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Inland Waterways

Ports, waterways and inland navigation

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List of parameters

Parameter	Unit	Description
a	m	Height upper part of the slope in case of a broken profile
A_c	m^2	Wet cross-sectional area of the undisturbed channel
A_c’	m^2	Wet cross-sectional area between ship and bankof the undisturbed channel
A_{ci}	m^2	Imaginary wet cross-sectional area
A_M	m^2	Surface of the immersed part of the midship section
A_0	m^2	Outflow opening orifice
A_r	m^2	Rudder surface
A_y	m^2	Wet cross-sectional area of the channel between canal axis and ship axis
B_s	m	Beam, width of ships at midship section
c	m/s	Celerity of an individual wave in unrestricted water
c'	m/s	Celerity of an individual wave in restricted water
c_a	-	Factor of bottom jet depending on the quay wall slope
c_{gr}	m/s	Celerity of wave group
c_i	m/s	Celerity of interference cusps
c_r	-	Rudder factor
c_t	m/s	Celerity of a transversal wave
C	$m^{1/2}/s$	Chézy coefficient
C_B	-	Block coefficient
C_D	-	Resistance coefficient in Bouwmeester formula
C_F	-	Resistance coefficient for friction
C_p	-	Resistance coefficient for pressure
C_w	-	Resistance coefficient related to waves
D	m	Draught of a ship
D_{50}	m	Average grain size diameter
$D_{50\%}$	m	Draught exceeded by 50% of all ships in a particular class
D_{air}	m	Air draught
D_n	m	Nominal draught
D_p	m	Propeller diameter
D_t	m	Thruster diameter
Dt,e	m	Effective thruster diameter
f_n	-	Percentage of maximum number of revolutions
f_p	-	Percentage of maximum installed engine power main propeller
f_t	-	Percentage of thruster diameter
F	N	Force
F_D	N	Drift force
F_L	N	Longitudinal force
Fr	-	Froude number
F_R	N	Rudder force
Ft	N	Force of thruster
F_T	N	Transverse force
g	m/s^2	Acceleration of gravity
G	-	Center of gravity
h	m	Water depth
h^-	m	Average water depth of the undisturbed canal (= A_c / W_s)
$h_{freeboard}$	m	Freeboard
h_p	M	Distance between propeller and channel bed
h_0	m	Water depth of the undisturbed canal
H	m	Wave height
H'_t	m	Wave height of transversal wave behind the ship near the bank
H_i	m	Wave height of interference cusps
H_t	m	Wave height of transversal wave

Parameter	Unit	Description
i	-	gradient
k	-	Blockage coefficient (= 1/n = A_s / A_c)
k	-	Wave number
l	m	Path length
l_1	m	Length of ship to be overtaken
l_2	m	Length of overtaking ship
K_T	-	Thrust coefficient
L	m	Wave length
L_{BP}	m	Length between perpendiculars
L_d	m	Wave length divergent waves
L_i	m	Wave length interference cusps
L_{OA}	m	Length Over-All
L_s	m	Ship length
L_{stop}	m	Stopping distance
L_t	m	Wave length transversal waves
m	-	Bank slope
m_s	kg	Mass of the ship
M_D	Nm	Moment due to drifting
M_R	Nm	Turning Moment
M_T	Nm	Moment due to transverse force
n	-	Blockage ratio (= Ac / As)
n_p	s^{-1}	Number of revolutions
p	N/m^2	Water pressure
P	Watt	Power
P_s	Watt	(Engine) power at propeller axis
p_z	N/m^2	Water pressure at height z
Q	m^3/s	Discharge
Q_{jet}	m^3/s	Propeller jet discharge
Q_{max}	m^3/s	Maximum discharge that can flow along a ship
r	m	Radial distance to the propeller jet
R_{bend}	m	Bend radius
Re_*	-	Reynolds coefficient
R_F	N	Friction resistance
R_p	N	Pressure resistance
R_T	N	Total resistance
R_v	N	Viscous resistance
s	m^3/s	Sediment transport capacity
S	m^2	Submerged wetted surface of a ship (~C_B*L_s*(B_s+2D))
t	s	Time
t_s	s	Stopping time
T_d	-	Tactical turning point
U_r	m/s	Return current w.r.t banks
U'_r	m/s	Relative maximum return current (compared to the undisturbed canal)
U_1	m/s	Return current caused by ship to be overtaken
U_2	m/s	Return current caused by overtaking ship
U_3	m/s	Return current caused by ship to be overtaken and overtaking ship
U_c	m/s	velocity of natural current
U_{cross}	m/s	Velocity of cross current
U_{local}	m/s	Local velocity
$U_{r,lim}$	m/s	Limit return current w.r.t banks
V'_s	m/s	Relative sailing speed of the ship (compared to the undisturbed canal)
V_{axis}	m/s	Velocity in the axis of the propeller jet
V_{bed}	m/s	Velocity near the bed
V_{lim}	m/s	Limit speed
$V_{lim,1}$	m/s	Limit speed of the ship to be overtaken

Parameter	Unit	Description
$V_{lim,2}$	m/s	Limit speed of the overtaking ship
V_p	m/s	Speed pressure point
$V_{x,r}$	m/s	Flow velocity in the propeller jet at location x,r
V_s	m/s	Ship's speed compared to the bank
$V_{s,1}$	m/s	Sailing speed of the ship to be overtaken
$V_{s,2}$	m/s	Sailing speed of the overtaking ship
V_w	m/s	Wind speed
V_0	m/s	Efflux velocity
W	m	Average width of canal
W_b	m	Width at the canal bottom
W_d	m	Width at the level of the ships hull
W_p	m	Swepth path or lane width
W_s	m	Width of a canal at the water surface
W_z	m	Width of a canal at height z
x	m	Distance from the bow
x'	m	Distance behind the ship (= x - l)
y	m	Distance from the axis of the canal
y'	m	Distance from the bank to the side of the ship
y_d	m	Distance in lateral direction from the side of the ship
y_s	m	Distance from the bank to the side of the ship
z	m	Water level depression
z_{coord}	m	Vertical coordinate relative to water surface (up is positive)
z_{lim}	m	Limit water level depression
z_1	m	Water level depression caused by ship to be overtaken
z_2	m	Water level depression caused by overtaking ship
z_3	m	Water level depression caused by ship to be overtaken and overtaking ship
z_{max}	m	Height stern wave
α	-	Correction coefficient Schijf
α	°	Slope angle
α	-	Factor
α'	-	Coefficient to determine the path width in bends
α_i	-	Coefficient to determine wave height interference cusps (dependent on ship type)
α_t	-	Coefficient to determine wave height transversal waves
β	°	Drift angle
β	°	Equilibrium drift angle
β_{cr}	-	Critical value
β_w	°	Extra drift angle caused by side wind
Δ	-	Relative density (= $(\rho_\sigma - \rho_\omega) / \rho_\omega$)
$\Delta W'$	m	Lane width
ΔW_d	m	Additional navigational width
ΔH	m	Water level difference
δ_r	°	Rudder angle
$\delta_{r,eq}$	°	Equilibrium rudder angle
γ	°	Angle
γ_t	-	Coefficient to determine wave height transversal waves
η	m	Water level above undisturbed level, related to Bouwmeester
η_T	-	Efficiency coefficient
λ	m	Wave length
ν	m^2/s	Kinematic viscosity
ρ	kg/m^3	Density

Parameter	Unit	Description
ρ_s	kg/m^3	Density of sediment
ρ_w	kg/m^3	Density of water
θ	º	angle interference peaks
ϕ	º	Drift angle, angle interference peaks
ψ_{cr}	-	Critical Shields parameter
∇	m^3	Water displacement

1. Introduction

No doubt that the inland vessel is one of the oldest means of transport. For primitive civilisations, very often water transport was the only way of transport which played a significant role in almost all aspects of (economical) development.

1.1. Inland shipping

Inland shipping differs widely from country to country, but in almost all regions this mode of transport provides the least expensive means of transport. In general, inland waterway systems are found in areas with large rivers. Canals extend and improve the use of those transportation systems.

It must be kept in mind that, to a large extent, the importance of inland waterways depends on the geographical situation. In the Netherlands, 45% of the total tonkm (national and international) is transported over water, compared to 12% in Belgium, 14% in Germany and 2-3% in France (1997). Especially for longer distances, waterborne transport is the alternative for road and rail transport.

1.2. Inland waterways

Planning of new inland waterways is expensive and the development and legislative processes are complicated. In the Netherlands the design and construction of canals became of importance during the Industrial Revolution in the beginning of the nineteenth century, ,almost 150 years after the invention of the navigation lock which took place in the second half of the seventeenth century. Nowadays, traffic on the international waterways, like the Rhine which is the most important link between the main port Rotterdam and the German ‘hinterland, is still growing. This asks for a well equipped infrastructure.

In the seaports, the majority of the cargo is transferred onto trucks, trains or inland vessels. However, a part of the cargo passes the seaport, without a stop, in so-called river-sea vessels on routes comprising both coastal and inland waterways. Another part of the cargo is transferred from deep-sea vessels onto feeders, which distribute the cargo to neighbouring ports. This usually takes place in the major seaports and is referred to as the mainport-effect of a port. Some cargo is only transported within Europe, especially from and to Scandinavia and southern Europe. This is known as short-sea shipping.

1.3. Advantages and threats

The main advantages of inland waterways are the high level of safety, the environmental friendliness, the low costs per tonkm and the capacity that still allows for significant growth without congestion. For smaller distances, transport over water has still difficulties to be competitive, especially due to the fact that the final destination often is only reachable by truck. Another reason was the surplus of small-scale vessels. Since 1998, governmental regulations have reduced the fleet capacity to an acceptable level, although the smaller inland vessels now threaten to become extinct. A threat to the inland and European shipping remains however the protectionism of the railways.

1.4. Lecture

The lecture “Inland Waterways” and the lecture notes discuss the design of inland waterways and canals, and the necessary adaptations for natural waterways to meet the shipping

demands. After an overview of the most important inland vessel types and ship characteristics, the lecture notes will deal with hydraulic phenomena, as they occur during navigation in confined waters. Hydraulic phenomena limit the speed and subsequently the size of vessels in canals and they determine the (minimum) dimensions of new canals. Some theory and equations to calculate these hydraulic phenomena, or to obtain a first-order impression of the magnitude, are presented.
Based on the hydraulic phenomena and extensive model tests and field measurements a number of standards for the design of canals are discussed, focussing on European circumstances. With respect to the instructions for the design of inland waterways, the directives given by the "Commissie Vaarweg Beheerders" (Committee of Waterway Managers) of the Directorate General for Public Waterworks and Water Management, are elaborated and applied.

A bibliography of relevant literature is presented in Appendix I. Furhtermore, some difficult terms concerning inland navigation are translated into Dutch in Appendix II. Interesting internet sites are regarding inland navigation are:

- www.informatie.binnenvaart.nl (Dutch site with news and information)
- http://ec.europa.eu/transport/iw/index_nl.htm (EU site)
- http://www.pianc-aipcn.org/index.php (international navigation organization)

The present lecture notes are elaborated as good as possible, but can always be improved. Suggestions for corrections to or improvements of the present lecture notes will be welcomed.

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2. Shipping on inland waterways

Although the inland waterways in Europe and the Netherlands (canals, rivers etc) are widely used by all kinds of commercial ships, but also recreational ones, to transport goods and people, there is still capacity left for significant growth.

2.1. Significance of inland navigation

In 1999 almost 5000 Dutch inland vessels operated on the European rivers and canals, which was 49% of the total European fleet. These ships are mostly owned by small companies. A total of 90% of all shipping companies own merely one inland vessel and 7% posses two to four inland vessels. However, in 1998 these small enterprises comprised 78% of the carrying capacity.

Inland navigation is especially engaged in international cargo transport (Table 2-1). In Dutch harbours cargo from overseas is transhipped on inland vessels and transported further into Europe. The national inland cargo transport is mainly carried out by road. Expressed in tons, the share of inland navigation in the international transport is 60%; expressed in tonkm even 67%, which underlines the role op inland invigilation as a long distance transport mode.

Modality	National cargo transport	International cargo transport
Road transport	77%	35%
Inland navigation	22%	60%
Rail transport	1%	5%
Total	100%	100%

Table 2-1 Cargo transport by Dutch companies in 1997 (tons)

When inland navigation is compared with other transport modalities some strong points, but also weak points, are noticed. Strong points are found in the field of transportation costs, safety and environmental aspects.

2.1.1. Strong points

The large capacity of ships makes the price per ton of water transport low compared to other transport modalities. Economic studies affirm that the cost of the ton-km transported by waterway is much less than that of rail or road transport. Comparative studies on transport of containers indicate that the following ratios in price per ton-km for distances over 100 km apply: inland navigation : road : rail = 1 : 3 : 3.4. Besides costs, inland navigation may be considered as a very safe means of transport due to the strict regulations, the systems of traffic guidance, the location of the fairways and the improved construction of the vessels. Furthermore, waterborne transport can be considered as environmental friendly. The emission per ton-km is low with respect to road transport, inland navigation causes little noise hinder and both aspects are still improving.

An important development in inland navigation is the introduction of the *Just-In–Time* principle. The foundation of this system is that transportation is as fast as necessary, instead of as fast as possible. This demands perfect planning at the delivering of the goods. Due to the introduction of computerised storage administration, the delivery of raw materials can be planned months ahead. In this way, the slower inland water transport becomes an attractive alternative for road transport.

2.1.2. Weak points

The weak points of inland navigation are especially related to the fragmentary structure of the branch, handling costs and competitiveness when it comes to door-to-door transport. The large number of ship owners impedes the adequate way in which is catered to the changing demands of the transport market. On the other hand, the ship owners together form an industrial branch with an important contribution to the economy. Inland navigation also has to cope with strong fluctuations in both supply and demand. These fluctuations are influenced to external causes, which are hardly manipulable.

In order to avoid a large surplus capacity the total transport capacity has been reduced in the last years by means of governmental regulations. Moreover, the number of vessel has decreased due to the continuing scale enlargement. As a result, some are concerned about the position of the small-scale vessel. However, there seems to be a market for this type of vessel due to its potency to reach more isolated places and thereby they could take over a part of the road transport. The fragmentary structure is also the reason of restricted possibilities to develop and to efficiently anticipate on changes in the market. The attitude of the ship-owners is therefore often reactive instead of pro-active. Still new ship types are being developed, which indicates that entrepreneurship is still present.

High handling costs are also a weak point of inland navigation, especially in relation to short distances. The development of new and advanced handling systems is, however, not only the concern of inland navigation; it also requires sufficient provisions on land. Especially for container transport, shipping lines are increasingly trying to set up an integrated transport chain between the producer and the consumer, in order to control and manage the entire transport cycle. If inland water transport forms part of this transport chain, it will require double handling. Besides the transhipment from seaship to inland waterway vessels the cargo has also to be transported on a truck. This is expensive, as mentioned above. Secondary transport for all origins and destinations not located at the waterfront, in the north-western European conditions, still turns out to be more economic above a certain minimum sailing distance.

2.2. Classification of ships and waterways

Ships are distinguished into different classes according to their dimensions, see Table 2-2.

Class	Ship type	Tonnage (t)	Length (m)	Beam (m)
I	Péniche Barge	250 - 400	38.50	5.05
II	Campine barge	400 - 650	50	6.60
III	Dortmund-Ems-Canal standard vessel (D.E.K.)	650 - 1000	67	8.20
IV	Rhein-Herne-Canal standard vessel (R.H.K.)	1000 - 1500	80	9.50
Va	Large Rhine vessels	1500 - 3000	95	11.40

Table 2-2 Ship types