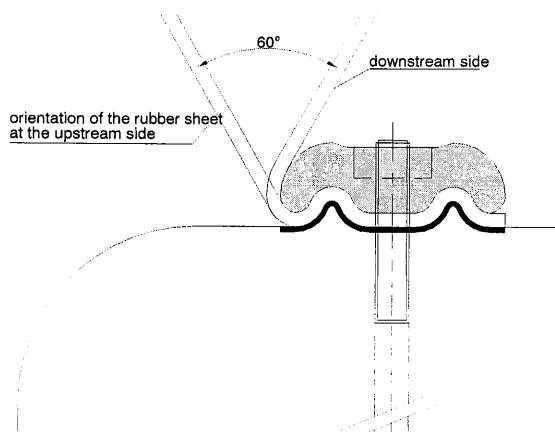


Fig. 6 Applied clamp system to connect the rubber sheet to the foundations

The finite element calculations are used to calculate engineering stresses in the rubber sheet under static conditions. The scale models are used not only to investigate the dynamic effects but also to mirror the shapes of the dams as calculated versus shapes observed in the scale model. Capacity in the end was assessed by the full scale tests on rubber sheets anchored in the clamps.

#### 4. Stresses in the rubber sheet

From a semi probabilistic analysis water levels were calculated to comply with the probability of failure of once in 10 000 years for the rubber sheet. To process these environmental conditions into engineering stresses, finite element calculations have been used.

Beside input parameters from the environment, also material properties are required. These were derived from extensive tests on samples. From the characteristics of the nylon material it was obvious that significant strains would occur; much larger strains than normally would occur in civil engineering.

Kinematic and constitutive equations of finite element programmes are based on small strains and will not correctly describe large strain conditions. Therefore the programmes of both the structural engineers of contractor and client had to be modified.

After this modification it proved to be feasible to calculate engineering stresses under non-linear material performance, non-linear geometry conditions and large strains. A typical of the geometry as calculated under extreme conditions is given in fig. 7.

The finite calculation results in terms of calculated geometry were continuously compared to the results of the investigations in the hydraulic laboratory.

