Guidelines for inland waterways in rivers

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Introduction
The Dutch Rijkswaterstaat is responsible for the design, construction, management and maintenance of the main infrastructure in the Netherlands. This includes the main inland waterway network and water systems. To support the design from a traffic point of view Rijkswaterstaat developed the Waterways Guidelines in 1996, which evolved into the latest 2017 edition (RVW2017) [Ref. 1]. The RVW2017 are restricted to waterways without current or with a limited longitudinal flow velocity (less than 0.5 m/s). However, it is evident that in almost all free-flowing rivers this longitudinal flow velocity is exceeded. That is why the Rijkswaterstaat decided in 2015 to develop integral guidelines for inland waterways, including rivers. These guidelines will consist of design guidelines, of tables and rules of thumb for dimensioning the waterway in a free-flowing river, as an extension of the existing RVW2017.
The extension of the RVW2017 to rivers started in 2015 by following the same design scheme as in the existing guidelines, identifying all aspects that would change when considering flowing waters. Only these aspects were dealt with. In the next sections some aspects of straight river sections and bends are discussed.

Reference waterlevels
In the case of rivers it is necessary to record the waterway dimensions at several reference water levels. From a nautical point of view for the Rhine branches the agreed low water level and the median water level are the most decisive reference water levels to define the waterway dimensions. The first because it indicates the minimum water level that is available for about 95% of the year, but may force larger vessels to limit the draft. The second because it allows to sail with maximum draft. For the Maas these levels are the median water level and the water level with a 1-year return time.

Fairway depth
A minimum aim for rivers is to achieve a normal profile for two-lane traffic. With the normal profile, the width-average depth of a cross section of the waterway must be at least 1.4 times the loaded draft of the design ship with respect to the reference water level. Depending on the reference plane, a different design draft can be chosen.

Waterway width on straight sections

For navigating, longitudinal current and a longitudinal current gradient are common features. The expectation is therefore that a limited additional fairway width is sufficient to compensate for the effects of current. This is supported by results from the literature. Several studies show that the variability in path width due to the combined effect of the human factor, instability of the ship and the effect of a longitudinal current fall largely within the manoeuvring margins [Ref. 3 and 4]. Based on observation of operational practice and results of manoeuvring simulations a lane of 1.3B (with B the ships beam) is used as base condition.
BAW [Ref. 3] has processed experiments of the US Army Corps of Engineers with pushed convoys on the Mississippi and supplemented it with its own experiments with motor vessels to get an impression of the extra path width as a result of the longitudinal current. The tests involved a wide variation in ships with regard to length and width, a large variation in sailing speeds and flow rates, both up and down. A contribution from the current was visible, although there was little difference between upstream and downstream. The latter indicates that horizontal instational effects of the current are the most likely cause for the contribution to the basic path width of a vessel. Together with the assumption that h=1,4T the following regression formula for the extra path width has been derived from the data:

$$\Delta b = (1.12*T*V_c +0.023*L*v_g) / v_r$$

with:

- Δb the extra path width;
- T the loaded draft of the vessel;
- h the water depth;
- V_c the longitudinal current velocity;
- v_r the sailing speed relative to the water;
- v_g the sailing speed relative to the ground.

For most inland vessels with a sailing speed of 13 km/h through the water and a current velocity of 0.5 m/s, the extra path width (Δb) is about 0.3B. Upstream slightly larger than 0.3B, downstream slightly smaller. This is in line with the 1.3B basic path width above. With increasing flow velocity, the additional path width increases.
Based on the previous discussion it is recommended to take into account an additional surcharge on width of the lane of 0.1B for current velocities from 0.5 m/s to 1 m/s and a surcharge of 0.2B for current velocities higher than 1 m/s. Below 0.5 m/s no surcharge is required. The surcharge must be applied per lane and must be available at the draft of the loaded ship.

Crosswind surcharge

No additional wind surcharges are necessary on the fairway width as long as the basic wind surcharge from the RVW2017 is also applied in bends.

Intensity surcharge

The intensity surcharge for dense traffic areas as described in the RVW2017 is independent of the current. The intensity surcharge can also be used for waterways up to Class VIIa with the prerequisite that the six-barge pushed convoys are sailing upstream in long formation and downstream in wide formation. In addition the intensity surcharge can be applied as long as the average loading capacity of passing ships is limited to a maximum of 3,150 tons and the number of passages per year is limited to 150,000 vessels. Otherwise, additional research is required.
The following formula can be used to derive the required additional fairway width:

$$\Delta b = cl*(lv-2050)^2+ci*(in-30{,}000)$$

with:

- Δb the recommended additional channel width;
- lv the average load capacity of the passing fleet;
- in the number of passages on an annual basis.

The coefficients c_l and c_i are:

- $c_l = 3.6*10^{-5}$;
- $c_i = 0.00053$.

It is not necessary to take into account differences in traffic composition and intensity with changing water levels as long as the minimum water level aforementioned is not underrun [Ref. 2].

Width surcharge in bends

In bends an additional width for the current must be taken into account. The allowance can be calculated in a similar way as in the RVW2017, in which an empirical model derived by Fisher can be used to determine the factor C as used in the RVW2017 [Ref. 5]. Fisher deduces that for large bend radii where $R \geq 4L$ the extra path width can be approximated by $\Delta b \approx C*L^2/R$ and $C=\frac{1}{2}C_F^2$ with C_F the relative position of the ship's pivot point relative to the length (L) measured from the stern to the bow (see Figure 1).

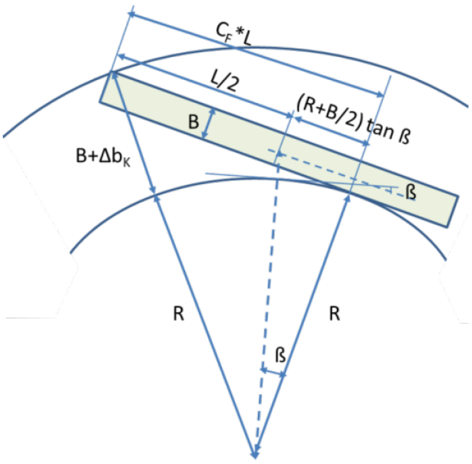

Figure 1 Definition sketch for the extra path width (Δb) in a bend.

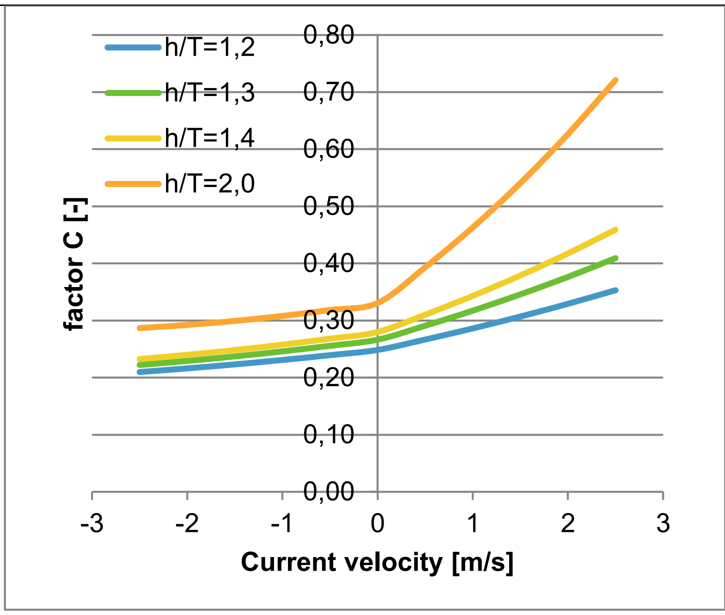

Figure 2 Factor C for a loaded CEMT Class Va vessel with a sailing speed of 13 km/h relative to the water.

In the empirical model, the factor C depends on the local water depth, the ship's characteristics (length, width and draft), the speed of the vessel relative to the water and the current velocity. The model can therefore take into account the local average water depth below the ship, so that a distinction can be made between a deep outer bend and a shallow inner bend when calculating the additional pad width.

Figure 2 illustrates the value for the factor $C=\frac{1}{2}C_F^2$ as it follows from Fisher's formulas for a loaded CEMT Class Va vessel with a sailing speed of 13 km/u relative to the water. C=0.25 is recommended by RVW2017. The factor is shown as a function of the water depth/draft ratio and the current velocity (positive for sailing downstream and negative for upstream). We see that the calculated value is just above the recommended value. The factor decreases with decreasing h/T ratio. The factor increases sharply as the current increases.

The empirical model can only be used if there is no interaction between the bends in a river. If there is interaction, such as in short consecutive opposite turns, additional research is necessary. Also for smaller bend radii (R<4L), additional research using maneuvering simulation models is required.

Line of sight (LOS) in bends

The minimum LOS in a bend is based on the requirement that vessels can respond to one another in time when meeting. From the relative speed principle it is concluded that the relative approach speed with respect to each other does not change as a result of the current. So there is no reason to adjust the LOS for a waterway with current. In addition it should be noted that tests with different ship classes showed that a controlled avoidance maneuver in an encounter situation requires a fairway length of approximately 2.5 L [Ref. 6]. Furthermore, ships with a starting speed relative to the water 13 km/h and a under keel clearance of at least 20% must comply with the following stopping properties: stop length not exceeding 550 m with respect to the shore on ships or assemblies with a length greater than 110 m or width greater than 11.45 m or 480 m otherwise [Ref. 7]. With that in mind it is recommended to use 5L for the LOS in a bend with a maximum of 600 m, but with an absolute minimum of 3L. In a formula: LOS=(max(3L,min(5L,600)).

[Ref. 1] Richtlijnen Vaarwegen 2017, Directoraat Generaal Rijkswaterstaat, december 2017.
[Ref. 2] Interactie beladingsgraad-vaarwegprofiel, MARIN memo 29242.601_memo_v2, 24 november 2017.
[Ref. 3] Driving Dynamics of Inland Vessels, Bundesanstalt für Wasserbau (BAW), Karlsruhe, Germany, 2016.
[Ref. 4] Zöllner, J., Fahrdynamische Untersuchungen der Versuchsanstalt für Binnenschiffbau zum Donauausbau Straubing-Vilshofen, Miteilungsblatt der Bundesanstalt für Wasserbau Nr. 80, 1999.
[Ref. 5] Fisher, N., Treiber, M., Söhngen, B., Modeling and Simulating Traffic Flow on Inland Waterways, PIANC World Congress, San Fransico, 2014.
[Ref. 6] Manoeuvreerproef Nieuwe Stijl, MSCN Rapport nr. OV127.10/3, mei 1997.
[Ref. 7] ES-TRIN Edition 2019/1.