Module name: Capacities of inland waterways

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List of parameters

Parameter	Unit	Description
A_r	m^2	Cross-section of a drain
A_k	m^2	Cross-sectional area of a lock chamber
A_s	m^2	Wetted cross-section of a ship
Asl	m^2	Opening area of a sluice
B_v	m	Width of virtual area around ship
B_s	m	Beam, width of ship
B_l	m	Width of lock
C	number ships/ time unit	capacity
C_s	tonnes/ time unit	average carrying capacity of the ships.
d	m	Ship's draught
H	m	Head difference
I	number ships/ time unit	traffic intensity
L	m	Length of a water way section
L_s	m	Ship length
L_v	m	Length of virtual area around ship
n	-	Number of ships
n_{max}	-	average number of ships over a large number of maximum capacity locking operations
P	kW or hp	Engine power
Q	m^3/s	discharge
S	m	Mutual distance
S_e	m	Equilibrium mutual distance
S_{min}	m	Minimum mutual distance
t, T	s	time
t_s	s	total locking time
t_w	s	total waiting time
t_{wr}	s	remaining waiting time
T	S	Filling time
T_b	s	Operating time
T_c	s	Cycle time
T_d	s	Locking duration
T_i	s	Entry time
T_l	s	Loop time
T_s	tonnes	average carrying capacity per ship
Tu	s	Departure time
Tp	s	Passage time of an individual ship
V_0	m/s	Average ship speed on a non-restricted waterway
V_{lim}	m/s	Limit speed of a ship
V_s	m/s	Average ship speed
W	s	Resistance of a waterway
W_c	s	Resistance of a waterway (constant part)

Parameter	Unit	Description
W_v	s	Resistance of a waterway (variable part)
μ	-	Discharge coefficient
φ	-	Friction or delay loss

1 Introduction

The lecture “Capacities of Inland Waterways” is the follow-up of “Inland Waterways”, CTWA 4330, which in fact is an upgrade of the lecture notes written by Ir. J. Bouwmeester in 1988. The edition of 2006 is an update of the version of May 1999 of ir. R. Groenveld.

Apparent from the title, this lecture will focus on the capacity of inland waterways. A great deal of research has been performed in this area in the past. In the Netherlands that research was mainly carried out by the Directorate-General for Public Works and Water Management (RWS) and the regional departments of this directorate, with Delft Hydraulics also being frequently involved.

A considerable amount of attention has been given to the standardisation of inland waterways, both at a national and international level.
At international level, the CEMT (Conference Europeenne des Ministres des Transport) has accepted a classification system in which inland waterways are divided into 5 classes that correspond with 5 standard ships, a 6th class was subsequently added in 1961.

In the period 1958 - 1969 the Economic Committee of the United Nations for Europe (ECE) drew up a classification which also included the East European countries. As the inland waterways in Eastern and Western Europe differ considerably, this classification was never actually implemented.
In 1977 the Netherlands Inland Waterway and Management Committee (CVB) commenced the adaptation of the design standards for Dutch waterways to the developments in the fleet of Dutch inland navigation vessels.

In the eighties it became clear that as a result of the increase in shipping traffic, the CEMT classification was beginning to become out-of-date.
Following a Dutch initiative, at the 1985 PIANC congress held in Brussels it was decided that a new classifications system be introduced; this was subsequently completed in 1992.
In 1996 the CVB published a complete set of rules and regulations with respect to the dimensions, design and organisation of inland waterways and structures. These rules have been thoroughly updated in the 2005 [11]

Although little consideration was given to the capacity of inland water systems in this standardisation, at present increasingly more use is being made of probabilistic simulation models for dealing with inland waterway traffic.
The Construction Department of the RWS, for example, now have the SIVAK model at their disposal, whilst on several occasions in the past use was made of the Prodim model for the dimensioning of inland waterways.

With an inland waterway load of more than 15000 passages per year it can no longer be considered responsible to draw up cross-sections on the basis of empirical rules, therefore making it necessary to carry out supplementary research with the aid of traffic-flow simulation models and navigation simulation models.

This report will deal with the following topics. First, a description of the terms used are described in chapter 2, followed by an introduction into capacities of open and closed inland waterways in chapter 3. Next, in chapter 4 the capacity of inland waterways restricted by locks will be discussed more thoroughly. The distinction between open and closed waterways has been made because locks are a determining factor for the capacity of closed inland waterways. Further significant aspects in the determination of capacity and safety are the traffic regulation systems (see chapter 5). Finally, chapter 6 deals with the topic of Safety. Furthermore, the appendix discusses trends and future expectations of inland navigation on the Meuse River (appendix I) and more general (appendix II).

Figure 1-1 A motorway and an inland waterway

2 Explanation of terms used

2.1. Open and closed waterways

As hydraulic structures are often determining factors with respect to the capacity of a waterway, a distinction is often made between open waterways, e.g. waterways without hydraulic structures, and closed waterways, which segmented by hydraulic structures like locks. The CVB (Commission of fairway managers) prescribes in its guidelines regulations for headroom, width of passage, underwater profile and above surface profile for waterways (open as well as closed) in the Netherlands [11].

2.2. Operational capacity

The *operational capacity* of an inland waterway is defined as the maximum number of ships that can pass through a specific cross-section of an inland waterway per unit of time, while taking into account safety and waiting times (*service level*). Waiting times may for example occur at a lock or bridge, or may be imposed by a Vessel Traffic System (VTS). The term "safety" and "acceptable waiting times" can be rather subjective. Therefore, one should first obtain some insight in these matters before the operational capacity can be determined.

In addition to the previous points, capacity is also depending on the following limiting conditions:

a. The infrastructure of the waterway. Not only the depth and width of the canal, but also irregularities such as bends, constrictions and structures affect operational capacity.
b. The fleet characteristics (dimensions, type, together with the volume pattern). For example, it is quite obvious that the irregularity of the volume pattern greatly influences waiting times.
c. The traffic rules and weather conditions.

2.3. Intensity and Density

Intensity is defined as the number of ships or tonnes of dead-weight capacity (DWT) that pass through a specific cross-section of an inland waterway per time unit (see Figure 2-1A). The *Density* is the quantity of shipping traffic, expressed in numbers of ships (or DWT), per unit of surface area or waterway length at a specific time (see Figure 2-1B).

A. Intensity

B. Density

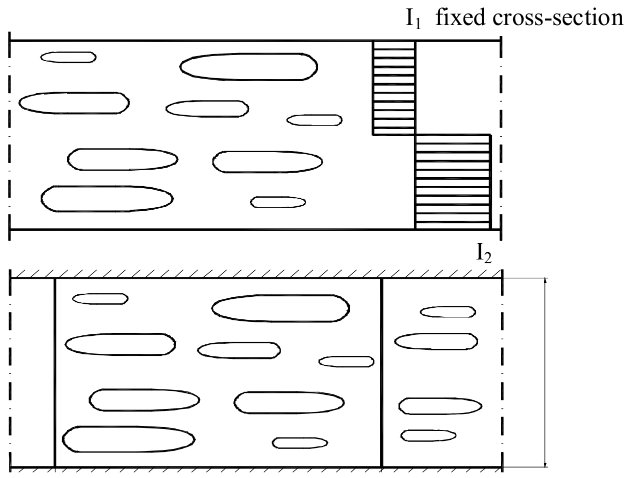

Figure 2-1 The intensity and density of an inland waterway

2.4. *Waterway resistance*

The resistance of an inland waterway is determined by the time required for a ship to pass a waterway section (travelling time + waiting time of the waterway). The total resistance of the inland waterway is equal to the sum of the sub-resistances of the various waterway sections, whereby the resistances can be considered to be connected in series (see Figure 2-2).

If the maximum acceptable waiting time is known, the "operational capacity" of the inland waterway can be determined.

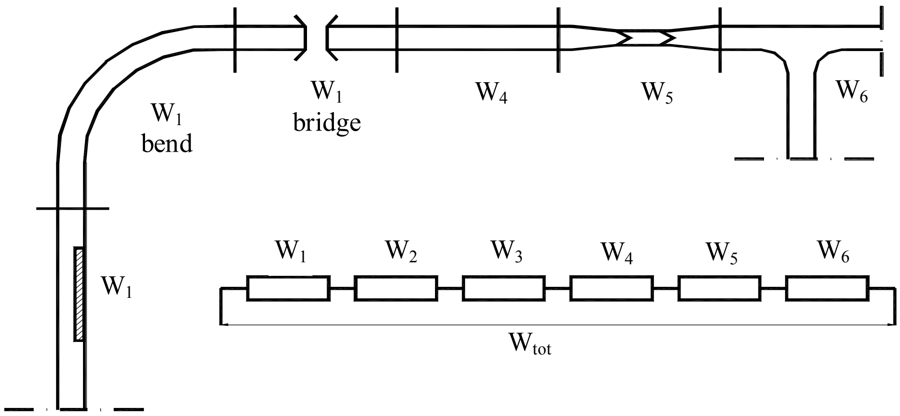

Figure 2-2 Resistances in a waterway

The resistance of an inland waterway can be subdivided into:

- a constant part (W_c) and
- a variable part (W_v), the waiting time at for instance bridges or locks.

The constant part, with no other traffic, depends on:

- the ship speed if possible of $V_s = 0{,}8 * V_{lim}$ to $0{,}9 * V_{lim}$ ($V_{lim=}$ limit speed vessel);
- shape and dimensions of the cross-section of the inland waterway;
- lay-out of the inland waterway with bends and other discontinuities;
- engine capacity of the ship under consideration; and
- conditions such as wind, current, visibility etc.

The variable part of the resistance (W_v) is the extra time loss that results from the interaction of the ship under consideration with any other shipping traffic. This W_v is determined by:

- Delays during overtaking and encountering manoeuvres with other ships, which are dependent on:
  - The number of shipping lanes
  - The speed differences and diversity of the various ships
  - The reaction and behaviour of the individual ship captains
- Temporary or total inability to overtake as a result of:
  - Excessive traffic density on the waterway
  - Safety traffic rules, e.g. overtaking prohibited.

In making a choice between routes A and B the ship's captain will, obviously, take the resistance of the different routes into account (see Figure 2-3).

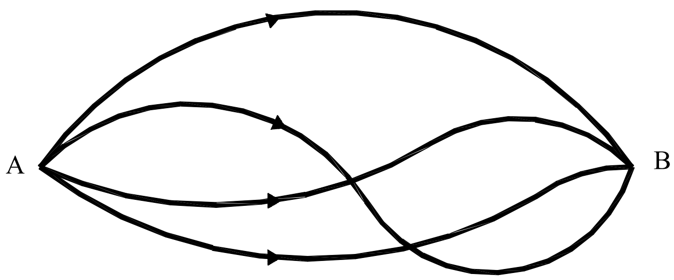

Figure 2-3 Different routes

Example (see Figure 2-4)

If ship 1 could continue travelling undisturbed at a speed of 0.8 * V_{lim} then the resistance would be equal to $W_c = L/(V_{lim}*0.8)$. As ship 2 is travelling at a lower speed, ship 1 wishes to overtake this ship. This is, however, prevented due to the approaching ship 3. As a result ship 1 has to reduce speed (time $t = t_1$) down to the speed of ship 2 until ship 3 has passed (time $t = t_2$). Ship 1 can subsequently commence the overtaking manoeuvre. However, the speed at which that can now be achieved is lower than ship 1's original speed. That is caused by the increased resistance the ship is subjected to in the limited cross-section. Furthermore, in most cases ship 2 should reduce its speed, as otherwise the overtaking ship would not be able to get out of the 'water level-depression' created by ship 2.

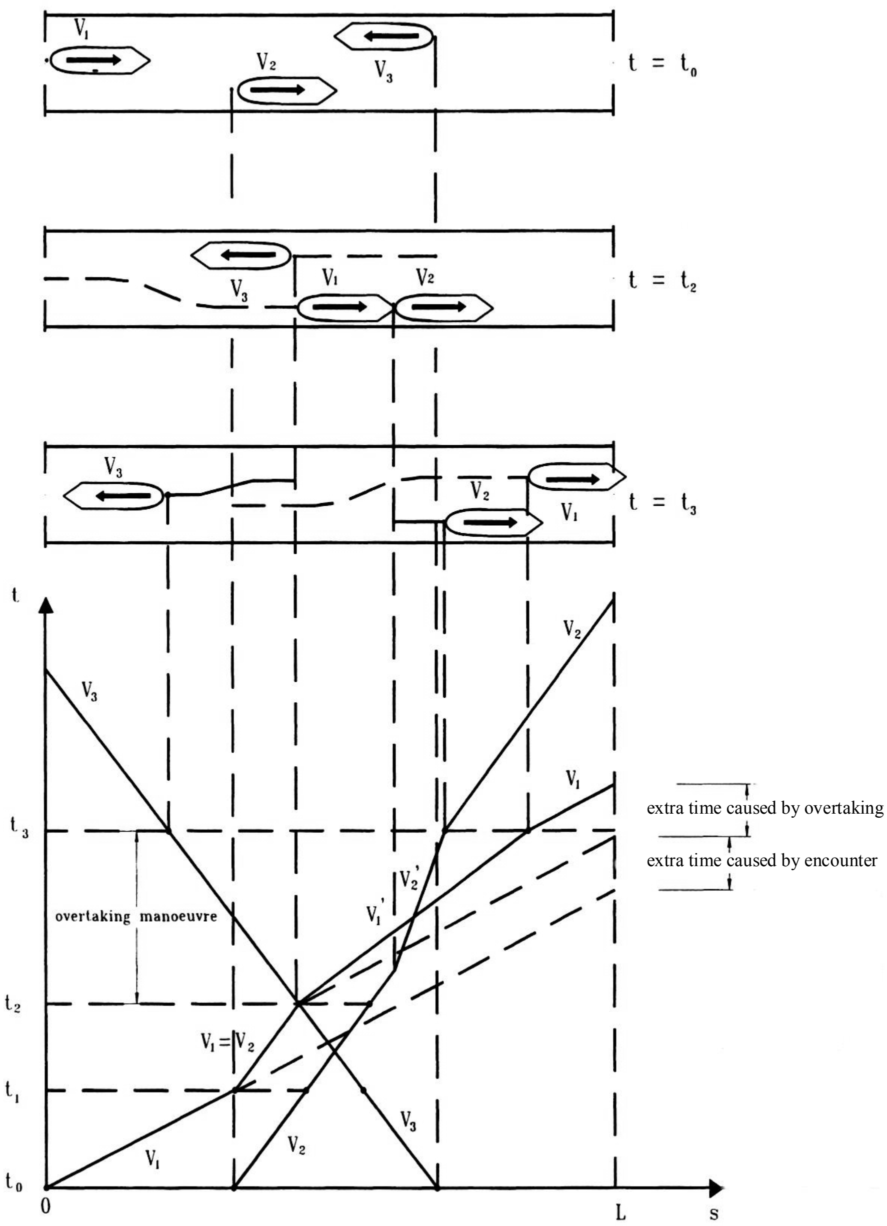

Figure 2-4 Structure of the resistance of a ship