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the case of the Meuse river in the Netherlands

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Publication date
2024

Document Version
Final published version

Published in
Proceedings of the 35th PIANC World Congres 2024

Citation (APA)
Koedijk, O. C., & ten Hove, D. (2024). Keeping weirs suitable for transit: the case of the Meuse river in the Netherlands. In J. S. Schoonees (Ed.), *Proceedings of the 35th PIANC World Congres 2024* (pp. 1418-1423). PIANC.

35th PIANC World Congress, 29 April – 23 May 2024, Cape Town, South Africa
Paper Title:
Authors Names:

Keeping weirs suitable for transit – the case of the Meuse river in the Netherlands

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Abstract: The weirs in the Meuse river in the Netherlands are after 100 years end of technical lifetime. As a consequence, Rijkswaterstaat is planning renovation or complete replacement. The present weir openings of 60 m wide are used for transit of vessels at high river discharges, when the weirs are lowered. Based on agreements between Belgium and the Netherlands from 1839 [1] and 1843 [2], the possibility of sailing through the weirs during high river discharges should remain (principle of non-deterioration). For the case of replacement, Rijkswaterstaat had a preference for a weir with three openings, for reasons of maintenance and water management. The Dutch MARIN institute executed fast time- and real time simulations to get insight in the navigability of a weir, with openings of 38, 38 and 24 m wide. Results were also used for improvement of the Dutch Guidelines for waterways 2020 [3]. The weir at Sambeek was taken as representative for the other Dutch weirs in the Meuse; 3D flow charts were delivered by the Dutch Deltares institute. The MARIN research showed, that the configuration studied was not feasible; recommended was a middle weir opening of at least around 50 m wide, corresponding with the swept path approaching the weir of 36 m plus ½B at both sides.

Keywords: Inland waterways, weirs, navigability of weir openings, simulation studies, Guidelines for waterways 2020.

Introduction

The Dutch weirs in the Meuse river are after 100 years end of technical life time and need to be renovated or replaced. From origin, the weirs exist of two parts. The major part (Poirée) of 60 m wide can be lowered at high discharges, allowing vessels to pass.

For reasons of watermanagement (less river blockage in case of failure, maintenance or replacement) Rijkswaterstaat wanted to get insight in the nautical feasibility of a complete new weir

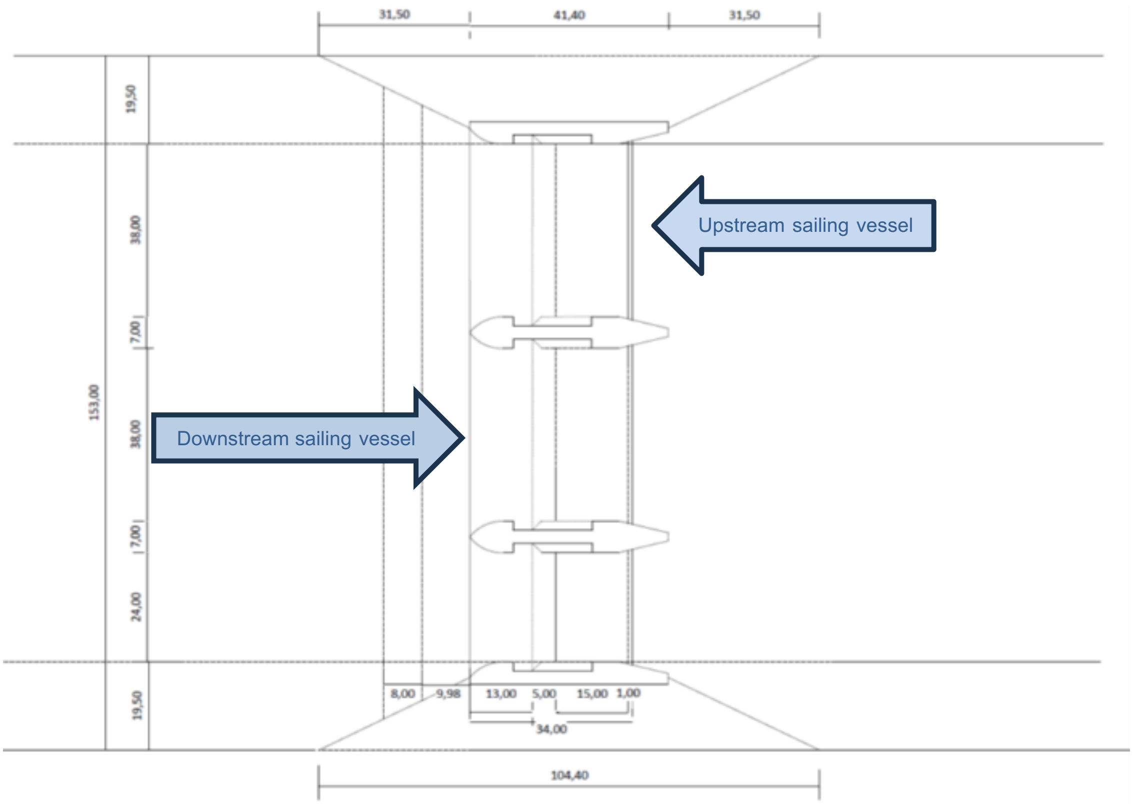

Figure 1 Drawing of the new weir (Source: [4])

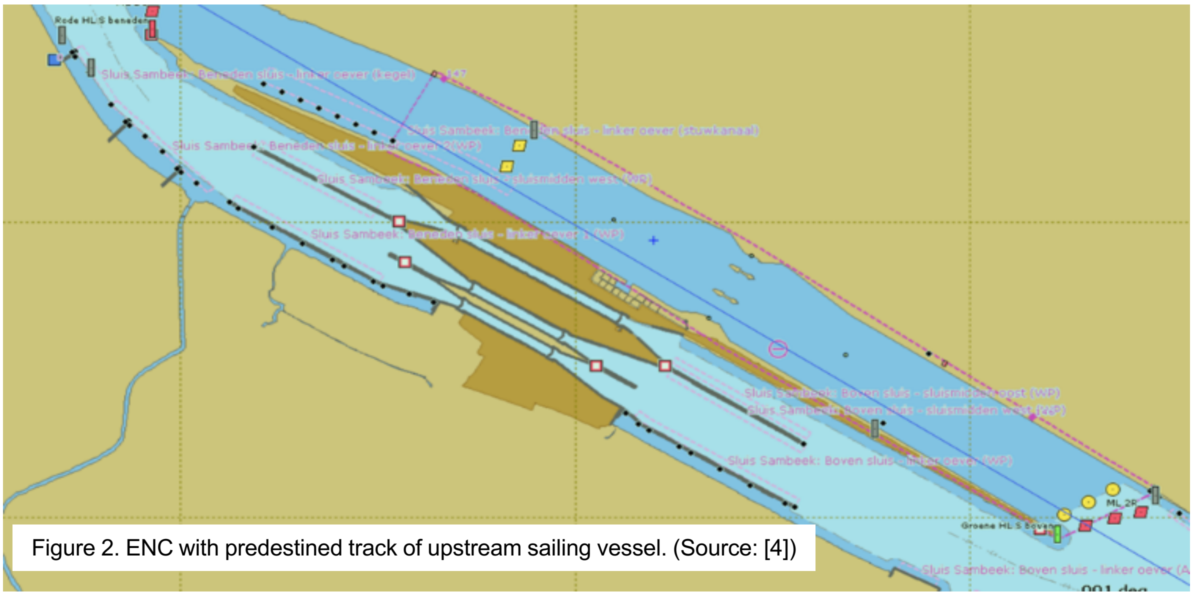

Figure 2. ENC with predestined track of upstream sailing vessel. (Source: [4])

configuration, existing of three openings. The results were also meant for improvement of the Dutch Guidelines for Waterways 2020.

A sketch plan was made (see Figure 1) and then the Dutch MARIN institute was ordered to carry out simulation research, based on flow charts delivered by the Dutch Deltares institute.

Starting point

The existing weir at Sambeek (see Figure 3) was taken as representative for the other Dutch weirs in the Meuse river. The Poirée part can be seen at the left side.

Figure 3. Existing weir of Sambeek (Source: [4])

The new weir to be tested consists of two openings of 38 m wide and one of 24 m wide. A view from above is given in the drawing (Figure 1); flow is coming in from the left.

The 38 m wide openings are to facilitate passage of CEMT classe Vb pushed convoys (193 x 13,50 x 3,50), being the largest allowed vessel on this waterway.

For upstream transit, the opening at the island side was assigned, for downstream transit the middle opening.

This way, there is no need for vessels to cross the fairway (and possibly the path of encountering vessels), being beneficial for nautical safety.

Fast time simulations

As a usual first step, fast time simulations were run to get a first impression of the nautical feasibility of the new weir [4]. For that, MARIN used the in house developed DOLPHIN simulator software, version 2023.10.

Set up simulation database

An Electronic Nautical Chart (ENC) of the area of Sambeek was the basis for the database. From this ENC, the existing weir is removed and the new weir was drawn (see Figure 2; flow coming in from the right side).

Waterdepth was 7,30 m. From 200 m upstream to 200 m downstream from the weir there was a 0,20 m fall in water-level. This was adjusted in the simulation model as an extra position dependent force on the vessel from 200 m upstream to 200 m down from the weir. Outside this range a fall of 0,13 m /km was accounted for.

Strongest flow is expected at a discharge of 1400 m^3/s. At higher discharges banks become flooded and flow does not increase anymore, actually starts decreasing slightly. Time dependent 3 D flow was determined as the quadratic average of the depth dependent flow over the draught (3,50 m) of the vessel and was available over a period of 30 minutes, with a time resolution of 10 seconds and a spatial resolution of 5 m over an area of 400 m upstream to 400 m downstream of the weir. Outside this area, flow was constant. The weir opening causes every 9 minutes a whirl at the downstream side. For an impression of the flow, see next Figure 4.

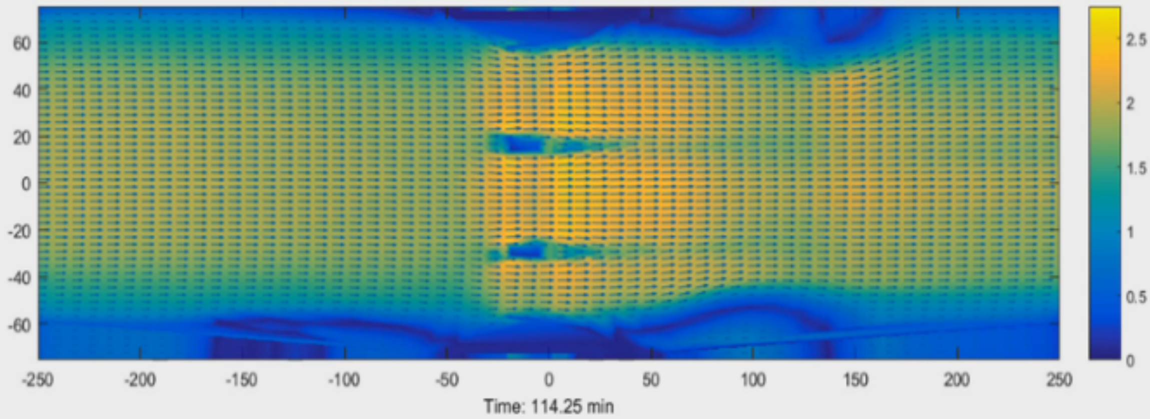

Figure 4. Impression of the flow during the simulations (Source: [4], [5])

To determine the representative wind conditions during the simulations, a time series of data (1991-2020) were taken from KNMI-station Volkel, which are given in average per hour at a height of 10 m. A southwesterly wind of 9,8 m/s was exceeded 5% of the time and was taken as basis. This windspeed was converted to a height of 4 m, being 8,25 m/s. Gusts of wind result in wind speeds varying from 7,5 to 9,0 m/s.

Mathematical model of the vessel

As representative vessel a two barge push tow unit was used. The mathematical model of the vessel takes into account the following effects and forces:

- Manoeuvre characteristics at 1,25 < h/T < 2,5
- Effect of propeller and rudder, including hull interaction
- Forces from flow and flow gradient
- Forces of wind, including gusts

Nautical scenarios

Key in the simulations was the controllability of the vessel passing the weir opening. Assumption was, that the flow would be the main challenge to cope with in the transit. As a result, simulations were executed with a loaded vessel only.

The vessel was navigated by an automatic pilot, following a predestined track in the middle of the opening and ½B at both sides from the middle of the opening. Simulations started upstream and downstream in the channel leading to the weir (see blue line in figure 2). Vessel speed relative to the water was set at 13 km/h sailing upstream and 9 km/h sailing downstream. Simulations started at 3 moments with an interval of 3 minutes, to ensure different passages regarding the whirl.

Simulations ended when the vessel passed the weir and was sailing straight, in a state of equilibrium.

After 18 scenarios based on interim results additional scenarios were added to check if exchanging the directional use of the opening (upstream sailing vessel using the middle opening, downstream sailing vessel using the left opening) would result in better controllability of the vessels during the passage through the weir.

Fast time simulation results

All simulations are recorded in dataplots, allowing analysis of the vessel speed and rate of turn in time, the distances to the weir pillar or shore, the deviation of the predescribed track, swept path and the use of propeller and rudder. A plot of the vessel sailing downstream is showed in Figure 5 below.

For numerical analysis of the results a safety index SI (see below) was used based on a ratio of rotational speed of the propeller and rudder angle compared to reference values.

$$SI_{steering} = \frac{\delta \, n^2}{\delta_{crit} \, n_{crit}^{\;2}}$$

The reference value for the rudder angle (δ_{crit}) is 20 degrees and the reference value for the rotational speed (n_{crit}) equals the engine (order) telegraph on half speed forward. If this safety index SI is larger

Figure 5. Plot of downstream sailing vessel. (Source: [4])

than 1 for more than 1 minute, the manoeuvre is judged as not safe.

Based on the Dutch Guidelines for waterways 2020, passage is judged not safe if the passing distance to the weir pillar or shore is smaller than ½B. To facilitate a small margin in the judgement, a range of 0,2B was added, resulting in the numerical analysis as follows:

- 0,0B - 0,4B not safe (red color);
- 0,4B - 0,6B at the limit (orange color);
- 0,6 B: safe (green color).

This way, the simulation results were analysed. E.g. see Table 1 for the results of the upstream passage, corresponding with the path from Figure 2. The two columns containing colored data are passing distance (left) and safety index (right).

Conclusions fast time simulations

The overall outcome was, that the weir opening at the island side did not meet with the postulated demands for safe transit, due to the combination of the periodical whirl and, to a much lesser extent, the side wind the vessel experienced.
Recommended was, to improve the design of the weir connecting to the wall, resulting in maximal reduction of flow gradient, both in cross and lateral direction. Moreover, placing of screens at the upstream side was recommended to reduce the side wind forces.

The middle opening was suitable for both upstream and downstream passage. This is only possible at low traffic (which is the case, especially when the weir is lowered) and proper traffic regulation: in case of simultaneous arrival upstream traffic awaits downstream traffic.

Run	Offset	Start-tijd	Vaar-snel-heid (STW)	Wind-snelheid	Wind-richting	ROT		Roerhoek		afstand tot de noord-pijler	afstand tot de zuid-pijler	afstand tot de kade	kleinste afstand	Safety index	Pad-breedte
			km/u	m/s		BB gr/min	SB gr/min	BB gr	SB gr	min m	min m	m	m		m
1	0	12:35	13	8.25	ZW	4.90	2.32	34.84	17.82	53.33	8.31	11.61	8.31	2.52	18.07
2	0	12:38	13	8.25	ZW	2.46	1.68	12.79	8.14	52.29	7.30	12.49	7.30	0.92	18.21
3	0	12:41	13	8.25	ZW	3.03	2.76	16.38	16.19	50.78	5.78	11.52	5.78	1.18	20.70
4	0.5B BB	12:35	13	8.25	ZW	4.65	2.23	32.79	17.26	48.15	3.14	17.38	3.14	2.37	17.48
5	0.5B BB	12:38	13	8.25	ZW	2.00	1.29	10.92	7.01	47.48	2.49	18.39	2.49	0.79	17.12
6	0.5B BB	12:41	13	8.25	ZW	2.70	2.31	14.13	13.93	46.22	1.23	17.29	1.23	1.02	19.48
7	0.5B SB	12:35	13	8.25	ZW	4.71	2.31	32.87	17.97	58.66	13.64	6.10	6.10	2.38	18.27
8	0.5B SB	12:38	13	8.25	ZW	2.63	2.01	14.23	9.42	57.13	12.13	6.89	6.89	1.03	18.98
9	0.5B SB	12:41	13	8.25	ZW	3.07	3.04	16.81	15.77	56.37	11.38	5.78	5.78	1.21	20.84
56	0	12:35	13	4.1	ZW	4.95	2.34	32.88	19.81	54.14	9.13	11.38	9.13	2.38	17.49

Table 1. Fast time results of the upstream passage. (Source: [4])

Examining the results and still giving preference to upstream transit by the weir opening at the island side and downstream transit by the middle opening, MARIN was ordered to execute real time simulations, whereby the design of the weir opening was improved as recommended.

Real time simulations
The method for the real time simulations was merely the same as for the fast time simulations [5]. This concerns the setup, evaluation criteria and analysis.

Set up real time simulation database
Again, from the ENC, the existing weir is removed and the new weir was drawn.

The 3 D reproduction of weir and surroundings was based on the sketch plan and on aerial photographs. This way, the helmsman got the next impression (see Figure 6 below):

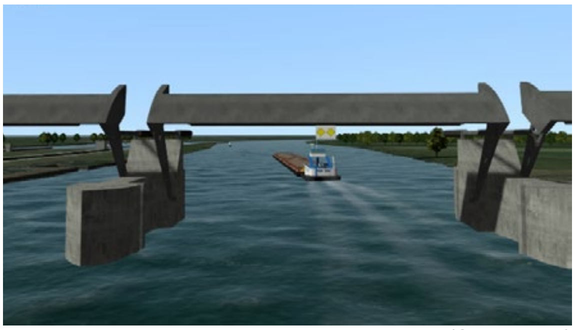

Figure 6. 3D impression sailing downstream (Source: [5])

As the fast time simulations showed more effect of side wind than expected, this time also simulations were executed with an unloaded two barge pushtow unit.

The two skippers were allowed to set the vessel speed themselves, at their comfort.

Simulations started at the river, downstream from the weir harbor sailing upstream and upstream from the weir harbor sailing downstream.

Simulations ended when the vessel passed the weir and was sailing straight, in a state of equilibrium.

Real time simulation results
Results were analysed in the same way as the fast time simulations. The results for the empty vessel sailing downstream through the weir opening at the island side are shown in Table 2.

Conclusions real time simulations
The simulations showed for the loaded vessel, that sailing upstream and downstream through both weir openings was safe. Improvement of the design was recommended to reduce the cross flow upstream.

Due to the side wind passage of the unloaded vessel sailing upstream and downstream resulted in swept paths up to 40 m upstream and downstream from the weir as a result from the inevitable drift angle. As a result, the vessel path partially extends onto the side of the waterway for oncoming traffic. The drift angle can only be reduced by sailing at higher speed, but is then getting too high for safe approach of the weir.

Overall was concluded, that weir openings of 38 m wide are too narrow for safe transit; the width should be at least around 50 m, based on a swept path approaching the weir of 36 m plus ½B at both sides. Persevering in a configuration of 3 weir openings, the 50 m wide opening should be located in the middle, which has the preference from a nautical point of view. This middle opening is to be used for both upstream and downstream sailing vessels.

Dutch Guidelines for waterways 2020
The outcome of the MARIN research was also meant for improvement of §4.8 of the Dutch Guidelines for waterways 2020, containing the text concerning weirs.

It was recommended, concerning the present instruction to avoid flow gradients upstream of the weir, to add also the downstream side of the weir. Moreover, it was recommended concerning the present demands regarding the width of one lane weir openings to add the demand of extra width for side wind, which should be determined case by case. At the next issue of the Dutch Guidelines for waterways, the text of §4.8 will be revised according the recommendations.

								uiterste waarden									
Run	Schipper	Beladings-conditie	Vaar-richting	Door-vaart-opening	Start-tijd	Wind-snelheid	Wind-richting	ROT		Roerhoek		afstand tot de noord-pijler	afstand tot de zuid-pijler	afstand tot de kade	kleinste afstand	Safety index	Pad-breedte
						m/s		BB gr/min	SB gr/min	BB gr	SB gr	min m	min m	m	m		m
13	A	leeg	Op	Links	12:35	8.25	ZW	14.28	15.67	11.96	19.23	54.72	9.77	4.01	4.01	2.13	24.22
14	B	leeg	Op	Links	12:35	8.25	ZW	25.11	26.14	23.33	31.28	49.05	4.26	7.89	4.26	3.46	25.85
15	A	leeg	Op	Links	12:38	8.25	ZW	12.96	11.90	7.64	11.43	56.38	11.38	3.30	3.30	1.27	23.33
16	B	leeg	Op	Links	12:38	8.25	ZW	28.20	22.94	41.55	27.08	57.68	12.70	5.94	5.94	4.60	19.35
17	A	leeg	Op	Links	12:41	8.25	ZW	11.51	16.40	13.20	17.68	52.73	7.78	2.92	2.92	1.42	27.30
18	B	leeg	Op	Links	12:41	8.25	ZW	34.69	34.95	39.77	41.88	55.52	10.58	2.49	2.49	4.40	24.93

Table 2. Real time results of the downstream passage of the unloaded vessels. (Source: [5])

Discussion

To a high extent, the results of the simulations were affected by the fact, that the Vb vessel was not equipped with a bow thruster in the barge upfront.

Although on this waterway Vb pushed convoys are allowed only when equipped with an effective bow thruster in the barge upfront [6], it was decided to execute the simulations without this bow thruster. The reason is, that in the real situation the high river discharge brings a lot of floating debris and as a consequence, a high risk of failure of the bow thruster.

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[6] Binnenvaart Politie Reglement, Besluit van 26 oktober 1983. See: article 9.05, paragraph 5.