

CHAPTER 254

Wave Impacts on the Eastern Scheldt Barrier Evaluation of 5 Years Field Measurements

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Abstract

During the past five years an extensive program of field measurements has been carried out to evaluate the effects of wave impacts on the Eastern Scheldt Barrier in the Netherlands, under operational conditions. High impact pressures were measured. The evaluation of the measurements shows that these high pressures affect only a small area simultaneously.

Introduction

The Eastern Scheldt Barrier is located in the southwest part of the Netherlands. The barrier has been built across three main channels in the mouth of the Eastern Scheldt, respectively one kilometer, one kilometer and two kilometers wide. The actual barrier consists of 62 basic sections that are 45 meters wide (see figure 1). The sand bed is covered by a filtermat. On this mat concrete piers are placed. The flow opening is formed by two concrete beams. A steel gate, driven by hydraulic cylinders, can close the opening. On top of the piers a motorway bridge is located. The piers and sill beams are packed in by a rubble sill structure. All structural elements, piers, beams and gates, were prefabricated at a dry construction site and have been placed in open sea with heavy floating equipment. The barrier has been completed in 1986. Until 1994 11 storm closures were performed.

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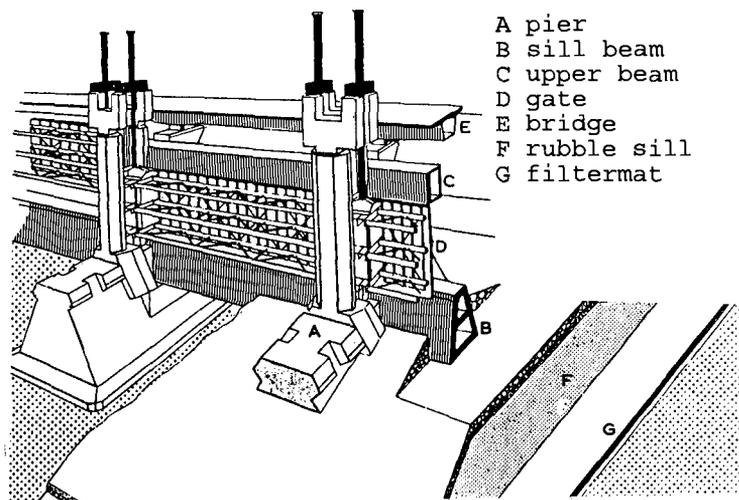


Figure 1: Elements in the Eastern Scheldt Barrier

Wave Impacts

Under storm conditions the barrier is subject to wave attack from the North Sea. During the more severe storm surges the gates of the barrier will be closed. These gates are subject to wave impacts during the closure operation of the barrier, when the girders of the gates, which are located at the North Sea side of the barrier, cross the water level. After the gates have been closed the front and top side of the upper beam are subjected to wave slamming. Wave impacts on the bottom of the beam occur, when the gates are open, under moderate storm conditions and with more severe conditions just before the gates start closing.

The design impact forces for the gates and the upper beam were determined from extensive scale model tests. For the design computations the wave impacts were schematized to a triangular pressure diagram, as shown in figure 2. The rise time and decline time have average values of respectively 0.05 s and 0.10 s. The peak pressure varies from 0.45 Bar to 0.65 Bar (1 Bar = 100 kN/m²) depending on the wave conditions and the location in the barrier.

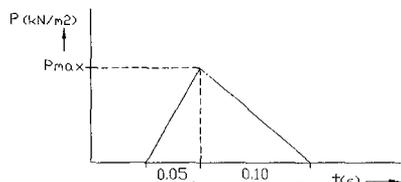


Figure 2. Schematized Impact Pressure

Monitoring Program on Wave Impacts

In an early stage of the design of the barrier it was decided to set up a monitoring program to evaluate the hydraulic aspects of the barrier. This program consisted of field measurements of hydraulic loads on the barrier and the response of the structure (Klatter, 1990). In this program the wave impacts on the barrier were included. For the monitoring program on wave impacts a selection was made on the most critical items of the design. Critical, because the construction was very sensitive to a certain aspect or because the design technique was uncertain. For the monitoring program wave impacts on the main girders and supports of the gate and against the bottom of the upper beam were selected as critical items for the design (see figure 3).

Wave impacts on the girders of the gates generated such large impact pressures that the design of the gate had to be adapted several times to reduce these pressures. These aspects were therefore included in the monitoring program. The girders were instrumented in two locations: one at the center part of a top girder, the other at the end of a bottom girder near the joint with the support.

For the upper beam wave impacts against the bottom of the beam were regarded to be critical, because the relatively light weight prestressed concrete beam could be lifted from its supports.

For the monitoring of the wave impacts, one gate and one upper beam were instrumented with accelerometers, pressure gauges, a water level gauge and force gauges. Details of the instrumentation are given in tables 1, 2 and 3, and in figures 4 and 5.

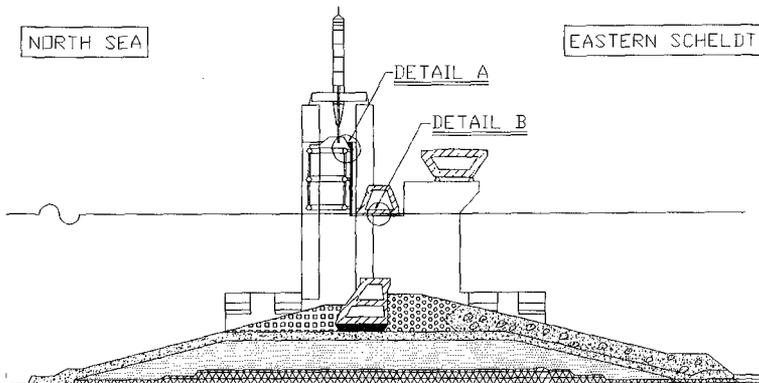


Figure 3. Locations for Wave Impact Monitoring

DETAIL A

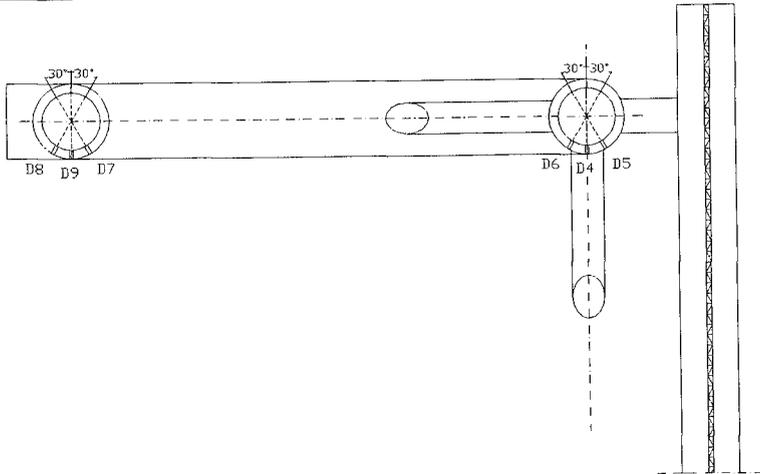


Figure 4. Locations Pressure Gauges Gate Girders

DETAIL E (bottom view)

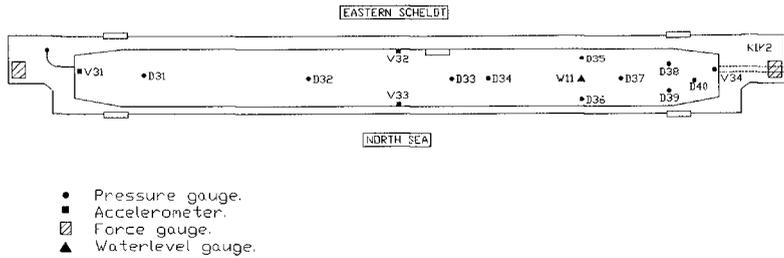


Figure 5. Instrumentation Upper Beam

sensor type	number	range	sample frequency
accelerometer	2	$\pm 250 \text{ m/s}^2$	1000 Hz
pressure gauge	6	3 Bar	1000 Hz
water level gauge	2	4 m	10 Hz

Table 1. Instrumentation Top Girder

sensor type	number	range	sample frequency
accelerometer	2	$\pm 500 \text{ m/s}^2$	1000 Hz
pressure gauge	5	6 Bar	1000 Hz
water level gauge	2	6 m	10 Hz

Table 2. Instrumentation Bottom Girder

sensor type	number	range	sample frequency
accelerometer	4	$\pm 25 \text{ m/s}^2$	100 Hz
pressure gauge	10	2 Bar	1000 Hz
force gauge	2	$\pm 10 \text{ MN}$	100 Hz
water level gauge	1	1.6 m	10 Hz

Table 3. Instrumentation Upper Beam

The water levels are measured on both sides of the barrier and the wave spectra are measured by a directional wave buoy, located approximately 500 m seaward of the barrier. The measurements were concentrated in measurement campaigns during storm closures of the barrier.

Results

The measurements of wave impacts on the top girders of the gate were performed during the closure operations of the gates, when the girders cross the water level. Under these conditions 10 successful measurement series were obtained. From these series the most severe impacts were selected for further analysis.

Date	Time	H_s	D4	D5	D6	D7	D8	D9
		m	Bar	Bar	Bar	Bar	Bar	Bar
27-feb-90	14:33:59.5	2,15	0,72	0,38	0,39		0,21	0,21
27-feb-90	14:35:47	2,15	0,24	0,05	0,43	0,16	0,05	1,17
27-feb-90	14:36:25	2,20	0,81	0,66	0,46	0,11	0,19	0,01
27-feb-90	14:36:29.5	2,20	2,27	0,14	0,44	0,10		
27-feb-90	14:36:43.5	2,20	1,10	0,18	0,53	0,58	0,01	0,08
27-feb-90	14:43:47	2,20	2,17	0,33	0,18		0,11	0,12
14-feb-89	06:28:59.5	1,80	0,28	0,12	0,09		0,26	0,53

Table 4. Maximum Impact Pressures Gate Girder

The measured maximum impact pressures are presented in table 4, for impacts with a maximum pressure over 0.50 Bar on one or more of the sensors.

The maximum impact pressure registered is 2.27 Bar with a significant wave height of 2.20 m. The time history of this impact is given in figure 6. In figure 7 the peak is given in more detail.

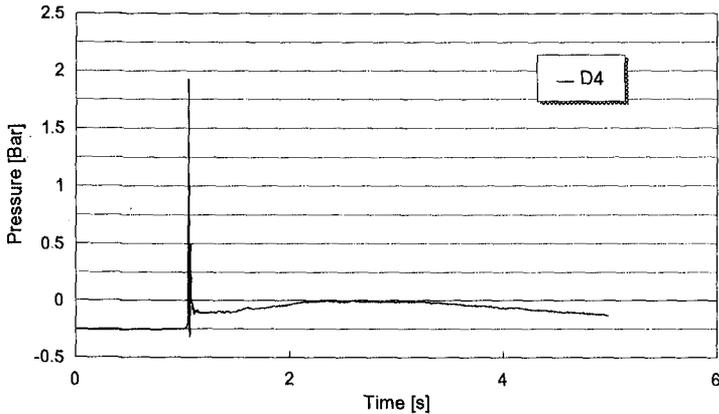


Figure 6. Registration Maximum Pressure

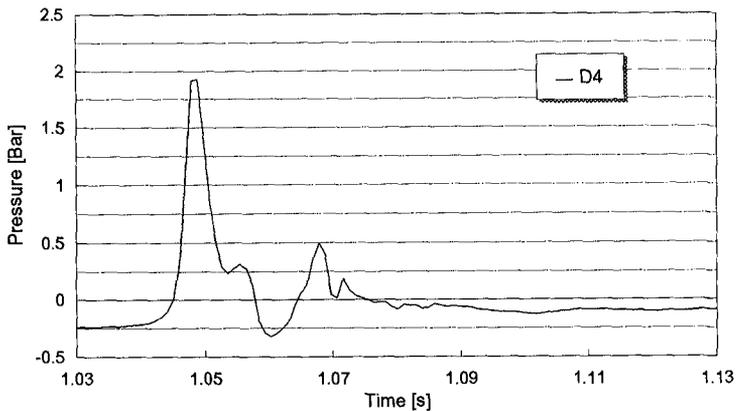


Figure 7. Pressure Peak (Detail)

The measurements of wave impacts on joints of the bottom girder and the support show relatively moderate impact pressures. The instrumentation is located close to the edge of the gate. The gate edge crosses the water level during the closure of the barrier at the first phase of a storm surge. At this time the water flows into the Eastern Scheldt. The closure causes a translation wave that accelerates the rise of the water level at the North Sea side. The result is that the instrumented section crosses the water level so rapidly that hardly any wave impacts occur. The maximum recorded impact pressure is 0.37 Bar.

The wave impacts measurements against the bottom of the upper beam start with an outside water level 1 meter below the bottom level of the beam and end with the start of the closure of the gates. Under these conditions 14 successful measurement series were obtained. From these series the most severe impacts were selected for further analysis. A problem for the analysis is that only 4 of the 10 pressure gauges functioned during all measurement campaigns. The maximum pressures recorded with these remaining gauges are presented in table 5, for the (7) most severe impacts registered.

Date	Time	H _g	D35	D36	D37	D39
		m	Bar	Bar	Bar	Bar
14-feb-89	05:06:17	1,45	0,31	0,59	0,07	
14-feb-89	05:09:47	1,45	0,27	0,52	0,04	
14-feb-89	05:30:37	1,50	0,14	0,29	0,20	0,22
14-feb-89	05:31:19.5	1,50	0,03	0,09	0,30	
14-feb-89	13:03:42.5	1,15	0,15	0,30	0,38	0,62
14-feb-89	13:13:50	1,05	0,29	0,17	0,25	0,29
14-feb-89	13:22:51	1,00	0,52	0,28	0,34	0,14

Table 5. Maximum Impact Pressures Upper Beam

To illustrate the wave impact on the upper beam and the response of the beam the time series of two pressure gauges (D35 and D36) of the impact recorded at 14th February 1989 at 13:13:50 are presented in figure 8. This figure shows a sharply peaked impact which first hits the North Sea side of the beam bottom and moves to the Eastern Scheldt side in the wave direction.

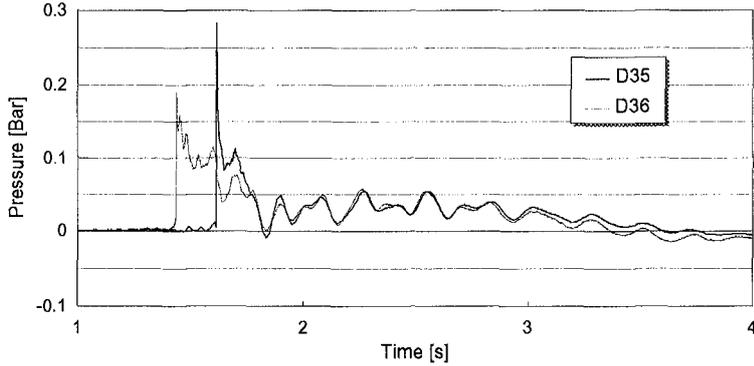


Figure 8. Registration Impact pressures Upper Beam

The response of the beam is illustrated by the acceleration registered at V33, presented in figure 9 (see figure 5 for the instrumentation). The response starts at the first hit of the beam. After the impact the beam vibrates in its natural frequency of approximately 5 Hz.

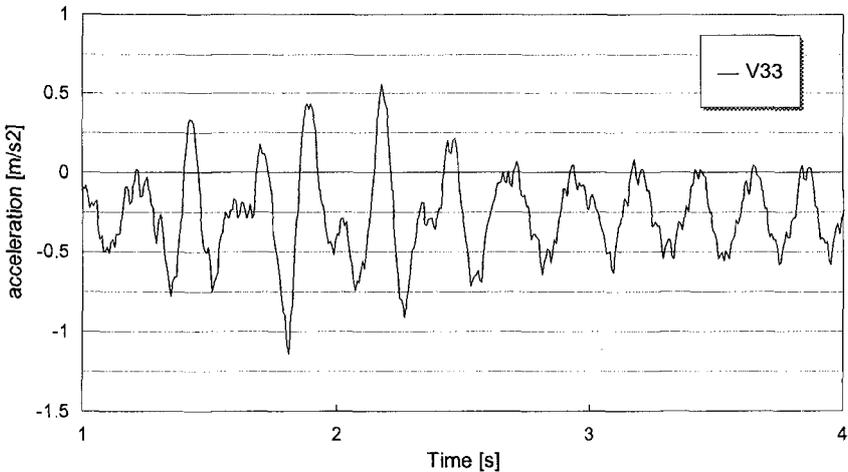


Figure 9. Registration Acceleration Upper Beam

The response of the support force to the impact is presented in figure 10. Note that the short wave impact (with a amplitude of 675 kN) is small in comparison with stationary support force (of approximately 6000 kN).

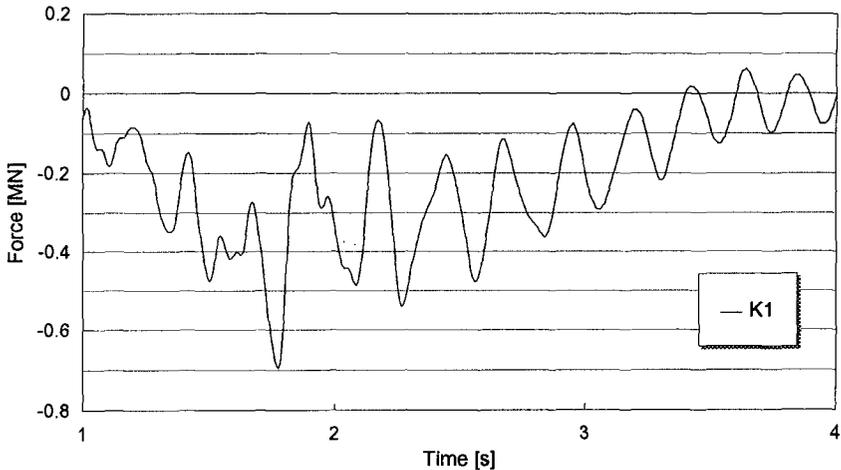


Figure 10. Registration Support Force Upper Beam

Discussion of the Results

In the field measurements high impact pressures were recorded (> 2 Bar). The frequency of exceedance of the maximum impact pressure on the gate girders and the upper beam is estimated between 1% and 0.1%, based on the total number of waves recorded during the measurements. These maximum pressures are higher than the design values (0.45 - 0.65 Bar). The design values were determined for larger impact areas, however. The measured peak pressures are representative for only a small area related to the dimensions of the sensors (diameter approximately 1 cm). The maximum pressures measured in the field show a very large spatial variation. Because of this variation, the impact pressure, averaged over a larger area, will be relatively small; smaller than the design values.

An other item of discussion is the type of wave impact. From the model tests impacts were expected with a sharp pressure peak and little air content. The impacts registered in the field show even sharper peaks and there is hardly any sign of the high frequency oscillations, that indicate air intrusion (compare Hattori 1990). The observed oscillations, see for example figure 8, are

related to the vibration of the structural elements itself. The pressure peaks were analyzed in more detail. The rise time was in the order of 0.01 s and the decline time in the order of 0.02 s, see figure 7.

A quantitative comparison of the results of the field measurements with the scale model tests appeared to be quite difficult for different reasons. In the field measurements local pressures were measured, while in most of the model tests impact forces, averaged over a larger area, were measured directly. Because the spatial variation is much greater than expected, the average impact force in the field can not be computed accurately from the individual pressure registrations. This effect is intensified by the failure of a number of the pressure sensors. Another handicap for the comparison of the field results with the model results are the instationary boundary conditions in the field measurements.

Conclusions

Wave impacts with high pressures were recorded during the field measurements. The wave impacts show sharp pressure peaks. The impact pressures show a large spatial variation. The impact pressure, averaged over a larger area, is relatively small.

The type of impact observed in the field is comparable with the type of impact, that was expected from the model tests. The spatial variation observed in the field measurements is much greater than expected from the model tests. The two-dimensional and stationar character of the model tests differs from the three-dimensional instationary field conditions.

Finally some general conclusions on field measurements of wave impacts can be given:

- This sort of monitoring programs are long term projects. It appeared to be very difficult to manage this type of projects in a constantly changing organisation with shifting priorities and budgets.
- The measurements are performed with relatively moderate boundary conditions. One has to keep this in mind with te selection of the phenomena to be measured.
- The measurements are not repeatable.

References

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Hattori M, Arami, A, "Impact Breaking Wave Pressures on Vertical Walls", 23rd International Conference on Coastal Engineering, Venice 1992.