INTERNATIONAL SAVA RIVER BASIN COMMISSION

MANUAL ON THE SAVA RIVER NAVIGATION

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Language:
English

Circulation:
Digital edition

Graphic design:
Tijana Dinić

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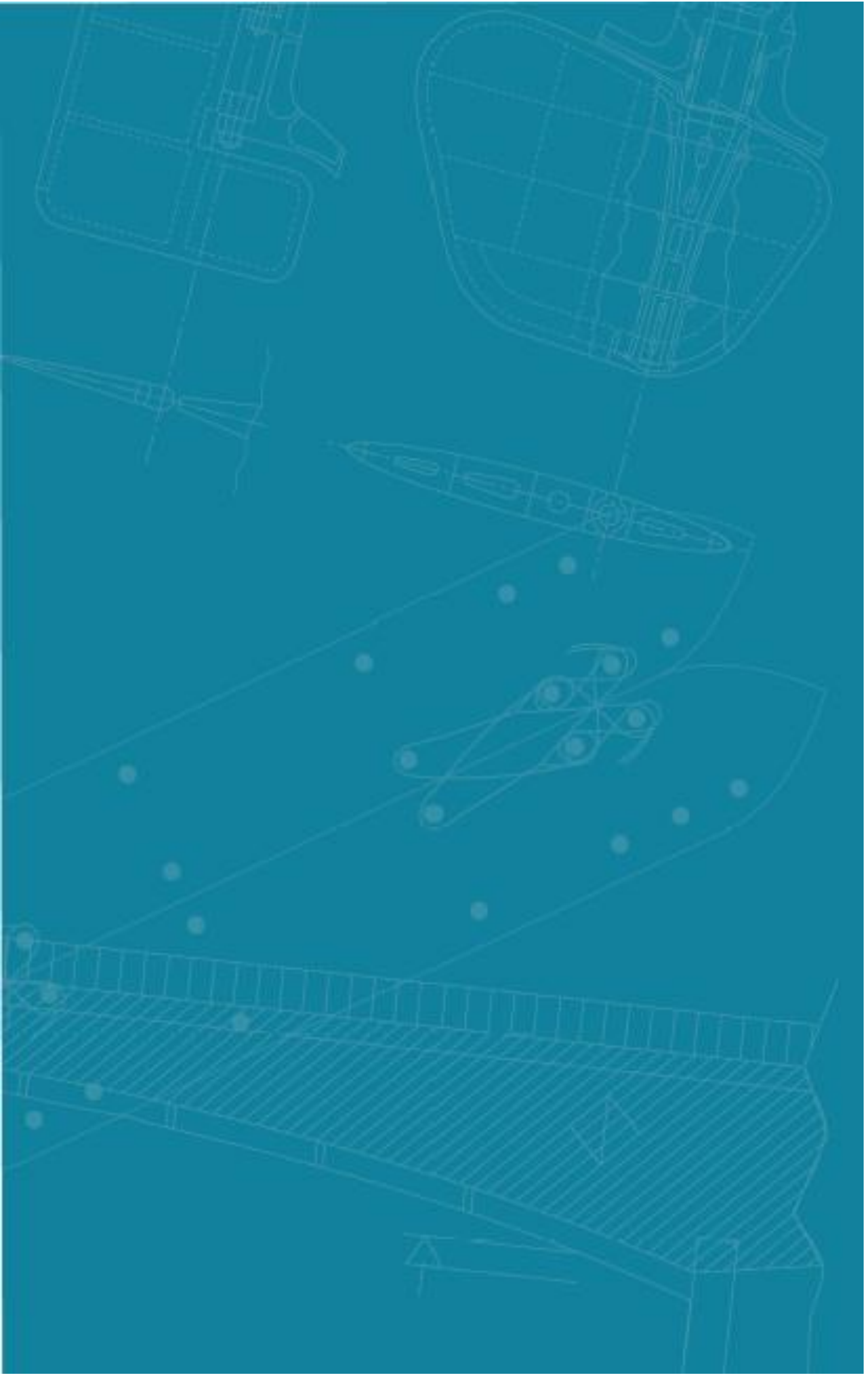
Zagreb, 2023



FOREWORD

As a conclusion to years of document gathering and systematisation, it is our great pleasure to present to you the second, revised edition of the Manual on the Sava River Navigation. Given that the first edition won high praise and received a positive response from the professional community and the educational systems of Member States to the Framework Agreement on the Sava River Basin, this supplemented edition addresses the latest technological trends and practices in inland navigation. The comprehensiveness of this edition of the Manual on Navigation was already confirmed during its preparation by a large number of our collaborators, who themselves made a significant contribution to the development, i.e., to the determination of the concept and the content of the Manual. This edition of the Manual encompasses almost all important issues and topics in the field of inland navigation, so that in one part it deals with general subjects in the area of inland navigation, while in the other part it addresses the specific characteristics of the fairway and navigation on the Sava River.

The Secretariat of the International Sava River Basin Commission (ISRBC - Sava Commission) developed this edition of the Manual with an aim of improving the knowledge and level of information, primarily regarding Sava River navigation, but also on the universal principles of inland navigation in general.

While developing this Manual, we used materials from all available publications, and particular attention was paid to the experience and opinions of numerous experts, to whom we are profoundly thankful. Aware that there are still unaddressed topics in the area of inland navigation, the Secretariat will continue to make efforts to collect and prepare the available material for forthcoming editions of the Manual on the Sava River Navigation. In addition, but of no less importance, we would like to note that we shall make this edition available to a wide circle of users both in the form of a printed brochure and in a digital edition on the official website of the Sava Commission. Therefore, we would like to invite all our readers who notice any inconsistencies, omissions or errors, to put forward their comments, remarks and suggestions that will allow us to make our future editions as accurate as possible, encompassing the latest achievements and trends in inland navigation.

We hope that this Manual will provide practical assistance, both to the current participants in navigation, as well as to those who attend schools or are about to obtain crew certificates in inland navigation.

1.

1.
GENERAL CHARACTERISTICS OF THE SAVA RIVER

1.1 GENERAL AND HYDROGRAPHIC DATA REGARDING THE SAVA RIVER BASIN

No river ends at its riverbank. Each river with its basin has its own diverse habitats and species that enrich life in the basin, and the life of people of different cultures, nations and countries. The same applies to the Sava River, which flows through four countries: Republic of Slovenia, Republic of Croatia, Bosnia and Herzegovina, and Serbia. Furthermore, the Sava River also connects three capitals of these four countries: Ljubljana in Slovenia, Zagreb in Croatia, and Belgrade in Serbia. The fourth state capital – Sarajevo in Bosnia and Herzegovina, also belongs to the Sava River Basin.

The Sava River is the Danube's third longest tributary, but the one with the highest average discharge. It is formed by two smaller rivers in Slovenia, the Sava Dolinka and Sava Bohinjka, joining near the town of Radovljica into a single stream and continuing to flow through Croatia, Bosnia and Herzegovina, Serbia, until its confluence with the Danube in Belgrade (Serbia).

From Radovljica, the Sava River flows through Carniola and the Ljubljana Basin, and then continues its course through 90 km-long Litija – Krka valley. It enters the Pannonian Plain near the town of Brežice and flows along its southern flank all the way to its confluence. The average longitudinal gradient from the confluence with the Kupa River to its confluence with the Danube is 42 mm/km, which results in a pronounced meandering flow that is characteristic of lowland rivers.

As a consequence of such a low gradient, the Sava River cannot carry the sediment brought in by its tributaries. Instead, the sediment is deposited on its riverbed downstream of the confluences with its tributaries, thus creating numerous sandbars and shallows, which, during the periods of low water level complicate or sometimes even completely prevent navigation. The Sava River water regime is typically pluvio-nival (rainy and snowy), with an average flow velocity of 3.2 m/sec.

The length of the Sava River from its main source in western Slovenian mountains to its confluence in Belgrade is approximately 944 km. The total basin area of 97,713 km^2 covers major parts of territories of Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and a small area of Albania (Table 1). With its average discharge of approximately 1,700 m^3/sec, the Sava River represents the greatest tributary of the Danube by volume of water, contributing with almost 25 % to the Danube's total discharge. This means that sustainable development of the Sava River Basin has a significant influence on the Danube River Basin.

Country	River basin area per country (km^2)	River basin share per country (%)
Slovenia	11,734.8	12.0
Croatia	25,373.5	26.0
Bosnia and Herzegovina	38,349.1	39.2
Serbia	15,147.0	15.5
Montenegro	6,929.8	7.1
Albania	179.0	0.2
Total	97,713.2	100.0

Table 1: Main data on the Sava River Basin

The Sava River is very important for the Danube River Basin due to its outstanding biological and landscape diversity. The Sava River Basin hosts the largest complex of alluvial wetlands in the Danube River Basin (Posavina – central part of the Sava River Basin) and large lowland forest complexes. The Sava River is a unique example of a river with some of the floodplains still intact, thus supporting flood alleviation and biodiversity.

There are seven Ramsar sites in the Sava River Basin, namely: Lake Cerknica (SLO), Lonja Field, Crna Mlaka (CRO), Bardača (BiH), Zasavica, Obedska pond and Pešter plateau (SRB), with numerous areas important to bird and plant life, as well as areas protected at the national level, and Natura 2000 sites.

Main information on the Sava River’s main tributaries is provided in Table 2.

River name	Tributary (l – left; r – right)	Basin [km²]	Length [km]	Country	Country area [km²]
Ljubljanica	r	1,860.0	41.0	SLO	
Savinja	l	1,849.0	93.9	SLO	
Krka	r	2,247.0	94.6	SLO	
Sutla / Sotla	l	584.3	88.6	SLO, CRO	SLO – 450.8 km^2 CRO – 133.5 km^2
Krapina	l	1,244.0	65.6	CRO	
Kupa / Kolpa	r	10,225.6	297.2	CRO, SLO	CRO – 8,412.0 km^2 SLO – 1,101.0 km^2 BiH – 712.6 km^2
Lonja	l	4,286.1	82.8	CRO	
Ilova	l	1,815.7	100.3	CRO	
Una	r	9,828.9	214.6	BiH, CRO	BiH – 8,142.9 km^2 CRO – 1,686.0 km^2
Vrbas	r	6,273.8	249.7	BiH	
Orljava	l	1,615.7	99.5	CRO	
Ukrina	r	1,504.0	80.7	BiH	
Bosna	r	10,809.8	281.6	BiH	
Tinja	r	904.0	99.4	BiH	
Drina	r	20,319.9	346.0	BiH, MN, SRB, ALB	BiH – 7,118.9 km^2 MN – 6,929.8 km^2 SRB – 6,092.2 km^2 ALB – 179.0 km^2
Bosut	l	2,943.1		CRO, SRB	CRO – 2,375.0 km^2 SRB – 568.1 km^2
Kolubara	r	3,638.4	86.6	SRB	

Table 2: Main tributaries of the Sava River

1.2 HISTORY OF THE SAVA RIVER NAVIGATION

First more organised prehistoric human settlements were erected on the banks of rivers and lakes. It should also be emphasised that the banks of major rivers was where further development of human society took place and where foundations for the first sciences - astronomy and geometry - were laid. Looking back at the historical development of shipbuilding, and a ship as its product, it can be observed that no human craftsmanship paints such a faithful picture of the level of human development as is the case with ships.

The development of shipbuilding and shipping activities led to the rise of first rowing boats that only sailed downstream, whereas later, use of more oars meant commencement of upstream sailing in cases where river flow velocity allowed it. Towing of vessels upstream was performed by horses and, in some cases, by people and horses (this method of towing was called “horseboating”).

Until the end of the 5th century A.D., oars had been used as the main means of propulsion, while sails provided just an auxiliary propulsive force and only if the wind direction was towards the ship’s stern.

In Donja Dolina, a village situated on the banks of the Sava River, a Bronze Age settlement originating from approximately 4000 years B.C. was discovered, where, among other findings, a 12.5-meter-long boat, carved out of an oak tree, was excavated. This boat, along with another one slightly shorter than 5 m, are exhibited at the National Museum of Bosnia and Herzegovina in Sarajevo.

There is no clear division line between the period dominated by ships powered by sails and the era of rowboats. It can only be approximately determined that sails started prevailing over oars at the end of the 12th and the beginning of the 13th century, when the occurrence of today’s sternpost allowed use of larger sails. Discovery of new sea routes and countries in the late 15th century additionally contributed to the development of sailing ships, shipbuilding and shipping in general, with the steadily increasing size of ships, their speed, manoeuvrability and navigational instruments.

The following factors were crucial for the rapid development of shipping and shipbuilding in the late 18th century: a general increase in labour productivity, the invention of the steam engine (in the 1780s), use of steel structures instead of wooden structures, the transition from handcraft to the industrial mode of manufacture, the application of scientific instead of experiential methods in the shipbuilding industry, and, later, the invention of the propeller (screw) – in the middle of the 19th century.

First steamboats (steam-powered vessels) appeared on rivers, which is understandable mainly for two reasons: first, the rivers have more suitable conditions for navigation (river water is calmer than sea, hence there is no danger of waves); and, second, because of the river currents, steamboats were more required on rivers than at sea, where sails provided for undisturbed navigation and manoeuvring.

The first steamboat was built approximately twenty years before the steam locomotive. It is very difficult to identify the inventor of the first steamboat. It is believed that it was Robert Fulton, an American painter from Pennsylvania, born in 1765, who built a large and sturdy steamboat in New York known as the “Clermont”, which was equipped with a steam engine purchased in Europe (company “Boulton & Watt”). Main features of this steamboat were as follows: length = 40.5 m, breadth = 5.48 m, side height = 2.74 m, displacement = 180 tons, and a steam engine with a power of 50 HP, which was incredible at that time. The steamboat “Clermont” commenced its first successful trip on 17th of August 1807 on the Hudson River.

First steamboats in Europe were constructed in England in 1816, and used to sail on the Seine, the Rhine and the Elbe.

The first steamboat on the Danube had its inaugural run in 1817, following the completion of test runs. The steamboat “Carolina”, built 1818 in Vienna, carrying 20 tons of loads, could travel 3.5 km/h when sailing upstream, and 15 km/h when sailing downstream.

The First Danube Steamboat Company (Die Erste Donau Dampfschiffarts Geselschaft, DDSG) was founded in 1829 in Vienna.

In 1830, the ship “Franz I” made its first trip between Vienna and Budapest and it is considered to be the first steamboat that regularly sailed on the Danube.

In 1834, the ship “Carolina”, running between Vienna and Oršava, was the first steamboat to sail through Đerdap.

The development of modern shipping, i.e., the appearance of first steamboats, raised the need to regulate the Sava River.

In 1834, the French steamboat “Sophia” (60 HP and 300 t deadweight) commenced its trip on the Sava River in order to test the conditions for navigation and, on 11th of September 1838, it arrived at Sisak. Four years later, ten steamboats of the company Danube Lloyd from Vienna sailed between Vienna and Sisak. The first Croatian steamboat “Florisdorf” was bought in July 1844. The vessel “Florisdorf” commenced its first voyage from Vienna on 21st of August 1844, and arrived at Sisak on the 8th of September 1844.

Next day, the steamboat was renamed to “Sloga” (Concord). It was the name of the first Croatian steamboat ever, both on rivers and the sea (first sea steamboat “Hrvat” (The Croat) sailed only in 1879). “Sloga” run the regular passenger line every 1st and 15th of the month, sailing downstream from Sisak to Zemun, and every 6th and 21st of the month, sailing upstream from Zemun towards Sisak. However, only one year later, on 14th of September 1845, the first Croatian steamboat “Sloga” had an accident near the town of Bošnjaci and sank. Only seven days after “Sloga” sank, the steamboat “Carl” of the company Danube Lloyd from Vienna sailed into the Sisak port, and was granted exclusive navigation rights on the Sava River. In 1846, the steamboat “Panonija” sailed into the Sava River and docked in Sisak. Regulation of the Sava River commenced in January 1856, leading to the establishment of a mixed Austrian-Turkish Commission, since the river’s right bank was under the Turkish rule.

Serious works on river training for commercial traffic on the Upper Sava commenced in 1871, which, with minor interruptions, continue to this day.

In addition, even back in 1829, the town of Šabac had a fully operating ship and ferry repair workshop, where, among others, the Danube ships from Poreč and Gradište were repaired.

First Serbian river steamboat “Deligrad”, (length = 58 m, breadth = 7 m, displacement = 275 tons, and power of 50 HP) had its inaugural run on the Danube in 1862. “Deligrad”, with its six barges that the Government of Serbia had procured in Italy, transported salt and petroleum from Romania, and passengers when needed. “Deligrad” was armed with two cannons. This ship was sunk by its own crew on 6th of April 1941 on the first kilometre of the Sava River.

First river kilometre marks were placed in 1877, from Sisak to Zemun. After World War I, river-training activities on the Sava River continued, and it became navigable as far as Rugvica, and on the Kupa River, from its confluence to as far as Pokupsko.

Back in 1870, the Steamship Company Šipuš and Morović was founded in Sisak, which had two steamboats, “Hrvat” and “Slavian”. In the 1880s, this steamship company was taken over by the newly established Bosnian Steamship Company, based in Brčko. This company renamed the aforementioned ships “Una” and “Sarajevo”, and then built five new boats: “Vrbas” and “Bosna” for navigation on the Sava River, and “Drina”, “Zvornik” and “Lim” for navigation on the Drina River.

The First Serbian Privileged Company was founded in Belgrade in 1890. This company purchased the ship “Deligrad” from Serbia, and then the ship “Mačva”, the barge “Beograd”, the steamboat “Stig”, as well as a number of other barges in Italy. With such a fleet size, regular traffic was established from Belgrade to Dubravica and Šabac.

In the year 1897, Rudolf Diesel announced his invention of the internal combustion engine (the diesel engine) that launched a technological revolution in the shipping industry. Its utilisation in river navigation commenced in 1912.

In the period between two World Wars, two strongest industrial plants, namely the Shell refinery and the smelting plant Caprag, were built on the bank of the Sava River, thus emphasising the economic significance of this river for the wider area of the Sisak region.

After the end of World War I, in 1918, a large number of ships from Austro-Hungarian and German shipping companies were located in the newly established State of Slovenes, Croats and Serbs. According to the Treaty of Rapallo signed in 1920, majority of those ships had come into its possession, thus the acquired fleet made the new state the leader by fleet size in the Danube region.

In July 1945, the new Directorate-General for River Navigation was founded, and the State River Shipping Company as a part thereof, which was renamed the Yugoslav State River Shipping Company in 1947. In 1952, following restructuring and decentralisation, it became the Yugoslav River Shipping Company – “JRB”, which is the name that has remained to this day. Taking into consideration the technical obsolescence of the fleet at the time, in the mid-1950s, the company commenced with the construction of ships, tugboats (the famous “JOTA” fleet), self-propelled cargo vessels, river-sea ships and barges for bulk cargo and tank lighters for liquid cargo. Until then, the average age of passenger ships was 60 years, of tugs 40 years, and of barges for dry and liquid cargo 45 years. The new fleet comprised of: “Džervin”, “Veternik”, “Košutnjak”, “Topčider”, “Jablanik”, “Javornje”, “Jagodnja”, “Jelašnica”, (from which the “JOTA” fleet got its name), “Vitorog”, “Trebević”, “Dinara”, “Komovi”, “Udarnik”, “Junak”, “Vitez”, “Kolubara”, “Mlava”, “Tamnava” and “Morava”. In 1961, the famous motor tugboat “Tara” joined the fleet. “Tara” was operating on the sector of Đerdap, and will be remembered by its power, navigational safety and a beautiful design.

After World War II, rivers Sava and Kupa experienced a remarkable expansion triggered by the state industrialisation plans, and as of 1952, the town of Sisak became the seat of the Danube Lloyd, one of the leading shipping companies founded following the decentralisation of the former state river shipping company. At that time, a modern river port was built on the Kupa River, which, owing to its capacities, became an economic focal point of the town.

In 1955, there were several attempts to revive the frequently professionally contested upstream navigation from Galdovo, but the most famous case was that of the ship “Bačka” that managed to arrive under the Jakuševac Bridge in Zagreb. Dredgers and wagons were then transported from Sisak to Zagreb, and after many dramatic moments, the entire endeavour was completed successfully, yielding the praise from the general public.

In the period between 1956 and 1961, a considerable number of vessels were built in river and maritime shipyards, which was quite significant by the standards of Yugoslavia at the time. During those years, strong motor tugboats such as “Biokovo”, “Sisak”, and “Boris Kidrič”, and motor tanker tugboats “Caprag” and “Sisak” commenced their river navigation, which were considered powerful even for the conditions on the Danube.

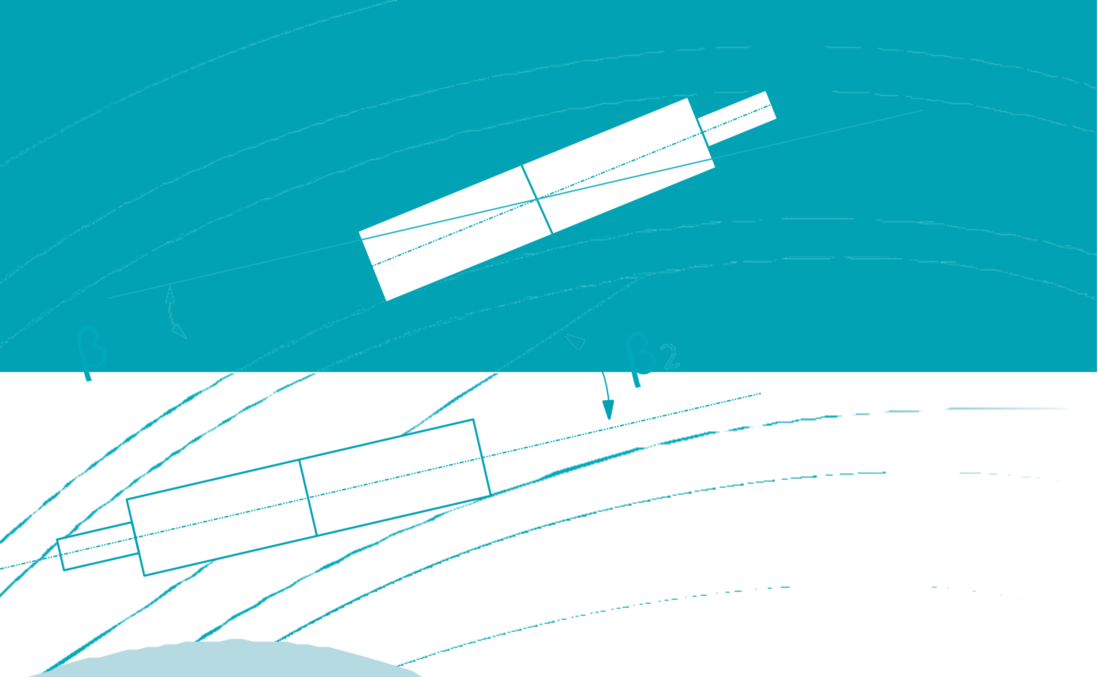
During the eighties of the last century, there was a significant increase in towing and pushing capacities, thus the major share of obsolete transport technology was decommissioned. During those years, transport on the Sava River reached its peak, and it mainly consisted of bulk cargo being transhipped at the Brčko port, as well as transport of crude oil and oil derivatives for refineries in Brod and Sisak.

The war and breakup of the former Yugoslavia in the 1990s led to a complete termination of navigation and any significant maintenance of the fairway.

It should be noted that the previous navigation regime on the Sava River was only of a national character, whereas traffic of foreign vessels was allowed only with special permits.

Following the normalisation of relations in the region, navigation was partly restored, but only for ships from riparian countries, which made a sound problem for future development of this form of transport.

Signing of the Framework Agreement on the Sava River Basin and the Protocol on the Navigation Regime to the Framework Agreement on the Sava River Basin in 2002 and its entry into force in 2004 meant the establishment of an international navigation regime on the Sava River. Simultaneously, significant and harmonised activities commenced on the rehabilitation of the fairway and harmonisation of legislation on inland navigation in the Sava River Basin.



2.

2.
THE SAVA RIVER FAIRWAY

2.1 FAIRWAY CHARACTERISTICS

The international navigable fairway on the Sava River and its tributaries is defined by the Protocol on the Navigation Regime to the Framework Agreement on the Sava River Basin that applies to the Sava River from the river kilometre 0.00 to the river kilometre 594.00, on the Kolubara River from the river kilometre 0.00 to the river kilometre 5.00, on the Drina River from the river kilometre 0.00 to the river kilometre 15.00, on the Bosna River from the river kilometre 0.00 to the river kilometre 5.00, on the Vrbas River from the river kilometre 0.00 to the river kilometre 3.00, on the Una River from the river kilometre 0.00 to the river kilometre 15.00 and on the Kupa River from the river kilometre 0.00 to the river kilometre 5.00.

In general, the Sava River fairway is divided into three sectors:

- Upper Sava from rkm 594 to rkm 467;
- Middle Sava from rkm 467 to rkm 139;
- Lower Sava from rkm 139 to rkm 0.

The Sava River is navigable for larger vessels from Sisak (conditionally, it is navigable from Rugvica near Zagreb to Sisak for smaller tourist vessels) to its confluence where it empties into the Danube in Belgrade. Due to years of insufficient and inadequate maintenance of the fairway, Sava is not sufficiently regulated for navigation. With the exception of a part of the Lower Sava sector, the fairway is distinguished by sharp bends with the radii of curvature of up to 200 m, which significantly impedes navigation, particularly for pushed convoys. It is considered that normal navigation requires a mandatory radius of curvature of 360 m, at least. In addition, shallows occur during low water levels, whereas high water levels can cause a collapse of riverbanks and widening of the riverbed, thus reducing its depth. Furthermore, there are many artificial obstacles in the fairway that hinder navigation, such as unfavourable selection of bridge locations and sunken vessels. The fairway is marked in accordance with its current state, but the marking system will change simultaneously with the regulation of the fairway.

The development of River Information Services will significantly facilitate navigation, especially at night and in unfavourable weather conditions.

Geographically, the Sava River fairway stretches between the Mediterranean and Central Europe. It is parallel with Corridor X, and crosses Corridor Vc, which ensures its exceptionally important role in planning of transport strategies of all riparian countries.

The actual situation is such that the fairway is not sufficiently utilised, even though its geostrategic position provides for development of combined and intermodal transport that would link Central and Western Europe with the Adriatic Sea. The rehabilitation and development of fairways and fairway infrastructure in general would significantly contribute to the competitiveness on the transportation services market, which is in line with all strategic documents for the transport policy of Member States to the Framework Agreement on the Sava River Basin.

2.2 WATERWAY CLASSIFICATION

Waterways are the subject of the homogenous and internationally recognised classification system established under the AGN Agreement (the European Agreement on Main Inland Waterways of International Importance). The economic significance for international water transport is linked to fairways of Class IV to VII. This classification system was established by UNECE (the United Nations Economic Commission for Europe) and ECMT (the European Conference of Ministers of Transport).

The key classification criterion depends on the basic dimensions of vessels, and variables used in the decision-making process include length, beam and draught, vessel tonnage and bridge clearance. The competitiveness of a fairway greatly depends on conditions at the navigable section of the river, which determine the capacity of vessels in inland navigation, and thus economic vitality.

Pursuant to the aforementioned classification under the AGN Agreement, the International Sava River Basin Commission adopted Decisions 21/06 and 13/09 on the adoption of the Detailed Parameters for Waterway Classification on the Sava River, on the basis of which Classification of the Sava River Waterway was adopted (Decisions 19/08, 14/12 and 5/17).

Classification of the international Sava River Waterway is a result of the current status of the waterway. In the future, there will be minor corrections, as a result of ongoing projects that envisage development of the design documentation and related hydro-engineering works, which are based on such documentation.

Classification of the Sava River Waterway is shown in the following table:

Section of the Sava River		Length (km)	Waterway class
rkm	rkm		
0.0 Sava confluence	81.0 Kamičak	81.0	Va
81.0 Kamičak	176.0 Rača	95.0	IV
176.0 Rača	196.0 Domuskela	20.0	III
196.0 Domuskela	313.7 Slavonski Šamac / Šamac	117.7	IV
313.7 Slavonski Šamac / Šamac	338.2 Oprisavci / Rit kanal	24.5	III
338.2 Oprisavci / Rit kanal	371.2 Slavonski Brod / Brod	33.0	IV
371.2 Slavonski Brod / Brod	594.0 Sisak	222.8	III

Table 3: Classification of the Sava River Waterway.

The Detailed Parameters bear great importance in comprehension of key criteria used in the development of the aforementioned Classification, and these are specified and explained in the following table and the annex thereto.

Annex 1: Annexes to the classification

DETAILED PARAMETERS FOR INLAND
according to Classification of European inland waterways, United Nations Economic

WATERWAY	IMPORTANCE		REGIONAL					INTERNATIONAL		
	CLASS		I	II		III		IV		
PUSHED CONVOYS	CONVOYS							P.1		
	l (m)					118 – 132		85		
	b (m)					8.2 – 9.0		9.5		
	t (m)					1.6 – 2.0		2.5 – 2.8		
	W (t)					1000 – 1200		1250 – 1450		
WATERWAY CLEARANCES	**T (m)**							2.3	2.2	
	T_v (m) + Δ		1.3	1.3	1.6	1.6	2	3.3	3.3	
	B (m)		35	45		45		55	30	
	B_{zav} (m)	for min l_{sast}	25	35		40		75	40	
		for max l_{sast}	35	45		45		75	40	
CLEARANCES UNDER BRIDGES AND OVERHEAD CABLES	**H_{most} (m)**		3	3		4		7		
	$_{min}B_{most}$ (m)		35	45		45		45		30
	H_{kab} (m)	Up to 110 kV From 250 kV From 400 kV	15 15.75 17	15 15.75 17	15 15.75 17	15 15.75 17	15 15.75 17	15 15.75 17	15 15.75 17	15 15.75 17
	H_{nnkab} (m)		12	12	12	12	12	12	12	12
	B_{kab} (m); B_{nnkab} (m)		B_{kab}; B_{nnkab} = horizontal clearance or distance							
SHIP LOCK CLEARANCES	**T_{prev} (m)**		1.6	2	2.25	2.5	2.5	3.0		
	$_{min}B_{prev}$ (m)		10	10		10		10.0 – 12.5		
	$_{min}L_{prev}$ (m)		60	60		70 – 75		90 – 190		

WATERWAY CLASSIFICATION – "SAVA INITIATIVE" PROGRAMME
Commission for Europe – Inland Transport Committee (UN/ECE, GENEVA 1996)

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<tr><td colspan="14">from outer edges of dykes on rivers above HNL+ 12.0 m</td></tr>
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l (m)	vessel length
b (m)	vessel breadth
t (m)	vessel maximum draught
W (t)	vessel tonnage
T (m)	depth on fairway for navigation with reduced draught (94 % duration)
Tv (m)	depth on a level of draught below LNL (with velocity submersion and skew)
Δ (m)	absolute reserve
B (m)	width of fairway at LNWLs on straight sectors
B_{zav}	width of fairway at LNWLs in bends
l_{sast}	length of characteristic vessel or pushed convoy
H_{most} **(m)**	vertical clearance under a bridge
${}_{min}B_{most}$ **(m)**	horizontal clearance under a bridge
H_{kab} **(m)**	vertical clearance under overhead power lines
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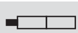
P.1.2	
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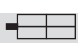
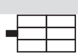
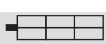
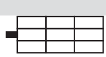
P.2.2	
P.3.2	
P.2.3	
P.3.3	
H_{nnkab} **(m)**	vertical clearance under overhead non-power cables
B_{kab} **(m)**	horizontal clearance under overhead power lines
B_{nnkab} **(m)**	horizontal clearance under overhead non-power cables
T_{prev} **(m)**	depth on lock gate
${}_{min}B_{prev}$ **(m)**	minimal lock width
${}_{min}L_{prev}$ **(m)**	minimal lock length

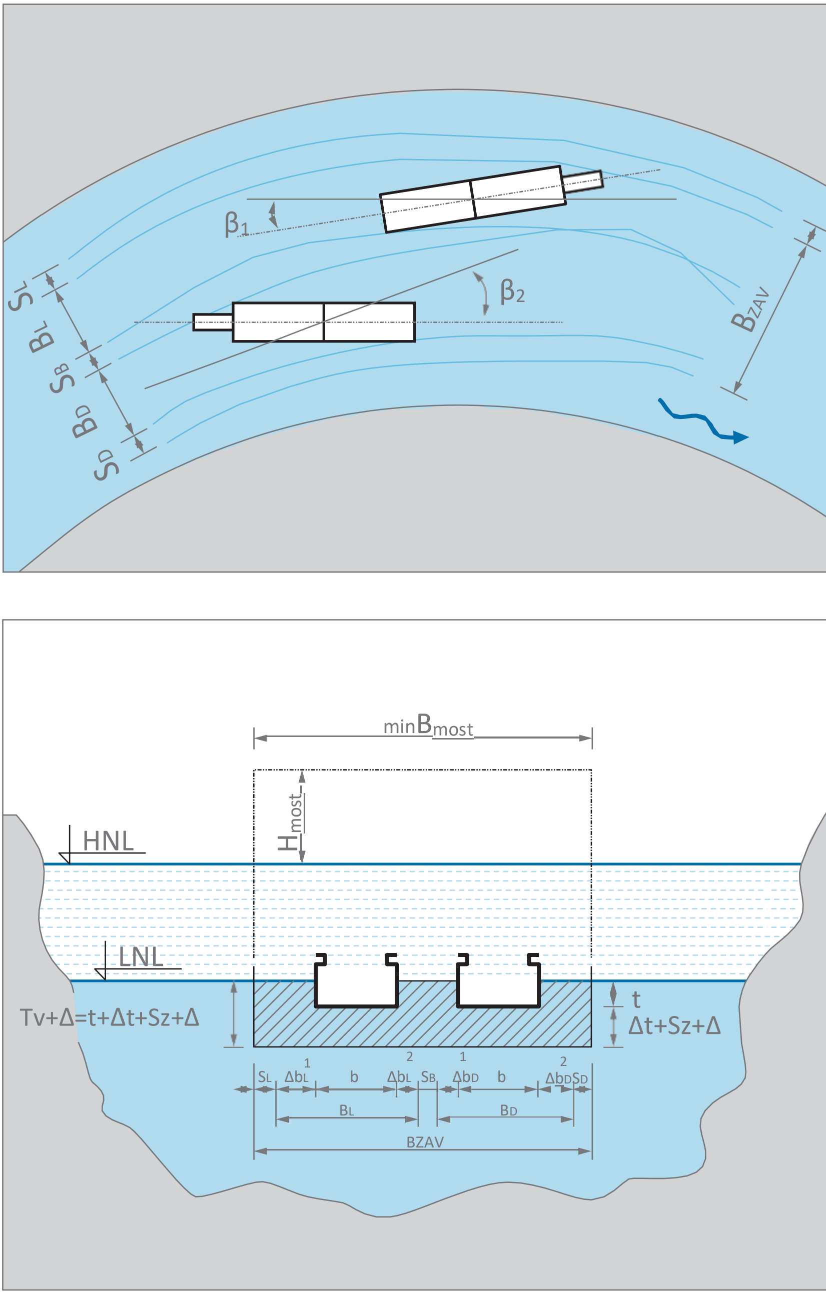


Figure 1: Cross-section and plain view of the riverbed and fairway in a bend for the appropriate case of passing-by

HNL	high navigable water level
LNL	low navigable water level
B_{zav}	fairway width at a bend
B_L, B_D	navigation lane width
S_L, S_B, S_D	additional width
Δb_L^1, Δb_L^2, Δb_D^1, Δb_D^2	vessel side-slip
B	vessel breadth
$T_V+\Delta$	fairway depth
t	maximum draught
Δt	vessel skew
S_Z	velocity submersion
Δ	absolute reserve
H_{most}	vertical clearance under a bridge
$_{min}B_{most}$	horizontal clearance under a bridge
β_1, β_2	horizontal angles of vessel side-slip

Definitions:

Low navigable water level – LNL:

Low navigable water level of a free-flowing river at a certain water gauge corresponds to the water level defined with a 94 % duration discharge ($Q_{94\%}$). LNL = $V_{94\%}$ [cm or m.a.s.l.] and at any point along the free-flowing river corresponds to the water-surface level with a discharge duration of 94 % of the days in a year. It is defined based on a statistical analysis of discharge duration taking into account 30 years of observation. Traditionally it is used to determine the flow profile at low water levels when navigation on smaller rivers is performed with a reduced draught of the reference vessel.

High navigable water level – HNL:

High navigable water level of a free-flowing river at a certain water gauge corresponds to the water level defined with a 1 % duration discharge ($Q_{1\%}$). HNL = $V_{1\%}$ [cm or m.a.s.l.] and at any point along the free-flowing river corresponds to the water-surface level with a discharge duratione of 1 % of the days in a year. It is defined based on a statistical analysis of discharge duration taking into account 30 years of observation. Traditionally it is used to define vertical clearance under bridges or overhead power line/ cables.

Water level with 60 % duration: $V_{60\%}$

According to AGN [Annex IIIb] for every waterway class safety navigation should be guaranteed 240 days during the year for a proper cargo vessel with maximum draught. This corresponds to the water level defined with the discharge duration of 60 % ($Q_{60\%}$). $V_{60\%}$ [cm or m.a.s.l.] in any point of free flow river corresponds to the water-surface level with the discharge of 60 % duration in a year.

Reduced draught

In practice vessels also navigate at water levels lower than LNL. According to AGN [Annex IIIb], year-round navigation (except during occurrence of ice) must in principle be ensured on international E-class waterways (Classes IV–VII) This means it should be ensured even at levels lower than LNL, but a reduced draught of 1.2 m is permitted.

Δt – vessel skew is the static sinkage of a vessel's bow or stern under load (on the vessel's longitudinal axis, transverse skew is disregarded) and the adopted value is 0.1 m.

S_Z – velocity submersion is a consequence of dynamic sinkage caused by the bow-and-stern wave system, flow velocity past the hull, size and shape of the vessel or convoy, wetted cross-section, and waterway restrictions; the adopted value is 0.2 m.

Δ – absolute reserve is the always-free water cushion between the vessel's hull and the fairway bed, which is never used for navigation or otherwise occupied; and adopted values are: for Classes I - IV = 0.3 m, for Class V = 0.4 m, for Classes VIa and VIb = 0.5 m and for Classes VIc and VII = 0.6 m.

Small radius categories:

R_{min} [m] – minimum radius of the waterway axis in a bend;

R_{izn} [m] – special radius of the waterway axis in a bend.

Minimum radius

Minimum bend radius of a waterway is the smallest radius of the waterway axis that allows undisturbed two-way navigation on low navigable water level.

Special radius

Special bend radius of a waterway is 25 – 30 % smaller than the minimum. Although generally undefined, in practice it is applied on river sections where topographic or urban constraints preclude the use of the minimum radius. In such cases a wider fairway than that calculated for the minimum radius is provided.

Navigation lane

A navigation lane is the part of the fairway within which navigation of vessels or convoys is performed continuously, i.e. a part of the water surface that vessels or convoys can reach during navigation, considering its beam, side-slip in bends or yaw in straight sectors.

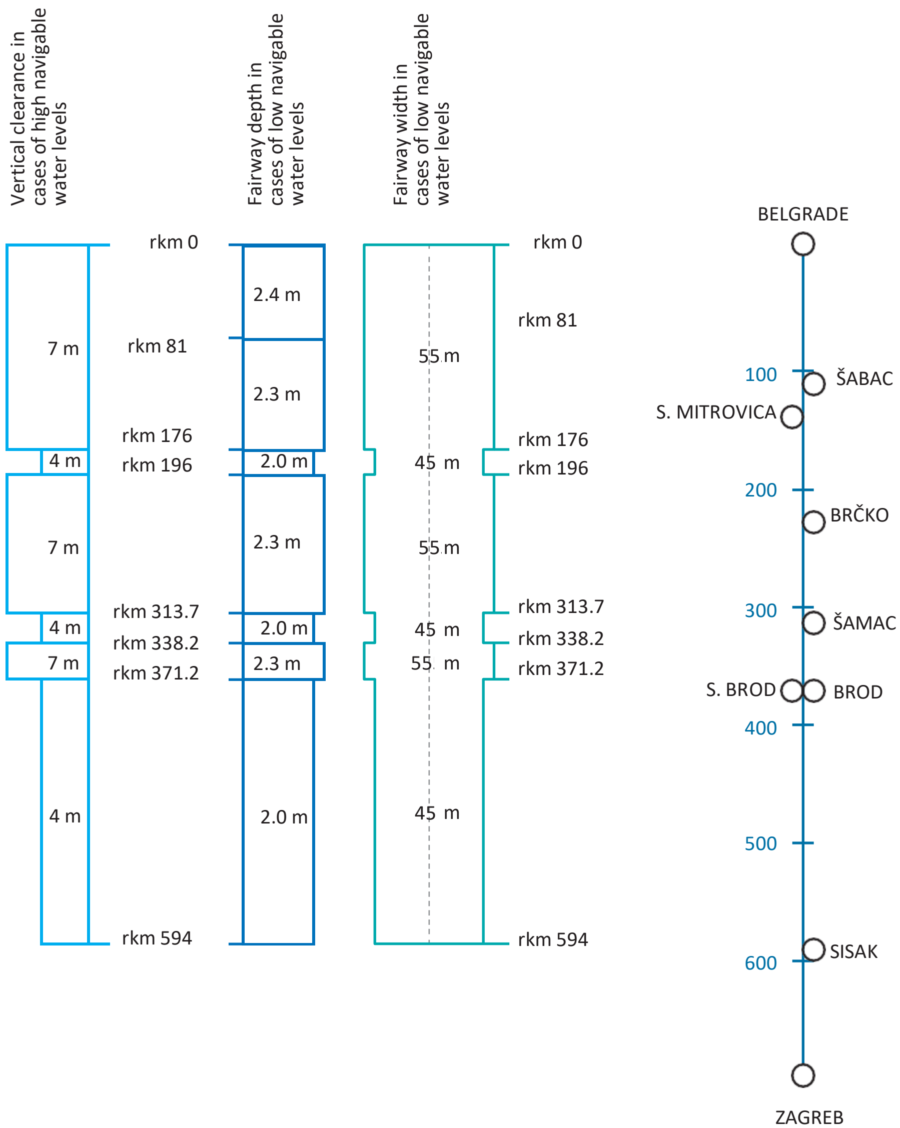
Fairway dimensions

Fairway is an imaginary rectangle in the cross-section of a waterway in which navigation is continuously performed; i.e. the part of a river cross-section that vessels or convoys can reach during navigation with regard to width and depth. Horizontally it is defined by the navigation lane and safety widths. One direction of a fairway consists of one navigation lane and safety widths. Vertically it is defined by the vessel or convoy draught, vessel skew and velocity submersion that occur during navigation.

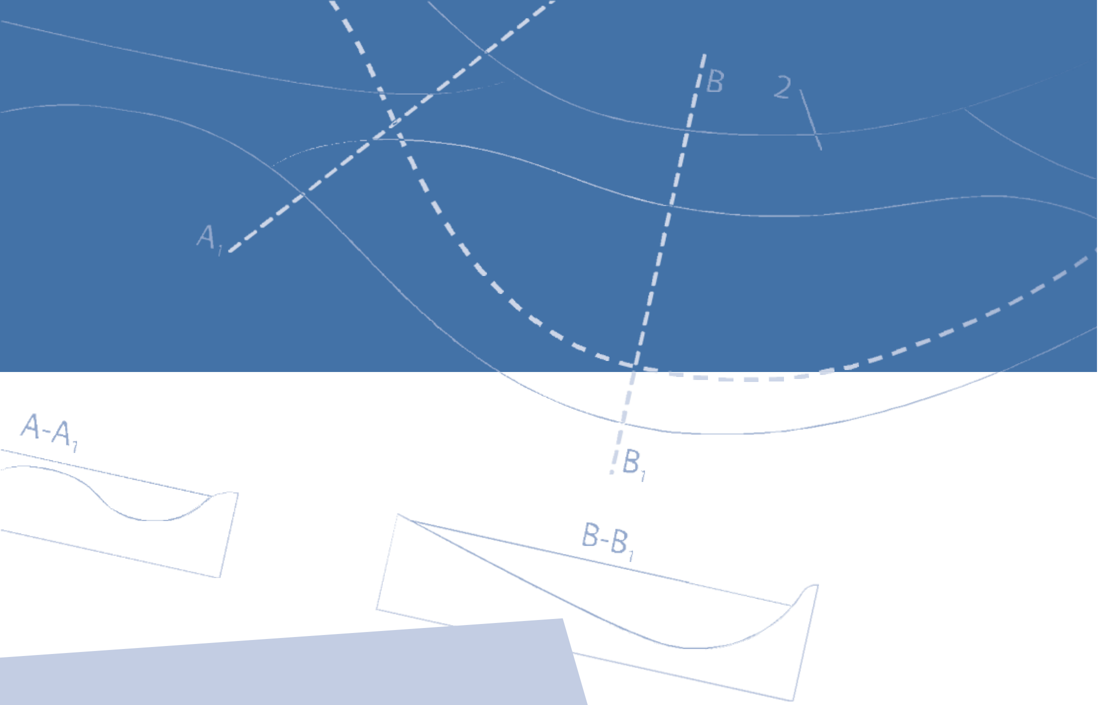
Clearance

Clearance under a bridge is the free space between the waterway and the bridge (Figure 1). Vertically, it is the space between the water surface and the bottom edge of the bridge structure; and, horizontally, it is the space between the inner edges of the bridge's river piers. Here, clearance under a bridge is defined as an imaginary rectangle defined with width B_{most} [m] and height ${}_{min}H_{most}$ [m] as the minimum clearance under a bridge for each waterway class. It contains extra space that a vessel cannot achieve neither concerning width nor height. During two-way navigation under a bridge, two-way navigation is reduced to one-way due to the security of the bridge construction, but the proclaimed fairway width is not reduced.

Annex 2: Sava River waterway profile.



Note: the values indicated are in accordance with applicable Detailed Parameters for Waterway Classification on the Sava River, and individual sections may deviate slightly.



3.

3.
INFRASTRUCTURE

3.1 PORTS AND TERMINALS

Ports are water areas of rivers, canals or lakes, and their directly connected land area with developed port structures that ensure efficient performance of port activities, whereas terminals / landing places are water areas and land areas directly connected to them, with facilities necessary for berthing and anchoring of vessels and for embarking or disembarking passengers or particular types of cargo.

In a broader sense, the term “port infrastructure” includes all water areas inside the port area (river access and port basins), all shoreside structures (quay walls and other embankments), all facilities within the port limits (developed and undeveloped), as well as public-transport infrastructure (roads, railway, bridges. etc.).

The degree of development, equipment and capability of ports and terminals / landing places largely determine their competitiveness and demand for waterborne transport in the freight-services market.

Bearing in mind the economic potential of Sava River Basin countries, it is evident that a sound network of ports and terminals / landing places exists and that they will, in parallel with fairway development, be modernised and their internal processes upgraded so as to be ready for the time when unobstructed navigation on the Sava River becomes a reality.

In general, there are two basic types of river ports, each with its specific roles, activities and special services:

- **Conventional river ports** – they provide cargo handling / transhipment services, transferring it from ships to the shore by inland vessels, using mainly traditional “Lo-Lo” (lift on / lift off) vertical cargo-handling technology of different types for dry cargo, including containers (ports not specialised for any “non-conventional” cargo or technology);
- **Specialised river ports** – they provide only dedicated services or mainly use non-conventional technologies in handling and / or in other port operations. They also include private ports where industrial plants and facilities are directly located on the fairway.

Apart from the previously described port types, it is necessary to explain the terms “terminal” and “place of transhipment”, which will appear frequently in the parts of this Chapter.

A terminal (literally, a “final destination” for a particular means of transport) is part of a port, or a separate cargo transhipment / temporary storage unit, that deals with particular types of goods, such as oil terminals, grain terminals, container terminals or Ro-Ro terminals. A terminal is in no case the cargo’s final destination; it is solely the place where the cargo transfers from one means of transport to another.

Place of transhipment is a suitably equipped and positioned location directly on the fairway bank that lacks a proper port basin. Such sites are used by industrial companies or by service operators engaged by a company to tranship cargo carried to or from that point by inland vessels.

The term “port superstructure” includes all structures and buildings erected within the port infrastructure and used for cargo transhipment, storage and distribution, and will not be discussed further in the following text. It includes handling / transhipment equipment (cranes), warehouses and silos, office buildings, and also private-transport infrastructure (private railway or rails running from a crane).

The following table provides an overview of principal ports and terminals / landing places in the Sava River Basin and accompanying key information; while more detailed data relevant to this Manual follow the table.

No.	Name		Country	River	Mileage (rkm) / riverbank	Type	Waterway class
1.	Sisak	Sisak port and warehouses	Croatia	Kupa	4.8/left	general cargo	III
2.		Passenger terminal Sisak	Croatia	Kupa	4.0/left	passenger	III
3.		Galdovo basin	Croatia	Sava	593.7/left	ship overhaul	III
4.		Oil terminal Crnac	Croatia	Sava	587.0/right	crude oil and oil derivatives	III
5.	Brod refinery cargo terminal		BiH	Sava	374.5/right	crude oil and oil derivatives	IV
6.	Slavonski Brod	Port of Slavonski Brod	Croatia	Sava	363.4/left	general cargo	IV
7.		Oil terminal Ruščica	Croatia	Sava	363.0/left	crude oil	
8.	Šamac	RTC Šamac port	BiH	Sava	313.0/right	general cargo	III
9.	Brčko	oil terminal	BiH	Sava	226.4/right	oil derivatives	IV
10.		Port of Brčko			228.4/right	general cargo	
11.		Passenger terminal			228.4/right	passenger	
12.	Sremska Mitrovica	Port of Leget	Serbia	Sava	135.7/left	general cargo	IV
13.	Šabac	oil terminal	Serbia	Sava	104.6/right	oil derivatives	IV
		Free zone			101.0/right	general cargo	
14.	Belgrade	Oil terminal Barič	Serbia	Sava	26.3/right	oil derivatives	Va
15.		Oil terminal Ostružnica			18.0/right	oil derivatives	
16.		Oil terminal of the Belgrade powerplant			5.0/left	oil derivatives	
17.		Passenger terminal			0.7/right	passenger	

Table 4: List of important ports and terminals on the

3.1.1 Sisak port and warehouses

Located on the left bank of the Kupa River, immediately upstream of the road bridge at the entrance to Sisak from Zagreb, the cargo port of Sisak was, until the 1990s, an important infrastructure facility where significant volumes of goods for the wider Sisak–Zagreb area were transhipped and stored. It is well connected to all major railways and roads, and it has its own shunting yard and a road-vehicle terminal. It also has a 170-metre vertical operational quay with a capacity to moor 4 vessels.

3.1.2 Passenger terminal Sisak

The passenger pontoon lies in the very centre of the town, on a regulated section of the left bank of the Kupa River, immediately in front of the harbourmaster's office, and can accommodate a large passenger vessel or several smaller (tourist) boats. The electricity supply is provided from the illuminated operational quay, which doubles as the main town promenade. A hotel, post office, police station, shopping centre and other facilities significant to crews and passengers are all located in the immediate vicinity.

3.1.3 Galdovo basin

The Galdovo basin is located at rkm 593.7 on the left bank of the Sava River; and essentially acts as a shipyard with overhaul facilities. The area of the Galdovo shipyard landing place is regulated under the Regulation on Designation of the Port of Sisak Port Area, which extends over an area of approximately 12 ha.

3.1.4 Oil terminal Crnac

Serving as the transshipment installation of the Sisak Oil Refinery, this oil terminal lies downstream of the Kupa River confluence on the right bank of the Sava River at rkm 587.0, and is dedicated exclusively to handling crude oil and oil products. It has two pontoons for transshipment of crude oil and one pontoon for transshipment of oil products.

3.1.5 Brod refinery cargo terminal

Serving as the transshipment installation of the Brod Oil Refinery, with its platform and ancillary structures, this terminal sits in the immediate vicinity of the oil refinery on the right bank of the Sava River, at rkm 374.5, and is dedicated exclusively to handling crude oil and oil products.

3.1.6 Port of Slavonski Brod

Situated downstream of Slavonski Brod on the left bank of the Sava River, at rkm 363.4, the port is organised as a modern freight logistics centre offering a wide range of services. According to spatial-planning documents, the port area belongs to an economic-production zone. It is connected by road and rail to international transport corridors as well as to economic operators of Slavonski Brod. The port is still in development, and currently stretches over 370 metres of vertical quay.

3.1.7 Oil terminal Ruščica

The oil terminal Ruščica, serving as a transshipment installation within the Adriatic pipeline system, and dedicated solely to handling crude oil, lies just several hundred meters downstream of Slavonski Brod, at rkm 363.0.

3.1.8 RTC Šamac port

With its geographic position, RTC Šamac port is a true example of an intermodal platform on the fairway, and its proximity to Corridor Vc and Corridor X, together with a good connection to the interior of Bosnia and Herzegovina, contributes to the recognition of this port as an important one for Bosnia and Herzegovina and beyond. Covering 58.8 ha on the right bank of the Sava River, at rkm 313.0, at the eastern entrance to Šamac, it offers a firm basis for further development of port services. The port has a 311-metre-long vertical quay, a basin with 150 metres of unfinished operational quay, 30,000 m² of open storage space, 3,600 m² of closed storage space, road and rail infrastructure, and mobile cargo handling / transhipment equipment. Anchoring and turning of vessels and convoys is made possible downstream of the port.

3.1.9 Port of Brčko

On the right bank of the Sava River, at rkm 228.2, the Port of Brčko, famous for its rich tradition of port services, occupies 14 ha in the very centre of Brčko and represents a significant potential and a respectable resource. Likewise, such an advantageous position also entails drawbacks in the form of limited opportunities for further development and problems related to traffic-access. Three anchoring points, arranged according to technological operations and types of goods, are located in the immediate vicinity of the operational quay. Operational quay length alongside an inclined quay is 104 m and 76 m alongside a vertical quay.

Four shunting tracks with a combined length of 2,586 m run next to the operational quay. A single-track railway section connects the port to the main railway station. The port has 61,000 m² of open storage and 11,000 m² of closed storage space.

3.1.10 Port of Leget

Port of Leget, owned by the company RTC, is located on the left bank of the Sava River, at rkm 135.7. It extends over an area of 80 ha and is positioned in the eastern part of the Sremska Mitrovica economic zone. An industrial railway track connects it with the Belgrade–Zagreb trunk line railroad. Port of Leget is equipped to provide handling and storage services for all types of goods arriving or departing via river, rail or road transport means. Goods are stored in public and customs warehouses, both of closed and open type. Closed warehouses cover an area of 20,000 m², while the open storage space extends over an area of 10 ha. The Port of Leget has a 100-metre vertical quay with a capacity to berth and load / unload all vessels navigating in the Danube Basin. A portal crane of 6,500-kg capacity stands on the vertical quay, and is capable of handling all types of general and bulk cargo. In addition, numerous forklifts and a 12.5-tonne mobile crane are also available for cargo handling purposes.

3.1.11 Free zone Šabac

The free zone Šabac, located on the right bank of the Sava River, at rkm 101.0, occupies an area of 47 ha within the free zone, and integrates road, rail and water transport. Cargo transhipment is presently suspended because depths at the basin entrance are insufficient for passage of vessels. With a water area of 4.5 ha and a basin, the site holds respectable potential. It can simultaneously accommodate 4 vessels and has the capacity to classify railway cars. The zone owns substantial mobile handling machinery and a 10,000 m² terminal, together with a 10,000-m² container-storage space. In addition, it includes a passenger terminal, 400 m of vertical quay plus 160 m of vertical quay at the basin head.

Storage capacity comprises of 22,000 m² of closed and 12,000 m² of open storage spaces, with an additional 5,000 m² of storage area designated for dangerous goods. The 7,000 m² free-zone area can accommodate provision of additional services, i.e., a customs office, weighbridge and all necessary ancillary facilities, which makes the site functional and attractive to users.

3.1.12 Passenger terminal Belgrade

The international passenger terminal is located on the right bank of the Sava River, stationed at rkm 0 + 750, in the immediate vicinity of its confluence with the Danube River (rkm 1171). Its exceptional position at the intersection of River Corridor VII and Land Corridor X makes the area an international traffic and transport hub, and the many attractions and rich tourist offer of Belgrade render it an extremely appealing tourist destination. The international Belgrade Nikola Tesla Airport is only 16.8 km away from the terminal.

3.2 INLAND WATERWAYS

Inland waterways include all water surfaces that can be used for navigation, such as rivers, lakes and canals. As a rule, the conditions for navigation on such water surfaces are generally secured within the designated fairway areas. The fairway in the Sava River Basin has already been defined in the first part of this Manual, so it will not be additionally elaborated here. Instead, focus will be put on its basic characteristics: width, depth, bend radius and river flow velocity.

An important and an indispensable part of the inland-waterway infrastructure is formed by safety-of-navigation facilities: floating signs and riverbank marks, navigation marks, winter harbours and winter shelters, anchorages, river-training structures that ensure that fairway dimensions remain unchanged, navigation locks, optical, acoustic, electrical, electronic, radar and other devices, etc. In the following text we shall address the most representative ones.

3.2.1 Winter harbours and winter shelters

A winter harbour is a safety-of-navigation facility consisting of a constructed or natural water area on the fairway that is arranged and equipped as a safe shelter, thus providing vessels protection from ice, high water levels or other unfavourable weather conditions.

A winter shelter is a natural part of the water area on a fairway, in a port, or other landing place, etc., which serves as an emergency shelter for vessels, protecting them from damage when ice, high water levels or other unfavourable weather conditions are imminent. The distance between winter harbours should not exceed 60 km, i.e., one day’s navigation during daylight hours.

Winter harbours and winter shelters on the fairway may be used on equal terms by all vessels, whereas vessels carrying dangerous goods must, in principle, use winter harbours specifically designated for that purpose.

Order in a winter harbour or winter shelter is laid down by the competent authority of the state in whose territory the winter harbour or winter shelter is situated, and the stay lasts for as long as the state of extraordinary circumstances is in force. Winter harbours and winter shelters may, at the ship's master's discretion, also be used outside the period of proclaimed extraordinary circumstances whenever this is required to protect and save human life, to safeguard the vessel and persons onboard, or to ensure the safety of navigation. Ship's masters, whenever possible, will notify the competent authorities of their intention to stay in a winter harbour or winter shelter, specifying the reason, location and time of stay.

Existing ports and terminals / landing places may be used as winter harbours and winter shelters.

General requirements required for defining winter harbours or winter shelters are:

- Location of the winter harbour or winter shelter;
- Systematisation (classification) of a winter harbour or a winter shelter by cargo type;
- Categorisation of winter harbours and winter shelters in accordance with the waterway class of the relevant sector;
- Marking of winter harbours and winter shelters.

Special requirements are defined by the competent authorities, and these refer to:

- Commanding authority at the winter harbour and winter shelter;
- Method of communication between vessels and shore;
- Vessel berthing (mooring) and anchoring method;
- Method for reception of waste and other substances;
- Fire protection, sanitary facilities with running water, ensuring provision of electricity supply;
- Access route.

Overview of winter harbours and winter shelters on the waterway

No.	Type	Name	River	Mileage (rkm / riverbank)	Total capacity / for tankers	Waterway class
1.	Winter harbour	PRELOŠĆICA	Sava	582.0/left	18/8	III
2.	Winter shelter	STARA GRADIŠKA	Sava	466.4 – 466.9/ left	8/0	III
3.	Winter shelter	PIVARA	Sava	461.0/right	5+1/0	III
4.	Winter shelter	DAVOR – Matura	Sava	428.7 – 429/ left	12/0	III
5.	Winter shelter	DAVOR – Lazine	Sava	424.5 – 425.8/ left	39/39	III
6.	Winter shelter	SL. BROD – Viseći most	Sava	374.9 – 375.5/ left	24/4	III
7.	Winter shelter	BROD	Sava	370.1 – 370.7/ right	20/0	IV
8.	Winter shelter	SL. BROD – Poloj	Sava	365.8 – 366.3/ left	16/16	IV
9.	Winter shelter	SL. ŠAMAC	Sava	315.5 – 316.2/ left	21/0	III
10.	Winter shelter	ŠAMAC	Sava	310.0/right	15/0	IV
11.	Winter shelter	VUČJAK	Sava	306.6 – 306.9/ left	12/12	IV
12.	Winter shelter	ŠTITAR	Sava	286.1 – 286.3/ left	8/0	IV
13.	Winter shelter	ŽUPANJA	Sava	261.6 – 261.9/ left	15/6	IV
14.	Winter shelter	GUNJA	Sava	228.1 – 228.6/ left	10/4	IV
15.	Winter shelter	BRČKO	Sava	228.1 – 228.5/ right	8/0	IV
16.	Winter shelter	RAČA	Sava	179.95 - 180.35/right	5/0	III
17.	Winter shelter	S. MITROVICA	Sava	134.6 – 135.4/ left	10/4	IV
18.	Winter shelter	PROVO– KAMIČAK	Sava	82.25 – 85.65/ right	25/25	IV
19.	Winter shelter	SKELA	Sava	55.9 – 57.5/ right	10/4	Va

Table 5: List of winter harbours and winter shelters on the Sava River

3.2.2 Hydraulic structures

General characteristics of free-flowing rivers

To address the problems of navigation, basic information on free-flowing watercourses must be provided from a navigational standpoint.

In general, a river course consists of bends interspersed with shorter straight sections. Unlike sea or lakes, a river has a current or flow, a force that directly affects navigation. River flow velocity depends on two most important factors: the gradient (slope) of the riverbed and the flow volume of water. Since the riverbed gradient is constant, any increase or decrease in river flow velocity depends on the increase or decrease in the flow volume of water, i.e., on water level oscillations.

The velocity of river flow is not uniform across the cross-section. It is greater at the surface and towards the middle of the river, and lower near riverbanks and the riverbed. As a rule, the greatest velocity (main current) corresponds to the greatest depth. In addition to the longitudinal flow, there are also transverse currents and circular movements (eddies and limans). These arise in places in which depth or width changes abruptly, due to submerged obstacles, river overfalls, etc. For example, when the river meets a “corner” — “elbow” (a place where it makes a sharp bend and the riverbank juts into the river), a part of the water mass abruptly turns in the opposite direction along the riverbank, creating the impression that the river “flows upstream”.

Adverse effects of river currents on navigation are reflected as follows:

- The speed of upstream navigation is reduced by the velocity of the river flow;
- Downstream navigation can be jeopardised if the force of the current is not taken into consideration during manoeuvring activities. For example, for the vessel to berth safely while navigating downstream, the vessel must turn and position itself for upstream navigation. In that manoeuvre, the current velocity and the width of the water surface must be taken into account for the turn to be completed successfully. The manoeuvre must be executed in time so that the vessel reaches a favourable position relative to the berth. Namely, with strong currents and low engine power, a vessel may, after completing the turn, find itself well downstream from the intended berth point.

- In case of engine failure, the vessel is carried by the river current with a risk of an accident and risking collision with other vessels, rocky riverbanks, bridge piers, etc. To prevent this, a back-up propulsion engine (if available) is activated, the anchor is dropped, or the vessel is rowed toward the riverbank and, at the moment of contact with the riverbank, the vessel is secured and moored.

Riverbanks

A *concave* riverbank is the outer bank of a bend, followed by a greater depth and higher water flow velocity. The main current flows closer the concave riverbank.

A *convex* riverbank is the inner bank of a bend. Currents flowing alongside it are always weaker, causing sediment deposition and shallower depths compared to concave riverbanks.

Left and *right* riverbanks are determined facing downstream, viewed always from the source towards the mouth / confluence, whereas river length is measured and marked from the mouth / confluence towards the source and expressed in kilometres.

River sediments, river islands and shoals

Watercourses carry huge amounts of sediment (soil, gravel, sand, silt, limestone). When the current's pulling force is not sufficient to keep the sediment particles suspended in the river, the sediment settles on the riverbed. The sediment created by erosion of the concave riverbank is carried in two directions — one towards the opposite convex riverbank, and the other along the riverbank that it affects, settling at its protruding section. When water level changes during high waters, the sediment is carried away and deposited elsewhere (so-called “shifting shoals”), and at places where shoals were previously located, depths emerge, and vice versa.

If the riverbed, where the main current shifts from one riverbank to the other, is wide, the power of the water significantly weakens (river flow velocity decreases), so a larger portion of the sediment settles in the river’s mid-section, creating transverse shoals, which later form river islands, dividing the river course into branches.

The sediment also settles along the straight sections of the river near the riverbank, where the water is calmer. The largest sediment deposits occur at river mouths and confluences.

Shoals in the riverbed can also form when the waterborne mass encounters any type of obstacle, whether natural or artificial, resulting in the water to lose velocity and power, thus leading to even greater sediment deposition.

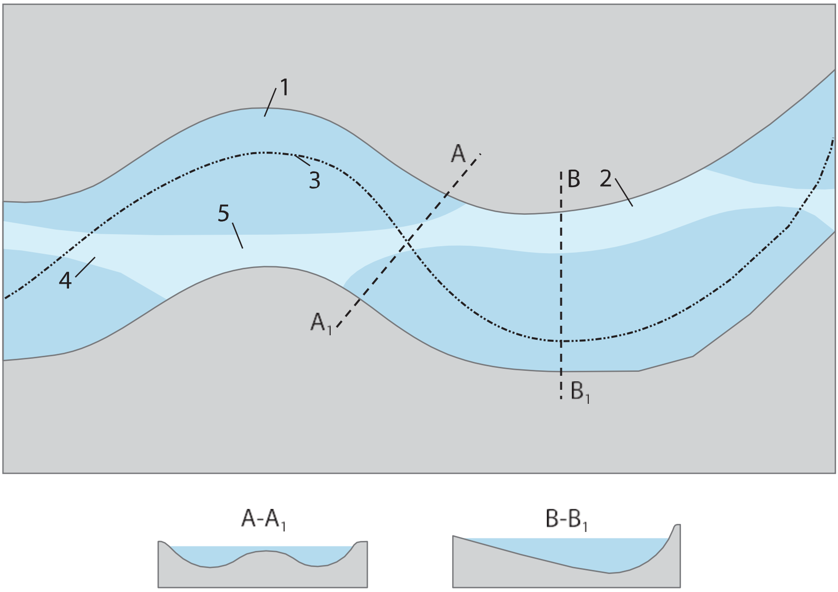


Figure 2: Sketch of a river section with shoals in horizontal projection and cross-sections: A-A, at the crossing, and B-B, when the main current runs along the concave riverbank. 1 – high concave riverbank; 2 – low convex riverbank; 3 – fairway axis; 4 – transverse shoals; 5 – shoals

River training for navigation purposes

Water action in a riverbed causes constant changes both in the riverbed and along the riverbanks. This is primarily reflected in the failure of riverbanks, which endangers the protective embankments, uncontrollably carries sand, gravel, and other materials, and creates new shoals. Actions of all these factors result in fairway shifts, and changes to its basic dimensions — width and depth.

The aim of river course training is to create and maintain depths, widths, and bend radii within the limits that ensure safe navigation. River-training works carried out for navigation purposes are typically part of the general regulation of riverbeds, thus contributing to flood protection, preventing ice accumulation, or eliminating the risks of so-called “ice floods” and other harmful water impacts.
In other words, the goal of river training is to stabilise the riverbanks and shape the riverbed for navigation purposes.

Measures implemented for regulating natural watercourses for navigational purposes can be very different and can generally be grouped into:

- Riverbed training; and
- Channelization of the river course.

These measures are also often used in combination.

Riverbed training for navigation purposes is executed with the aim of forming a secure fairway of specific dimensions at low navigation water levels (LNL).

River-training activities can be categorised into three types:

- *Biotechnical measures*, when, for example, various types of vegetation are used for protection of riverbanks against failure;
- *Dredging works* executed in the riverbed for excavation, clearance and maintenance of fairway dimensions; and
- *Fairway regulation*, involving traditional river-training works and structures.

These river-training measures can be applied individually or in combination.

Riverbed training for navigation purposes implemented through river-training structures and works is most commonly applied in inland waterways. In the training of natural watercourses for navigation purposes, direct application of river-training structures in the riverbed, and works to widen river bends (meanders), are also involved. River-training structures are used for:

- Protection of against riverbank failure;
- Construction of new riverbanks;
- Reduction of the curvature, i.e., increase of the radius of bends;
- Closure of branches;
- Deepening of narrow riverbeds at low water levels using the riverbed gradient, thereby increasing the river's cross-sectional flow profile;
- Stabilisation of the riverbed.

River-training structures can be made of stone, sand, willow branches, twigs, unreinforced and reinforced concrete, various types of wire, galvanised wire mesh, plastic films filled with sand, etc.

Revetments (bank protection structures) are structures built along concave riverbanks, which are prone to failure due to the action of water currents in bends. Reinforcement of riverbanks prevents riverbed shifting. Revetments are most commonly made from gravel and crushed stone, or of concrete blocks on a gravel base.

Many different types of revetments are used in hydraulic engineering. They can be divided into vertical and sloped structures.

Vertical structures must transfer horizontal loads to the ground, whereas in the case of sloped structures, the ground takes over such loads directly (addressing the stability of slopes). Vertical structures are further divided into two basic groups, also with regard to the transfer of horizontal forces. The first group includes gravity-based structures, where horizontal loads are transferred to the ground through the structure's own weight. There are no tensile stresses occurring within the structure itself. The second group includes types where horizontal loads are transferred through internal forces occurring within the structure.

Figure 3: Vertical gravity-based revetment made of gabion mattresses / baskets

Sloped revetments are generally categorised by their cladding type. The most common cladding material is stone in various forms:

- Riprap (stone protection);
- Hand-laid cladding (rolling);
- Mortared stone cladding;
- Stone blocks bonded with asphalt mastic;
- Stone-filled gabions.

Figure 4: Sloped revetment with crushed stone cladding.

Due to their simple construction and competitive cost, sloped structures are the most commonly used solution for riverbank protection. Each sloped revetment has two essential constitutive elements that characterise it. These are used to counter the action of hydrodynamic forces of water. They are: cover layer and toe protection.

Guide bunds are also used for training of concave riverbanks, particularly at those sections where structures should be placed on the riverbed, in order to reduce the river bend radius. They can be made of stone or sand-filled bags, on a base made of crushed stone or fascine mattress (fascine - bundle of willow twigs). The body of a guide bund is connected to the riverbank by traverses, thus creating inter-traverse fields. In these, the velocity of the water mass that overflows the traverses is reduced, which increases the sediment deposition rate and prevents water from flowing between the structure and the riverbank. This accelerates development of new riverbanks. Guide bunds can also be applied in river-training of straight sections if it is necessary to narrow the riverbed or to increase the depth. In such cases, these structures are simultaneously built on both the left and right riverbank.

Figure 5: First guide bund on the Sava River.

River groynes are the most common used type of structure. As a rule, groynes are constructed on convex riverbanks, but can exceptionally be constructed at straight river sections as well. Groynes are built exclusively in series. Their function is two-fold: they narrow the riverbed, increase the riverbed gradient, depth and flow capacity with regard to sediment transport, and, on the other hand, they cause sediment deposition between the groyne fields. During periods of medium and high water levels, water flow over the groynes loses its velocity, i.e. its power for sediment transport, and the material it carries is deposited in groyne fields, which results in the formation of a new riverbank. If the convex riverbank is protected by groynes, the opposite concave riverbank must be protected with a revetment or guide bunds.

Groynes and guide bunds are often competing solutions for the same purpose. Each has its own advantages and disadvantages. Consequently, guide bunds have an advantage over groynes due to the uniform flow along the structure, as the continuously defined regulation line prevents local erosion in the riverbed, and sediment transport is uniform along them. The disadvantages of guide bunds include the following: high construction costs, difficult and expensive error correction / repairs, difficulties during execution due to problems with foundation works in deep water, slow filling of the old riverbed and the need for a sturdy toe of the structure. What are disadvantages for groynes, are advantages for guide bunds

Figure 6: Groynes on the Sava River –
Rača sector (top) and Skela (down)

and vice versa. Consequently, groynes have the following advantages: easy adjustments and error correction, efficient filling of the old riverbed, and lower construction costs. The disadvantages of groynes are the occurrence of a transverse flow in the riverbed, frequent damage during periods of high water levels (overflows), and the point-like definition of the regulation line (as opposed to a continuous one). Special types of river-training structures have also been developed, such as the "hockey stick" and "T-head" groynes. These are a combination of longitudinal structures and groynes, where the groyne head is completed by a part of the longitudinal structure (guide bund). These technical solutions help avoid the greatest disadvantages of traditional groynes, such as the point-like definition of the riverbank and the occurrence of transverse currents in the riverbed.

Weirs play a significant role in training of rivers, which are characterised by numerous branches and waterway bifurcation. After selecting the river branch that will be used for navigation, other branches are closed-off with weirs, thus concentrating the flow of water into one river branch. Similarly, weirs are used to close-off abandoned branches after the construction of cutoff.

A river bend cutoff was once a very common river-training measure on rivers with sharp bends. A cutoff starts with the development of a new riverbed that is suitable for navigation and shortens the river's course, and is used at sections where a natural meander should be shortened for navigation needs, increasing watercourse flow, or for other purposes (e.g. establishment of an inland port or winter harbour).

The location of the cutoff (or channelization) is accompanied by a combination of river-training structures. They include revetments in the riverbed, upstream and downstream of the cutoff, stone deposits at the cutoff itself, a cutoff channel as a main channel and weirs. The following figure shows an example of a cutoff.

Figure 7: Cutoff example - Prelošćica on the Sava River

Revetments prevent the occurrence of adverse changes on the beds of watercourses, before and after the cutoff. The new channel, as a main one, is constructed as a channel reaching up to the level of the underground water, and is always routed closer to the convex (inner) bend of the riverbank. Deposits are used to control the spread of the cutoff and limit it to the designed width. Weirs are constructed both upstream and downstream of the cutoff, or only on the upstream section, depending on whether the abandoned riverbed is to be used for other purposes (e.g., port) or not. They are constructed only after the new riverbed is almost completely developed, i.e., once it is developed enough to allow water, sediment, and ice to flow through it without hindrance (so as not to cause excessive water deceleration and potential flooding upstream of the cutoff). Weirs accelerate the final formation of the cutoff, but they are usually constructed in phases (either by height or length), so that large water waves can still pass through the old riverbed during the formation of the new one. Cutoffs require relatively extensive works in the watercourse, resulting in changes in the flow regime, sediment transport regime and changes in the geometry of the riverbed, not only at the location of the cutoff, but in the wider area as well.

Figure 8: Confluence of the Drina River

Confluence / mouth engineering is carried out in a bend and on the concave bank of the main stem, thus providing the most efficient mixing of waters from both watercourses, followed by adequate transport of sediment and ice. For the confluence / mouth to remain permanent, it must be reinforced with appropriate river-training structures, most often revetments. Problems arising during tributary confluence / mouth training are hydrological and hydraulic in nature. They include the flow regime of tributaries, the flow regime of the main stem (parent river), mutual relation of the aforementioned two regimes (problems of coincidence of high waters, propagation of a flood wave) and the characteristics of the tributary with regard to flashiness. Changes in water level of the main stem cause deceleration or depression in the tributary. Deceleration causes the occurrence of sediment depositions in the tributary, while in the case of depressions, erosion of the tributary bed and sediment deposition downstream of the confluence / mouth in the main stem is to be expected. If high water levels of tributaries cause deceleration in the main stem, sediment deposition upstream of the confluence / mouth in the main stem should be expected. When the water wave of the tributary decreases, increased velocities in the main stem can be expected, with pronounced erosive action and sediment deposition downstream of the confluence / mouth.

When river-training structures represent a navigation hazard due to low water levels, they are marked with riverbank marks and floating signs. Heights

Figure 9: Ship lock

of guide bunds, traverses and groynes are determined based on altitude. Namely, their top end ("a crest") is at the level of the minimum navigable level plus one metre. Since all water gauges have defined minimum navigable water levels, it is possible to determine the water level at which the upper end of the structure or groyne will emerge for each relevant water gauge. Since small vessels navigate outside of the defined fairway, these data are crucial for them. Based on the aforementioned, it is always possible to determine the water depth at the location of these structures, i.e., to ascertain whether and to what extent the structures are above water. Weirs closing individual river branches are, as a rule, set at the same elevation as groynes and other river-training structures. However, some weirs are constructed at a higher elevation than the other river-training structures (usually one metre) due to reasons of a hydrotechnical nature. Some weirs have shorter bodies and lower crest elevations, allowing smaller vessels to pass through during periods of low water levels.

Channelization of the river involves dividing it into one or more profiles with artificial barriers – dams, which significantly change its hydrological regime contributing to favourable navigation conditions. Impoundment / channelization of the river creates a discontinuity in the water surface level (difference in upper and lower water levels), which vessels overcome using ship locks, cranes or water slopes.

Application of new river-training measures in waterway regulation

In recent years, discussions regarding European rivers have intensified, focusing on the protection of river ecosystems and natural landscapes. A key objective of the EU Water Framework Directive is to prevent further deterioration and protect and improve the status of aquatic ecosystems. Furthermore, discussions on river protection, considering the need for continued economic development, have led to a growing understanding of the need to harmonize the interests of economic development and environmental protection during future fairway improvement activities.

In this context, the Joint Statement on Guiding Principles for the Development of Inland Navigation and Environmental Protection in the Danube River Basin, adopted in 2007 by the ICPDR (International Commission for the Protection of the Danube River), the Danube Commission, and the International Sava River Basin Commission (ISRBC), was drawn-up as a key tool to guide the process of planning and implementation of projects on inland waterways.

The objective of the Joint Statement is not merely to avoid environmental harm, but — through the application of ecological engineering solutions, i.e., eco-engineering — to improve the current status of aquatic ecosystems. As assistance to all those involved in the design, construction, and maintenance of fairways within the EU project PLATINA, the PLATINA Manual on Good Practices in Sustainable Waterway Planning was developed, which, among other things, contains examples of applying so-called eco-engineering. One example of applying eco-engineering (according to the PLATINA Manual) in fairway regulation is the construction of so-called declining groynes (groynes that are detached from the riverbank), which represent a very high-quality solution from an environmental protection standpoint, guided by the idea of reducing the impact on the aquatic ecosystem, especially with respect to sediment deposition.

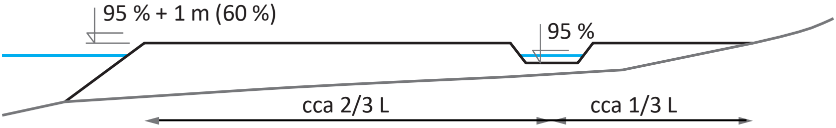


Figure 10: Declining groynes
(ref. *Applied River Engineering Centre web-site)*

The application of eco-engineering also includes returning excavated river sediment to the watercourse at suitable upstream locations, and the construction of declining groynes separated from the riverbank allows for the following: fish migration in the near-shore area, reduction of sediment deposition around the groynes, and a reduction in the formation of terrestrial habitats in the riverbed section between the groynes.

Likewise, as an additional example of good practice, or a mitigation measure (according to the PLATINA Manual), during the construction of declining groynes, placement of wooden logs behind every 3 to 4 groynes can be noted. In this way, the flow of water over and around the logs creates pools that provide additional shelter and resting places for fish, thereby increasing micro-habitat diversity, while erosion is localised between the riverbed and the riverbank. Such solutions have rarely been applied in Europe, but their application in the training of critical sectors on the Sava River (e.g., Jaruge – Novi Grad) has recently commenced, as an attempt to reconcile the interests of fairway regulation and environmental protection.

3.3 MARKING THE WATERWAY / FAIRWAY

The connection between navigation regulations and the necessity for safe passage is expressed through internationally standardised rules for navigation marking infrastructure broadly. The fundamental requirement for this markings is to ensure, throughout the navigation season, the safety of vessels and the continuous flow of traffic both by day and by night, as well as to provide shipmasters with clear and unambiguous indicators regarding the direction and boundaries of the fairway.

In terms of the objective pursued, the marking system comprises of two categories of signs:

a. Signs used to regulate navigation on the waterway, and
b. Signs and signals installed on the waterway.

In addition to these marks, the fairway is marked with kilometre marks and, when required, the fairway can be additionally marked every hundred metres. All signs, which are prohibitory, mandatory, restrictive, recommendatory, informative and auxiliary signs, are set out in Annexes that constitute an integral part of the Navigation Rules on the Sava River Basin.

During navigation, vessels' crew members shall obey the requirements and take into account the recommendations or indications brought to their attention by these signs. Combination of floating signs and riverbank marks are used to indicate the limits, the direction and the depth of the fairway and, in addition, to mark obstacles and permanent structures on the fairway or in its vicinity. The number of signs, bank marks, floating signs and their on-site location shall meet the requirements of navigational safety. The selection of marks and the determination of their number depends on the local characteristics of the fairway and the function of the mark. They are installed in such a way as to ensure visibility from one mark to the next.

The luminous range of lights and their colours should be kept with the standard of the International Commission on Illumination (**CIE** "Colours of light signals" S 004/E-2001, class A).

The marking system shall be installed by the specialised competent authorities that are obligated to:

a. Regularly observe the state of the riverbed and the changes taking place in it, and, on the basis of the results of these observations, correct the positioning of the signs and marks and, where necessary, add new marks so that they indicate fairway dimensions;

b. Regularly measure the depth and the width of the marked fairway and provide the ship's masters with necessary information regarding minimum fairway depths, widths and river water levels;

c. Establish a plan for the installation of signs and marks in their respective sectors and establish the type and number of floating signs and riverbank marks to be used, in terms of the requirements of navigational safety and local conditions;

d. Ensure, as far as possible, the uninterrupted operation of all floating signs and bank marks;

e. Inform ship's masters in a timely manner of the date of installation and removal of signs, of all alterations of importance to navigation to their number, type, positioning and lighting, and of the rules they establish for the purpose of permitting passage of vessels in restricted sections where meeting and passing are prohibited.

3.3.1 Requirements to be met by signs and marks and their Marking Plan

The marking system shall, as far as possible, be continuously (by day and by night) in operation all along the navigable section of the river, and when the waterway is free from ice until its occurrence; Likewise, corrections on the fairway will be implemented in cases of water level fluctuation.

In accordance with the state of the fairway, the marking system shall be positioned in such a way that the vessels sailing downstream can use the part of the river with high flow velocities, while the vessels sailing upstream can use the part of the river with low flow velocities.

During periods of high water levels and icing, regular floating signs, which are removed with the aim of preserving them from possible damage, shall be replaced, as far as possible, by marker posts and spars, the topmarks and colours of which shall correspond to those adopted for the respective side of the fairway.

Riverbank marks serve to guide the ship's masters and to indicate the direction of the fairway. Floating signs supplement the riverbank marks in sectors where, in order to ensure the safety of navigation, it is essential to indicate not only the direction of the fairway but also its limits, and to mark places where obstacles are present.

If there is a subsequent drop in water level, reconnaissance soundings shall be performed on some sections of the river in order to check whether the positioning of the signs is adequate and to establish whether the marking needs to be supplemented by new signs. The frequency of these soundings shall be determined by changes in water level. The more rapid the drop in water levels, the more frequent soundings need to be.

3.3.2 Visibility of signs and lights

Regardless of the position of the vessel in relation to the sign or the marker light, the characteristics of the sign or light shall remain unchanged. For daytime signs, these characteristics are: form (topmark) and colour; for night-time signs: type and colour of the lights.

The forms and colours of topmarks, and types and colours of the lights, are set out in detail in corresponding Annexes to the Navigation Rules on the Sava River Basin; while sketches of the signs and marks with minimal dimensions can be found in special rules regulating the obligation and manner of fairway marking.

The basic requirement to be met by signs and marking is the guarantee of good visibility of all signs and lights by day or night. There are three degrees of visibility of signs and marks:

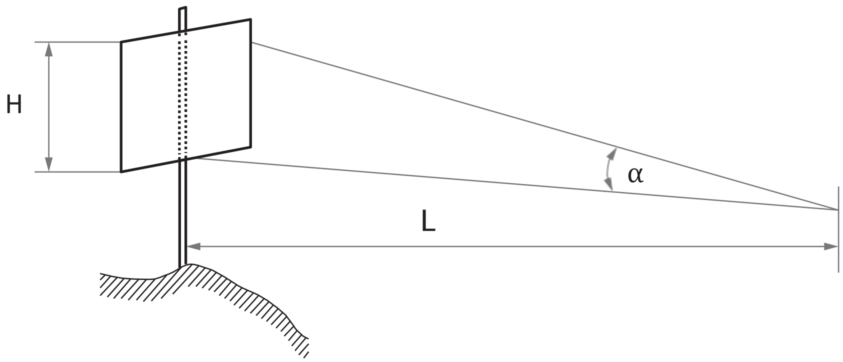
a. The sign is visible to the naked eye;
   The meaning of the sign is not yet identifiable (simply visible);

b. when the sign is clearly visible and identifiable according to Navigation Rules on the Sava River Basin (identifiable);

c. The sign is identifiable and distinguishable from its surrounding background (conspicuous).

The minimal angle of distinction in daytime for simple shapes (cylinder, cone, sphere etc.) is between 3 and 5 angular minutes, and for complex shapes (numbers, letters, etc.) between 5 and 8 angular minutes. For the ship's master to be able to recognize the daymark (without any optical aids) at appropriate distances and visibility, the following formula can be used for the calculation of required minimum dimensions of simple and complex shapes:

$H = L \cdot tg\ \alpha \cong L \cdot \sin \alpha$	H (m) – height of the sign; L (m) – distance; α (°) – viewing angle.



Signs and signals used in the Sava River Basin, unlighted buoys and unlighted riverbank mark boards shall be covered with reflective material. Light buoys and lighted riverbank mark boards may also be covered in the same manner and with the same material. The colours of these materials shall correspond to those established for the buoy lights or the boards. In all cases, the topmarks of light buoys shall be covered with reflective paint or material.

The visibility of signs and marks regulating navigation on the fairway shall be ensured at night by lighting them with fixed directional white lights, operating uninterruptedly and positioned so that the light does not incommode the ship's masters. If electric lighting is used, the sign boards are usually covered with reflective material of a corresponding colour.

It can often be observed that, in addition to markings, e.g., lower parts of bridge structures and their piers, approaches to locks, sections of canals, etc. are also illuminated. Luminous intensity is regulated under applicable EU Directives.

For night navigation purposes, solar navigation lanterns have recently come into use as part of modernisation of fairway-marking systems. Such a marking system significantly enhances navigational safety thanks to better visibility of the signals on the fairway. Solar navigation lanterns contribute to a substantial reduction in maintenance costs, and their use has no adverse environmental impact.

Figure 11: Solar navigation lanterns (ref. *Plovput web-site*)

3.3.3 MARKING OF CHARACTERISTIC RIVER SECTORS

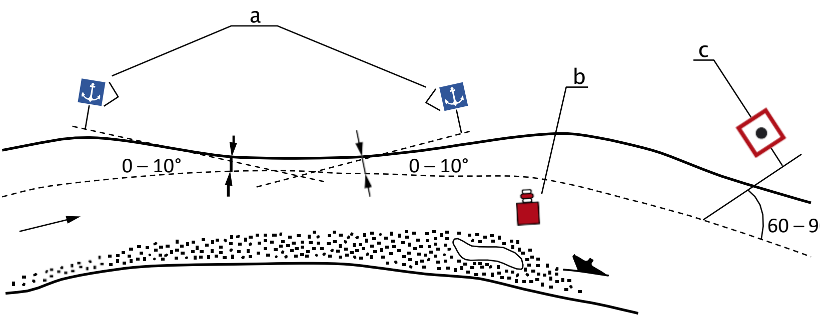
Signs have two possible orientations, namely:

a. Parallel to the axis of the fairway;

b. Perpendicular to the axis of the fairway.

Signs of type (a) are predominantly prohibitory or indicative signs, and are placed on the side of the fairway to which the prohibition or the indication applies.

Riverbank marks, which are used in relation to navigation in both directions (upstream and downstream), shall be oriented as described under (a). Most signs are positioned as described under (b), and generally do not apply only to one side of the fairway. These signs are erected at right angles to the axis of the fairway so that they are visible to vessel users. Riverbank marks, which are used in relation to navigation in one direction (upstream or downstream), shall be oriented as described under (b). In some cases (better visibility), the angle between the mark and the axis of the fairway cannot be less than 60° (Sketch 1, sign c).



Sketch 1

As a rule, lighted or unlighted buoys shall be used to mark the upstream and downstream extremities of sills, riverbanks that narrow the fairway in meandering sectors, riverbanks protruding into the fairway, piles of stones, reefs, water supply engineering structures, and underwater hazards or obstacles (sunken vessels, anchors, etc.).

Marker posts and spars shall be used as additional signs supplementing buoys in order to provide a clearer indication of the limits of the fairway over difficult hazards and in order to mark underwater obstacles. In some cases, and in some sectors, buoys may be replaced by marker posts or spars.

On sectors of the river intended for daytime and night-time navigation, forks, junctions and the axis of the fairway, along with obstacles to navigation lying within the fairway, shall be marked by light buoys or riverbank marks and lights. Floating signs shall be installed at such a depth and at such a distance from the obstacle so that the safety and ease of movement of vessels shall be guaranteed at night and in poor visibility. On sectors where the riverbed is narrow, preference shall be given to bank marks.

3.3.4 Marking of meandering sectors

Installation of cross-over marks and riverbank lights

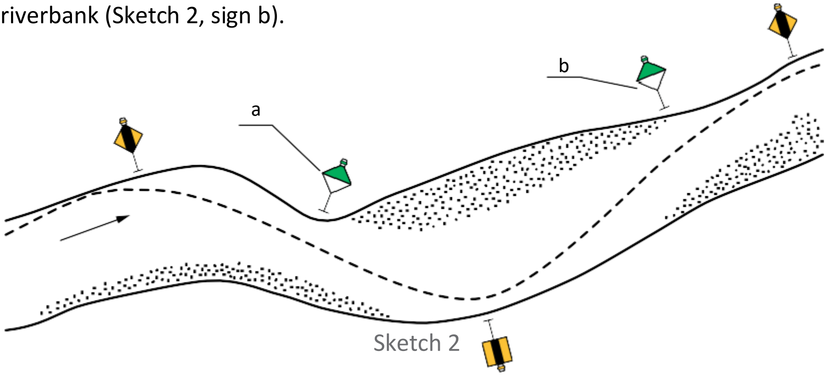
Cross-over marks and bank lights may be used in meandering sectors in order to indicate that the fairway crosses over from one riverbank to the other. Meandering sectors are marked with cross-over marks and bank lights when the fairway is sufficiently broad, when its safety is ensured, and when the direction only requires to be indicated approximately.

Riverbank lights and cross-over marks shall be selected in such a way so as to differentiate cross-overs in terms of their length, in other words, in terms of the distance between two neighbouring signs. The length of the cross-over is relative, since it depends on the width of the fairway.

Cross-over marks and riverbank lights provide the best results on distances up to 3 km. On such sections, cross-over marks and riverbank lights (without floating signs) can be placed under conditions where the available width for navigation is more than two times wider than the minimum width prescribed for the fairway in a particular sector. If the available width for navigation is less than the minimum width prescribed for the fairway, cross-over marks and riverbank lights (without floating signs) cannot be placed at a distance greater than 1.0 – 1.5 km

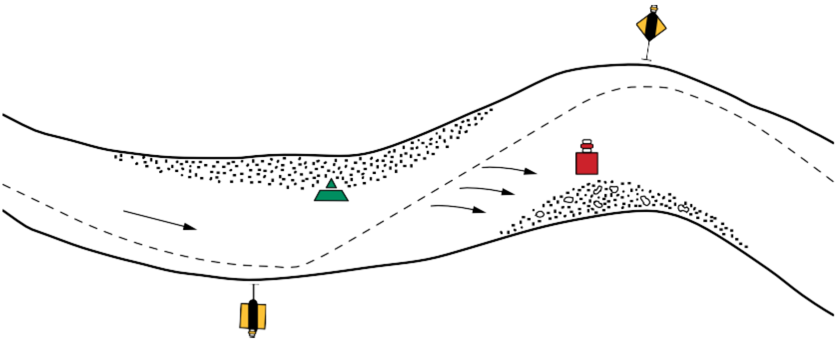
If the distance between two neighbouring cross-over marks exceeds the calculated visibility, and when the fairway passes close to the riverbank, a riverbank mark with lights, which additionally marks the position of the fairway, is to be placed between those two neighbouring cross-over marks (Sketch 2, sign a).

The riverbank mark with lights is also placed when the fairway passes near the riverbank (Sketch 2, sign b).



Sketch 2

When the direction of the main current is at an angle to the fairway, in case of strong side winds or when a similar situation occurs, the fairway can be marked by additional navigation marks according to local conditions (Sketch 3).

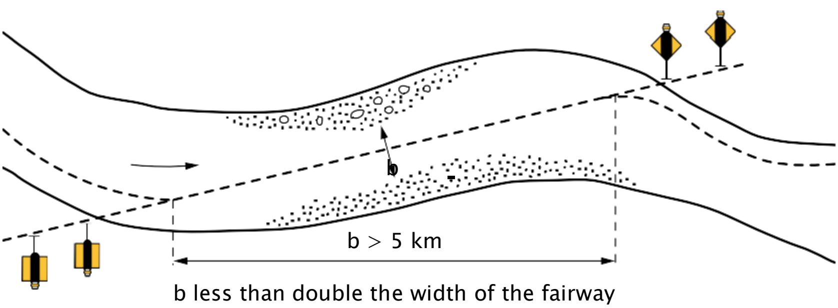


Sketch 3

When the fairway follows the middle of the riverbed over a long distance or it crosses abruptly from one riverbank to the other, its axis may be indicated by a pair of cross-over marks on each side of the fairway, as shown in Sketch 4.

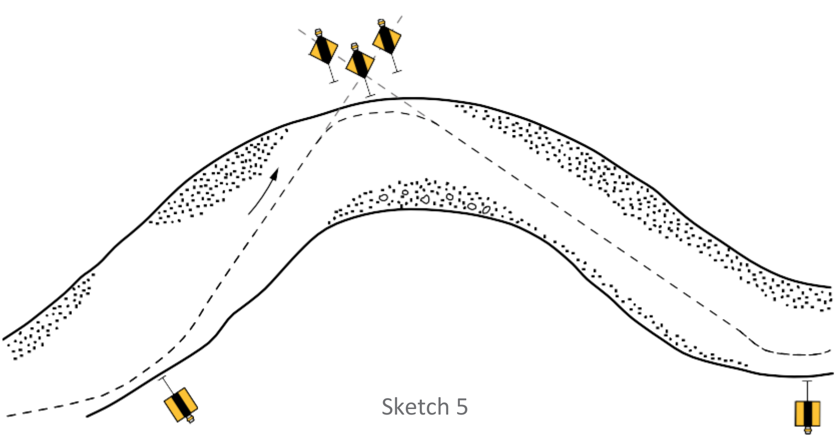
The advantage is given to cross-over marks on each side of the fairway in case of straight-line sections longer than 5 km, where the available width for navigation is less than double the value of the minimum width prescribed for the fairway in a particular sector. In that case and when the riverbank configuration allows it, the cross-over marks are placed on both margins of transition (Sketch 4).

When the fairway is narrowed by certain obstacles constituting threats to navigation or other hazards marked by floating signs, it is always preferable to have two cross-over marks on each side of the fairway.



Sketch 4

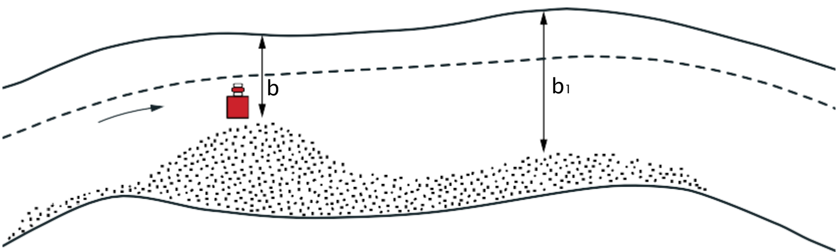
In sectors where the fairway, immediately after moving to the opposite riverbank, abruptly crosses once again to the other riverbank, three cross-over marks (the front shall have two boards) must be placed (Sketch 5). In that case, lights of the back cross-over marks shall be oriented strictly along the axis of the fairway: one upstream and the other downstream.



Sketch 5

Installation of floating signs

In meandering sectors, where the fairway passes along the middle of the riverbed, or along the riverbank or passes slowly from one riverbank to the other, floating signs are used to mark formations in the riverbed or obstacles (both natural and artificial) on the sides of the fairway (riverbanks, shores, islands, stones, sunken vessels, wrecks of bridges, etc.), when these obstacles protrude into the fairway and reduce its width (Sketch 6).

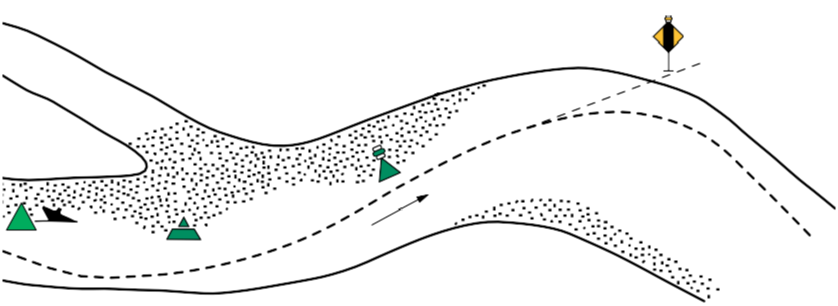


b < double width the fairway; b_1 < double width the fairway

Sketch 6

These underwater obstacles are marked in meandering sectors by floating signs if, within the limits of the width indicated above, the depth of water over such obstacles does not exceed the minimum depth reported for the sector. If the obstacle is not too wide, a floating sign with light shall be installed on its upstream section. A marker post or a spar may be installed on its downstream section, depending on its length.

Floating signs marking the underwater obstacles of considerable length are installed in such a way that the parts situated closest to the fairway are marked by light signals, between which unlighted signs are placed, thus enabling a given obstacle to be marked completely (Sketch 7).



Sketch 7

In parts of the riverbed where the opposite shore, followed by the fairway line, is bordered by an inshore bank that favours upstream navigation in calm water, the riverbank is marked by floating signs independently of the width of the riverbed.

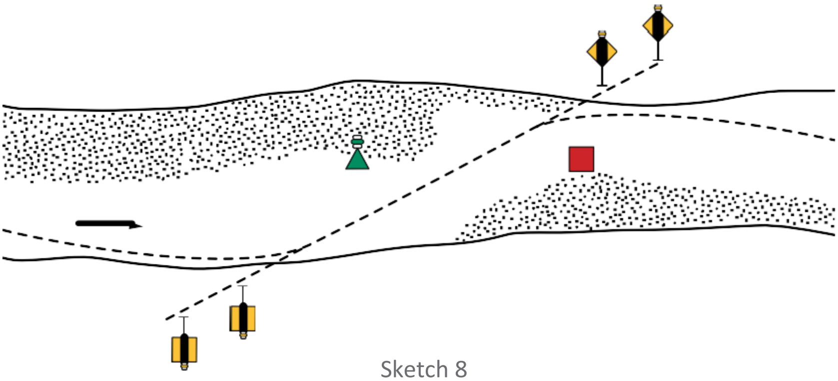
In meandering sectors, the riverbank marking system generally remains the same in periods of high water as in periods of lowest water levels, except in sections where, when water levels are high, it is advisable to find another fairway with better navigational features. In this case, the selected fairway shall be marked appropriately.

Marking of shallows

In shallows, as in other sections, the principle of continuous marking of the direction of the fairway, shall be applied.

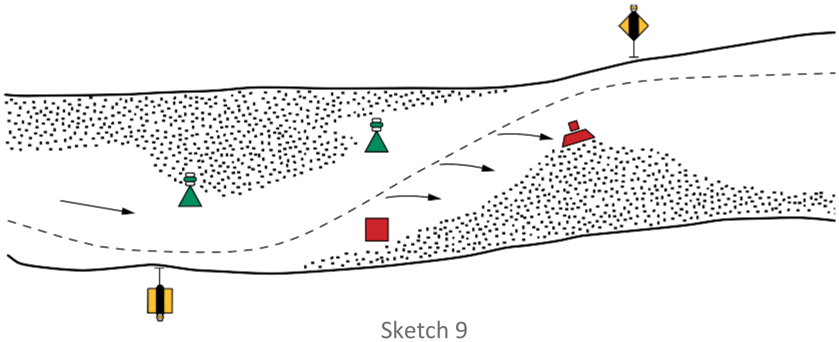
In shallows, the fairway can be marked by riverbank marks and floating signs.

Alternately located shallows may also be marked by cross-over marks, with sufficient available width for navigation in which vessels are able to pass through them in a straight-line manner (Sketch 8).



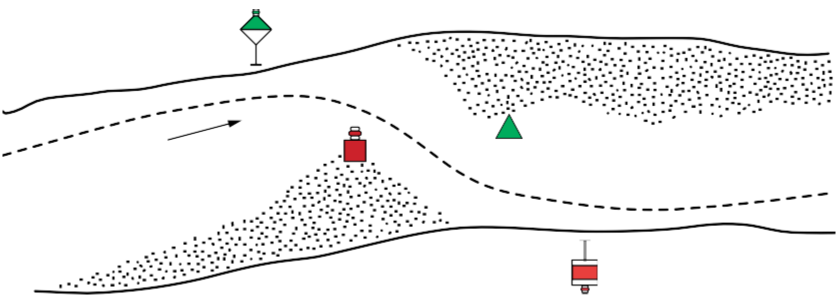
Sketch 8

A fairway passing over shallows is usually marked by floating signs (Sketches 8 and 9).



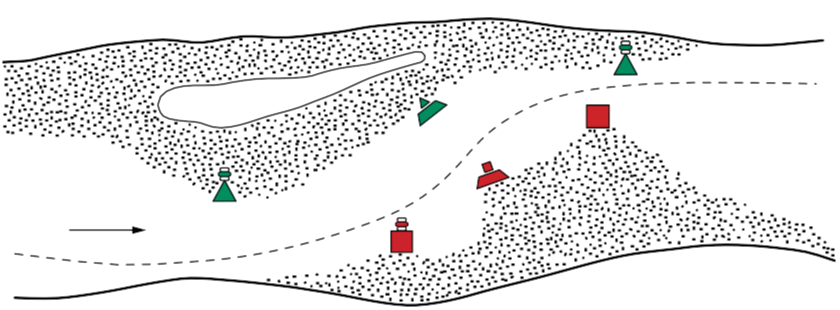
Sketch 9

If the fairway passes in a straight line between sandbars, reaching far into the riverbed, it is necessary to place at least two floating signs at the entry and exit of such a section: one at the top of the upstream and the other one on the top of the downstream sandbar (Sketch 10).



Sketch 10

If the fairway is curved in the section between sandbars, it's necessary to place additional floating signs (Sketch 11).



Sketch 11

Additional floating signs shall also be placed on the entry and exit of rugged sections with sandbars, which are also characterised by side streams.

In case the application of cross-over marks is impossible, the fairway across a shallow may be marked by floating signs, on one or both sides, depending on the width of the fairway and hydrological conditions.

Marking of the vicinity of bridges and navigable passages through bridges

The navigation of vessels and towed or pushed convoys in the vicinity of bridges and through bridge passages (navigation span) requires particular attention and precautions on the part of ship's masters because of the narrow fairway. These sections must, therefore, be marked with the greatest care.

The basic condition that must be met to ensure safe passage through bridge passages is the marking of the direction of the fairway and also, where necessary, its sides. Floating signs and riverbank marks may be used in addition to boards and lights for marking navigable passages through bridges.

The choice and positioning of marking signs depends, in each case, on local conditions in the section where the bridge is located.

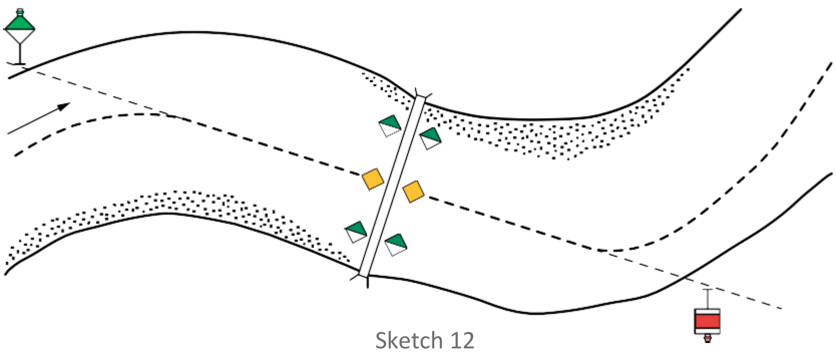
The installation of marking signs in the vicinity of bridges and the buoying of navigable passages shall comply with the following requirements:

a. In order to indicate permission to use the navigable passage of a bridge, only signs A.10, D.1 or D.2 from Annex 7 to the Navigation Rules on the Sava River Basin shall be used;
b. The installation of marking signs shall be based on depth and current direction measurements, measured for the immediate vicinity of the bridge and in the approach sections;
c. The positioning of the signs installed in the vicinity of a bridge shall be modified as conditions of navigation change;
d. If, when approaching the bridge or the navigable passage, the direction of the current forms an angle to the bridge, giving rise to eddies around the pillars of the bridge, the signs on the water shall be installed so as to indicate the direction of the eddies.

Floating signs may be installed at the approach to the navigable passage to give an exact indication of the position of the fairway.

The following examples show the placement of the aforementioned signs marking the section near the bridges:

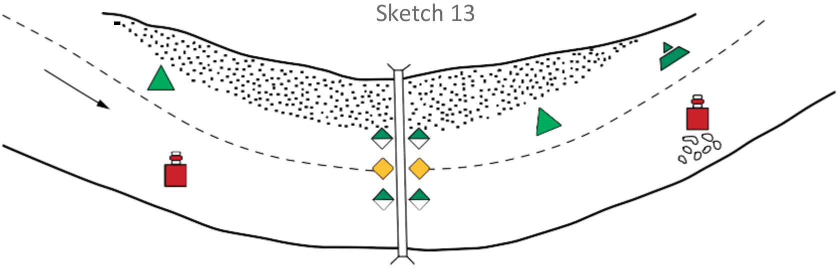
a. If a bridge is in a meandering section of the river, the direction of vessels passing through the bridge passages may be marked by riverbank marks (Sketch 12).



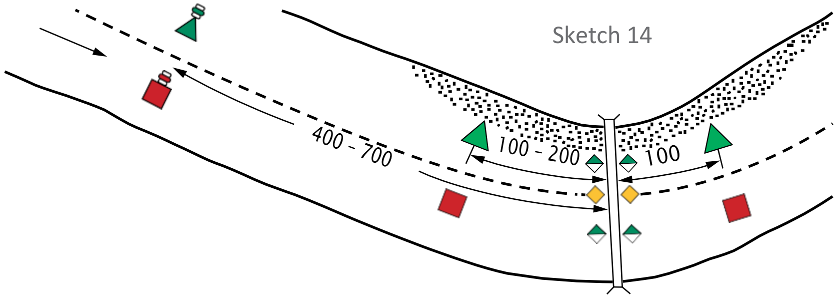
Sketch 12

b. If, due to the larger curvature of the fairway or some other reasons, marking by the aforementioned signs is not possible, floating signs (buoys, etc.), placed so as to follow the current, may be used (Sketch 13).

Sketch 13



c. If the bridge is positioned on a section where the current makes an angle to the axis of the navigable passage, marking may be done by two pairs of buoys upstream of the bridge. One pair of buoys is placed at a distance of 100 m - 200 m upstream of the bridge, and the second pair, 400 m - 700 m upstream of the bridge. Buoys further away from the bridge are placed in such a way so that they mark the river flow in combination with a pair of buoys closer to the bridge. Another pair of buoys may be placed downstream of the bridge at a distance of 100 m from the bridge (Sketch 14).



Navigational marks with an AIS AtoN station

It should be noted that buoys may also be fitted with an **AIS AtoN** base station, and further details on AIS (Automatic Identification System) will be given in Chapter 6.4 – River Information Services (RIS).

In conceptual terms, an AIS AtoN is a real or virtual aid to navigation of relevance to navigational safety that is shown as an electronic symbol on the integrated shipborne ECDIS display.

Fitting a buoy with an AIS AtoN station supplies unambiguous information on the buoy type, name and true position, in all conditions of visibility, to all vessels equipped with an AIS device and electronic charts. Moreover, the dedicated position flag in the Inland ECDIS system highlights any large deviation of the buoy's actual position from the position specified in the Waterway Marking Plan, enabling the competent authority to detect that the buoy has drifted, been stolen or struck by a vessel.

Figure 12:
Buoy with an AIS AtoN base station (ref. *IECDIS EG / VTT EG presentation 25 June 2015*)

Installation of radar reflectors on marking signs, riverbank marks and navigable passages through bridges

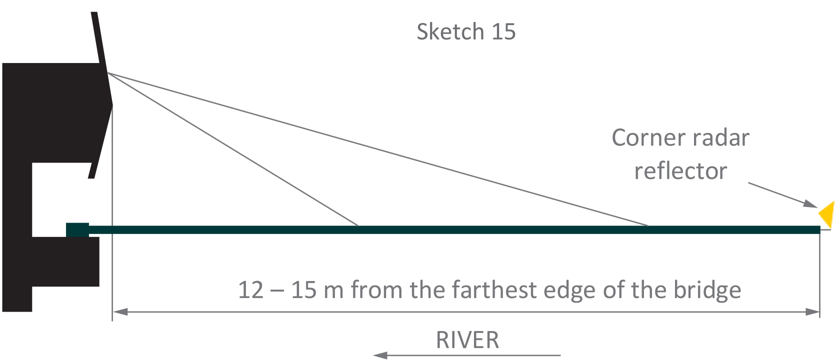
It is important to equip riverbank marks and floating signs with radar reflectors so as to ensure their visibility.

When marking signs equipped with radar reflectors are installed, account must be taken of the furthest distance between the vessel and the sign in terms of perception of the sign on the radar screen.

This distance depends on the technical characteristics of the radar equipment, the reflective capacity of the radar reflectors and the specific conditions of the river, the height of the antenna installed on the vessel and on the height of the radar reflector, both in relation to the water surface.

Since the visibility of bridge pillars is usually insufficient on radar screens, the bridge piers intended for passage of vessels upstream and downstream must be marked either by buoys equipped with radar reflectors, placed not less than 15 – 20 m before the bridge, or by radar reflectors installed on the bridge itself, not less than 12 - 15 m from the farthest edge of the bridge construction (Sketch 15).

Sketch 15



Navigational hazards and various obstacles (sunken vessels, groynes, other river-training structures, etc.) located in the riverbed may also be marked by signs equipped with radar reflectors. If the groynes or other river-training structures marked by radar reflector signals are located along one of the riverbanks while the fairway follows the opposite riverbank, which is low and flat, the radar reflector signals may also be placed on that riverbank so as to facilitate the orientation of vessels navigating by radar.

Radar reflectors on buoys are most often manufactured using two vertical metal plates set as a cross, with a horizontal metal plate intersecting them at a right angle.

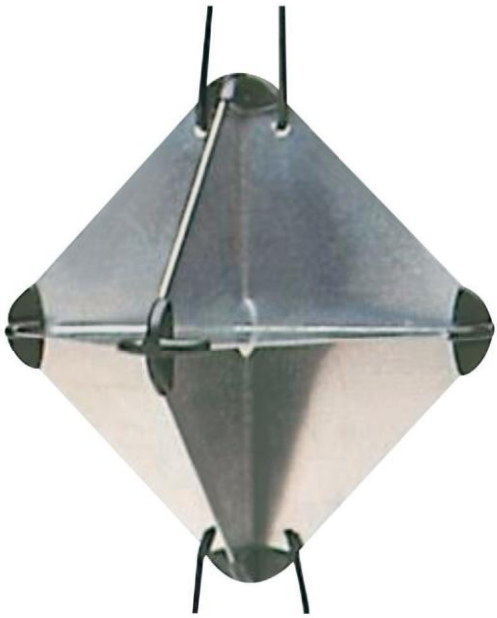
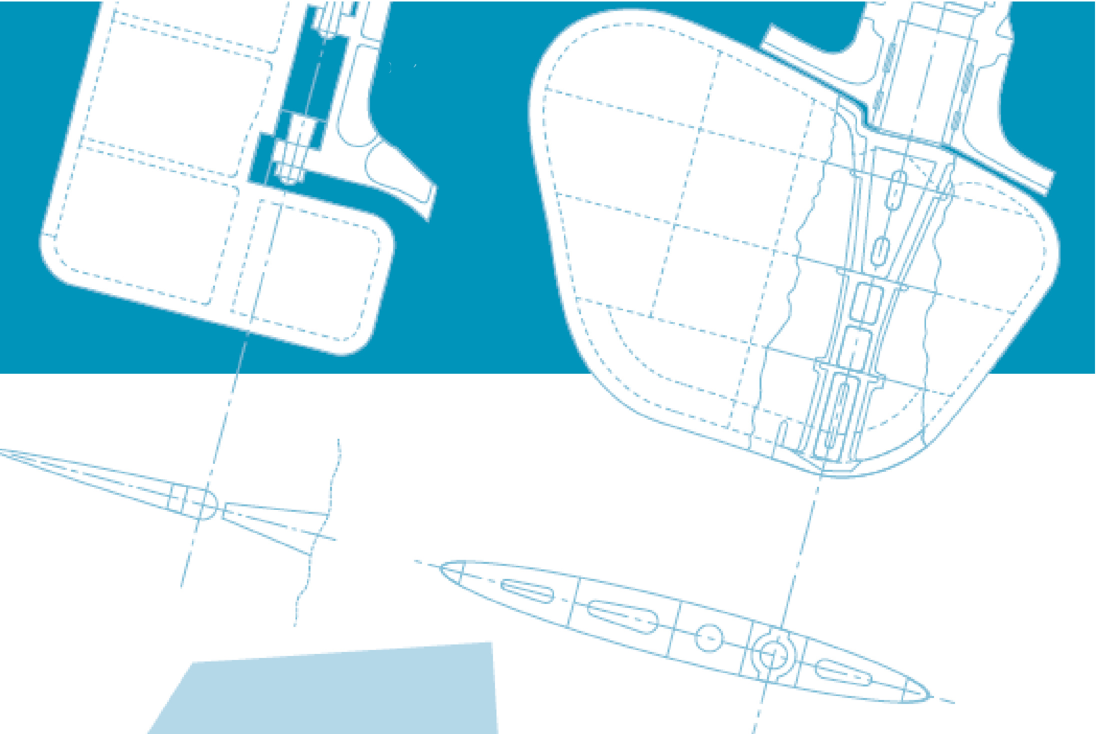


Figure 13: Modern foldable radar reflector

Radar reflectors should be made of aluminium or stainless steel.



4.

4.
BASICS OF SHIPBUILDING AND PROPULSION

4.1 BASICS OF SHIPBUILDING

Shipbuilding is a branch of engineering, concerned with constructing one of the most complex products – a ship. It is a combination of science and art, and it reflects the rate of technological advancement of a country. The scientific component of shipbuilding ensures a ship's required features such as speed, strength, unsinkability, stability and manoeuvrability, so that it can resist frequently difficult navigation conditions. The artistic segment is important since a ship must be aesthetically striking and recognisable. Shipbuilding plays a substantial role in the security of a country during a war and in its economy, both in peace and wartime. The knowledge of shipbuilding has increased over the last few decades in various fields, from hydrodynamics to probability theory, simultaneously using the experience and knowledge of many auxiliary sciences of engineering. Shipbuilding entails construction and repairs of ships, barges, platforms and other floating vessels. Facilities for shipbuilding are called shipyards. Scrap yards are places where old ships are cut into scrap metal.

Figure 14: Tugboat Bačka navigating on the Kupa River, 1959

4.1.1 Ship constructions

Ship is a watercraft operating on seas, rivers and lakes, used for the transport of goods and people (cargo / freight and passenger ships), fishing (fishing boats), naval military operations (warships), specialised operations on seas, rivers and lakes (cable layers, pipe layers, research vessels, etc.) and performance of other various tasks (tugboats, ice breakers, etc.).

A ship is a large buoyant watercraft, whereas smaller vessels are called boats. Contrary to a raft, ships and boats have a cylindrical shape that provides it with the upthrust required for floating on water. Each ship consists of many inter-related parts that make up the whole.

Following the figure below, the principal parts of a ship identified by numbers are as follows:

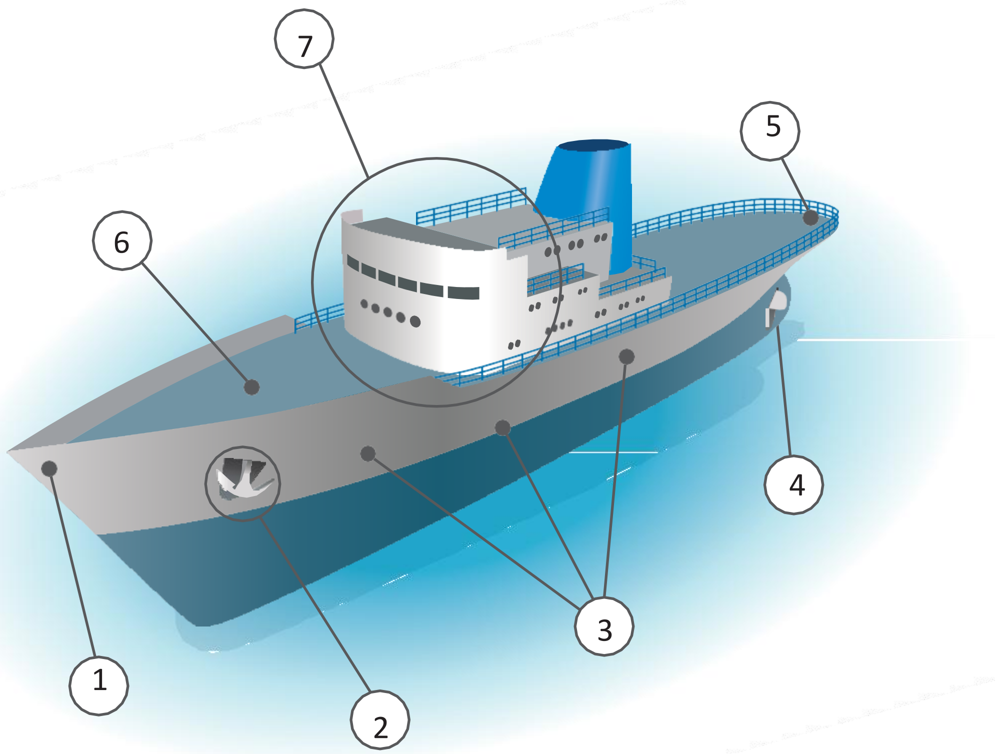


Figure 15: Parts of the ship

- **Bow** (1) – is a forward part of a vessel, opposite of a stern;
- **Anchor and anchoring gear** (2) – one of the most important onboard systems that keeps the ship in position and, in emergencies, enables rapid stopping. A ship can have an anchor at the stern, in which case it is referred to as a “stern anchor”. Anchoring gear consists of: anchors, anchor chains, an anchor winch / windlass, chain locker in which the chain is stowed, an anchor hawsepipe through which the anchor chain is fed, hawsehole in which the anchor rests and an anchor chain stopper;
- **Hull** (3) – a load-bearing part of a ship, and the one ensuring its unsinkability. It consists of the bottom, sides and the deck. It does not include masts, a rudder, engines, etc. More precisely, the hull consists of the framework (a lattice structure composed of appropriate carrier beams and profiles, depending on the vessel type) and plating (tightly fixed to the framework on the outer and inner sides, depending on the vessel type). The inside of the hull is divided vertically into decks and longitudinally by transverse bulkheads, the role of which is to divide a ship into functional areas, increase the ship’s structural rigidity and strength, and create watertight compartments that can contain water in case of a hull breach or other leaks, thus preventing its flooding and sinking;
- **Propeller** (4) – is a part of the propulsion system that drives the vessel by its rotation. A propeller shaft connects the propeller to the ship’s internal engine. Main characteristics of a ship propeller are: number of blades, direction of rotation, diameter and pitch of a propeller. Abaft the propeller is the rudder, which is used to steer the ship.
- **Stern** (5) – the back or aftmost part of a ship. The stern lies opposite of the bow, beneath which the propulsion unit of the ship is located.
- **Main deck** (6) – a horizontal structure placed over the ship’s hull, fully or partly covering the inner space of a vessel. The space beneath the deck is referred to as the “down below”;
- **Superstructure** (7) – an upward, covered and closed extension rising above the vessel deck. If it spans over the entire width, from one side of the ship to the other, it is called a superstructure; if narrower, it is called a deckhouse. As a rule, the ship’s command bridge with its control / navigation equipment is located on the highest part of the superstructure, The superstructure increases the ship’s structural strength.

In addition to the aforementioned parts, there are some other no less important elements and assemblies, such as:

- **Hull equipment / outfitting** – all ship parts that do not contribute to its strength (interior linings, ceilings, flooring, the fitted furniture, etc.).
- **Propulsion equipment** – all parts that enable a vessel to move (for example, in motor vessels: engine, shaft assembly and propeller).
- **Auxiliary devices** – all devices, machines and installations used in auxiliary operations in engine-rooms and on decks (generators, various pumps, anchor drive, wheelhouse, plumbing and electrical installations, etc.);
- **Mobile equipment** – navigation equipment, safety equipment, mobile engineering gear and the like.

Ship's main characteristics and dimensions

Ship's main characteristics include:

- Ship's own weight / light weight – expressed in tons;
- Displacement – expressed in tons or m^3;
- Deadweight – expressed in tons;
- Volume capacity – expressed in m^3, but also in register tons.

The ship's own weight / lightship weight is the weight of a fully equipped ship without fuel, technical and fresh water, ballast water, supplies of food, cargo and crew's weight with their luggage. It is expressed in tons.

Displacement can be defined in two ways:

- as a volume (∇), expressed in m^3;
- as a mass, i.e. weight (Δ), expressed in tons.

The *deadweight* is the difference between the displacement and the lightship weight of the ship. It is expressed in tons. There are two types of deadweight:

- Useful deadweight – the weight of cargo (freight) and passengers with their luggage, i.e., the weight on which freight charges are based.
- Total deadweight – sum of the useful deadweight and weight of fuel, food, provisions, and the crew with their luggage.

The ship's *volume capacity* measures the cubic volume of all enclosed spaces of a ship. It is expressed in m^3, and also in register tons.

Register ton is a measure of the internal (enclosed) volume of a vessel, and equals 2.83 m^3. This is a formula-derived measure (from Anglo-Saxon units of measurement) where 1 rt = 100 ft^3 = 2.83 m^3.

There are two types of register tons:

- Gross Register Tonnage (GRT) –
  - measure of all internal (enclosed) volume in a vessel;
- Net Register Tonnage (NRT) –
  - measure of internal (enclosed) volume in a vessel space intended for cargo and passengers.

The main hull dimensions include:

1. Longitudinal dimensions:

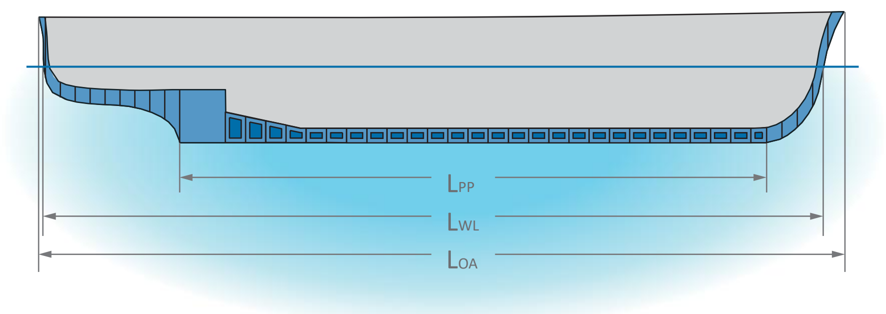


Figure 16: Longitudinal section

L_{OA}	Length Overall – is the length equal to the distance between two transverse planes of frames that pass through the extreme forward and after points of the vessel's structure, measured parallel to the design waterline.
L_{PP}	Length between perpendiculars – is the length equal to the distance between the bow (forward) and the aft (after) perpendicular.
L_{WL}	Length at the (design) water line - is the length equal to the distance between the intersection of the design waterline with the outline of the stem and the corresponding intersection of the same waterline with the outline of the stern frame.

Also, no less important hull dimensions are:

L_P	Parallel midbody length of the ship - the length of the constant cross-section of the hull below the design waterline.
L_R	Length of run (length of the abaft part of the vessel's sectional area curve) - measured from the parallel midbody, or from the dead-flat frame (if there is no parallel midbody), towards the stern end of the design waterline.
L_E	Length of entrance (length of the abaft part of the vessel's sectional area curve) - measured from the parallel midbody, or from the dead-flat frame (if there is no parallel midbody), towards the bow end of the design waterline.

2. Cross-sectional dimensions:

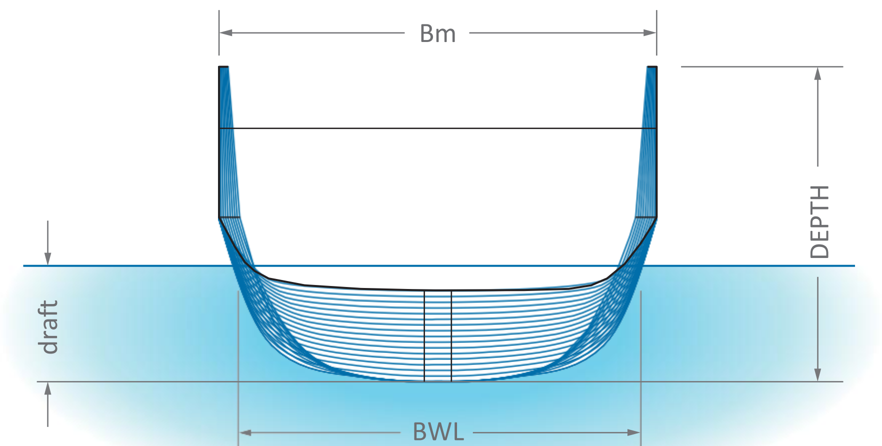


Figure 17: Cross section

B_M (beam)	Extreme breadth of a vessel measured at the outside of the hull amidships.
B_{OA} (breadth overall)	Extreme breadth regardless of whether it lies below or above the waterline.
B_{WL} (breadth on waterline)	Extreme breadth on the design waterline, regardless of the position.
B_X	Breadth on the design waterline at the dead-flat frame.

3. Vertical dimensions:

D_M (H)	Depth moulded – measured in the plane of the midship frame from the top edge of the keel to the top edge of the beam at the side of the uppermost continuous deck at side. For wooden vessels, the depth is measured from the outer rabbet of the planking on the keel up to the top edge of the beam at the side.
F_M	Freeboard - the height of the vessel's above-water portion, measured at mid-length of the LPP, from the design waterline to the upper edge of the deck plating (including any wooden deck sheathing, if fitted).
T_A	Draught aft – measured on the after perpendicular from the baseline to the waterline.
T_F	Draught forward – measured on the forward perpendicular from the baseline to the waterline.
T_M	Mean design draught – height of the immersed part of the vessel, measured at mid-length of the LPP, from the top edge of the keel to the designed waterline.
T_X	The draught at the dead-flat frame (greatest cross-section) - height of the immersed part of the vessel, determined at the dead-flat frame point, from the top edge of the keel to the designed waterline.

4.1.2 Vessel hydrodynamics

Vessel hydrodynamics is a discipline studying:

- Motion of vessels through the water and phenomena occurring during such a motion;
- Vessel mobility issues and steering;
- Behaviour of vessels on waves.

Mobility of a vessel represents its ability to change position in water using the thrust force. The thrust force can be calculated based on the ship's resistance and propulsor features.

Vessel resistance is the force (N) working against the vessel's motion. For a body to be able to move at a certain speed in fluids, a certain force must be applied to overcome resistance. The movement of vessels through fluids is opposed by hydrodynamic forces of fluids and aerodynamic forces of air. When vessels navigate through water the principal phenomena observed are:

- Eddies, which are formed in the immediate vicinity of a ship's hull due to the water friction acting against the hull (boundary layer);
- Large eddies that form on the ship's stern;
- Waves, which are generated following a vessel.

Ship resistance elements are divided into:

- Resistance of the underwater part of the vessel (water resistance) - R_V;
- Resistance of the above-water part of the vessel (air resistance) - R_Z;
- Other / additional types of resistance - R_O.

Additionally, water resistance consists of:

- Frictional resistance - R_F;
- Wave resistance - R_W;
- Pressure resistance - R_P;
- Resistance of appendages - R_{PR}.

Ship's resistance is calculated as:

$$R = R_V + R_Z + R_O = R_F + R_W + R_P + R_{PR} + R_Z + R_O$$

Frictional resistance represents the main component of the ship's total resistance, making up for 50 % - 90 % of the ship's total resistance.

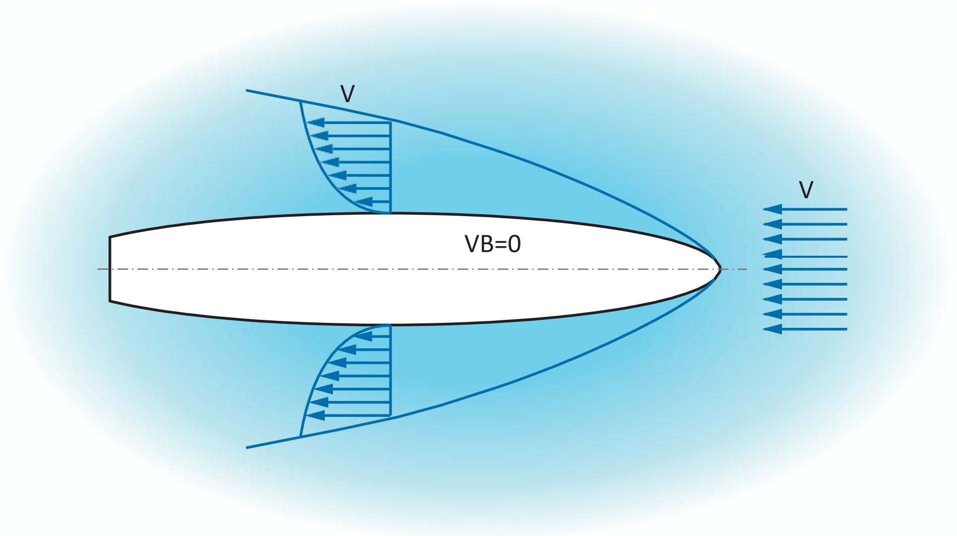


Figure 18: Ship's frictional resistance

Frictional resistance R_F is a consequence of the viscosity of water, which manifests itself as internal friction during the vessel's motion. Within the thin layer of water adjacent to the hull surface, called the *boundary layer*, energy is transferred from the ship's hull to the surrounding water, thus generating frictional resistance.

The boundary layer extends from the ship's stern towards the bow, since the increase in ship's length also increases the area of water affected by friction. The frictional resistance depends on:

- Roughness of the outer shell of a vessel – increase of frictional resistance due to roughness of the ship's outer shell is on average 15 to 20 %;
- Size of the vessel wetted surface area – an increase in the size of the wetted surface area yields higher frictional resistance;
- Vessel speed – increase in speed increases frictional resistance;
- Vessel length – increase in length increases frictional resistance.

When studying water-flow phenomena governed by viscous and inertial forces, a dimensionless parameter called Reynold's number (RE) is of primary importance:

$$Re = \frac{L \cdot V}{\nu}$$

L – vessel length (m);

V – vessel speed (m/sec);
ν – $\mu \cdot \rho$ = coefficient of kinematic viscosity (m^2/sec)
μ – coefficient of dynamic viscosity (N · sec/m^2)
ρ – fluid density (kg/m^3)

Depending on the Reynold's number and hull roughness, flow in the boundary layer may be laminar or turbulent. Laminar flow is characterised by layers of water sliding over one another along the hull contours, without any major variations in velocity. Turbulent flow is characterised by unsteady particle motions, causing continuous mixing of fluid masses and large velocity oscillations at every point. Frictional resistance is substantially higher in areas with a turbulent flow. In practice, flow is almost exclusively turbulent; any laminar flow near the bow rapidly destabilises and disappears. Consequently, it is important that the vessel's plating, especially in area of the bow, is as smooth as possible. Increase in frictional resistance developing due to the increased roughness of a vessel is 15 % to 20 % on average, but can exceed even 40 %.

Wave resistance - R_W arises due to water resistance, i.e., due to the water resisting the change of its own state. Any increase in vessel speed increases the size of waves, i.e., causes an increase in wave resistance.

The waves created by the ship can be:

- Divergent waves;
- Transverse waves.

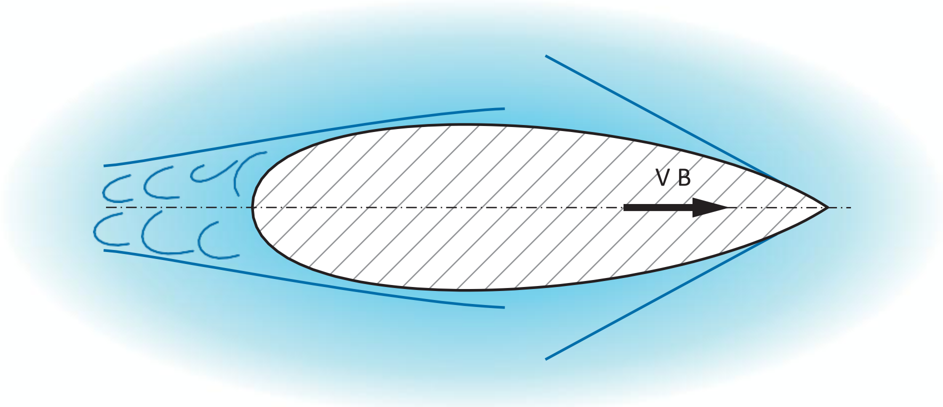


Figure 19: Shape favourable for wave resistance

At low speeds, transverse waves are barely perceptible, while divergent waves are visible. Every increase in speed causes the increase in intensity of transverse waves, and their crests and troughs become clearly visible along the sides of a ship. A number of transverse waves along the vessel's sides increases with growing speed, so at very high speeds only a single wave may occupy the ship's entire length.

Waves are generated only by vessels navigating on the water surface. If a vessel (e.g., a submarine) sails one-and-a-half to three of its own diameters beneath the surface, the waves disappear, i.e. there is no wave resistance either.

Wave resistance depends on:

- Vessel speed – any increase in speed causes a progressive increase in the size of transverse waves, and, consequently, in their resistance;
- Vessel shape – any increase in beam-to-draft ratio (B/T) causes an increase in wave resistance;
- Vessel length – an increase in length reduces wave resistance (but increases the frictional resistance; optimal solution needs to be found).

Wave resistance can also be reduced by fitting a bulbous bow, which, at higher vessel speeds, can cut total resistance by as much as 18 %.

Pressure (eddy) resistance - R_P, i.e. form resistance, arises because water streamlines at the stern do not run exactly along the shape of a vessel's hull. Therefore, the pressure at the stern and the pressure at bow differ. This difference in pressures creates the eddy resistance.

Eddy resistance depends on speed, and, primarily, on the shape of a stern, i.e., on the manner in which the hull is "sharpened" from the parallel midbody towards the stern. The main cause for formation of eddies around vessels with a conventional form is the expansion of the boundary layer, which causes a change in the principal flow regime.

On a full after-body (full stern), boundary-layer water streamlines cannot follow the contour of the body. Consequently, the boundary layer detaches, the water streamlines change direction and create eddies. With sharper stern forms, the boundary layer thickens more gradually, the detachment occurs at a point close to the stern, and eddy resistance is correspondingly lower.

Air resistance - R_Z occurs due to above-water structure moving through air. To reduce air resistance as much as possible, it is advisable to:

- Construct the lowest possible superstructure;
- Round off the superstructure and make its form streamlined;
- Construct the superstructure in a gradual (stepped) form, towards the bow and towards the stern.

Resistance of appendages - R_{PR} is the cumulative resistance caused by appendages such as bilge keels, struts, rudder, stabilising fins, etc. The relatively small surface area of appendages causes a low frictional resistance. However, occurrence of eddies at and around appendages has a greater impact on resistance, thus their shapes on the part of a ship below the waterline should be slender and free of sharp edges.

4.1.3 Ships and convoys in inland navigation

Types of vessels in inland navigation, **by their intended use,** are categorised as follows**:**

- **Merchant ships** – vessels that carry passengers or cargo (20 m and longer, tugboats and pushers, regardless of length);
  - Cargo vessels / freighters – ships carrying exclusively various types of cargo;
  - Passenger vessels – ships that are intended to carry more than 12 passengers (daytrip or cabin ships);
- **Special service ships** – vessels intended for special operations and tasks – public vessels (harbourmaster's office, police, fire service), floating / technical equipment (dredgers, elevators, floating cranes), fishing boats, ice breakers, etc.;
- **Warships** – vessels primarily intended for military operations on rivers and lakes.

In addition, **cargo vessels / freighters** can be:

- **Self-propelled ships (motor ships)** – vessels using their own mechanical / motor drive, apart from vessels using engines exclusively for minor transfers (in ports, at anchoring points) or for increasing manoeuvring capacities in convoys;
  - **Tugs / tugboats** – vessels specifically designed and equipped to propel towed convoys;
  - **Pushers** – vessels specifically designed to propel pushed convoys;
  - **Self-propelled vessels** – motor ships equipped with their own means of propulsion, intended for transport of cargo in their own holds.

Note: In practice, there are also combined vessels that are designed for transport of cargo in their own holds, but at the same time are equipped for propelling of pushed convoys:

- **Non-propelled vessels** – vessels not using their own mechanical means of propulsion; designed and equipped for navigation in convoys propelled by motor ships;

- **Pushed barges / lighters** – vessels specifically designed and equipped for navigation in pushed convoys, i.e. to be pushed;
- **Barges** – vessels specifically designed and equipped for navigation in towed convoys, i.e. to be towed.

Special types of merchant cargo vessels / freighters, with and without their own means of propulsion are:

Tankers – intended for transport of various kinds of cargo in liquid form, including:

- Oil and oil derivatives;
- Chemical products;
- Liquefied gases.

The majority of the goods mentioned above are dangerous goods, which are transported using special tanker vessel units with appropriate safety features. European regulations and recommendations, such as ADN, ADN–R and ADN–D, as well as national laws governing the transport of dangerous goods, are especially relevant in this context.

Modern vessels have a double hull that prevents spillage of transported goods in case of outer shell damage. A ship’s hold is often divided into several individual compartments / tanks, which can be split into individual areas. This means that a tank filling system and fire suppression systems (gas return pipe, residual gas pipes and tanks) are entirely separated. All these systems are essential for preventing environmental contamination with residual toxic gases and liquids. Tanks made of stainless steel or holds with a special coating are used to prevent any reaction between dangerous goods and the tank surface. Heaters and valves are used in transportation of cargo that can easily freeze during winter, while a deck sprinkler system protects tanks from summer heat. Transport of liquid cargo requires utilisation of cutting-edge technology.

Container vessels are ships intended for transport of all types of containers mainly with high-tariff goods requiring a high degree of preservation. Container transportation is believed to be one of the main growing markets for transport on inland waterways. While the traditional bulk cargo sector tends to be saturated, container transport shows the greatest growth potential.

Specifically designated ships are being developed in order to cope with increased demand. In well-developed river systems with good navigation conditions, container shipping tends to be more economical.

RoRo vessels are mainly designed to carry all types of road vehicles. The main advantage of RoRo transportation is most pronounced in less-developed countries of Eastern Europe; it requires relatively small investments in port infrastructure; thus, RoRo services represent an immediate intermodal solution for countries whose port installations are less advanced. Main disadvantages of RoRo navigation include a nearly optimal utilisation of ship space, as well as use of expensive mechanisms such as trailers.

Basic types of convoys on the Sava River

In order to reach an optimal degree of utilisation of the Sava River fairway, as well as of various transportation means, especially when moving low-value bulk goods (construction material, timber, ores, grain, etc.), vessels (lighters and barges) are organised into convoys. The main types of convoys are:

A pushed convoy - consists of a rigidly connected formation of vessels in which at least one vessel is located ahead of the motor vessel propelling the convoy and is known as a pusher. A convoy made up of a pusher and pushed crafts whose coupling gear allows a controlled, limited angular deviation of the pushed crafts from the pusher's heading is likewise considered rigid.

On the Sava River, it is customary to attach 2, 4 or 6 lighters that are propelled by a pusher of appropriate power. Standard lighters usually used on the Sava River measure 76.5 m in length, 11.0 or 11.4 m in width, have an average deadweight of approximately 1,650 tons and a draught of 2.5 m. A large convoy of 6 lighters measures up to approximately 185 m in length (one pusher and two rows of three lighters in a side-by-side formation). Pushed convoys are dominant on the Lower and Middle Sava as far upstream as Slavonski Brod. The size of a pushed convoy depends on the condition and dimensions of the fairway.

A towed convoy means any group consisting of one or more vessels, floating establishments or assemblies of floating material towed by one or more motor vessels, the latter forming a part of the convoy and being termed tugs.

Even though barges towed by tugs are nowadays almost a completely abandoned form of transportation on European fairways, they are still used to a limited extent on the Sava River for carrying crude oil.

A side-by-side convoy is a group of vessels lashed beam-to-beam, with none positioned ahead of the motor vessel propelling the convoy. Such a formation is often assembled for manoeuvring in ports, locks and anchorages.

4.2 SHIPBOARD EQUIPMENT

For ships to be used for their intended purposes, it is necessary to equip them with a so-called shipboard equipment, which entails ship fittings / accessories and devices. The diversity of shipboard equipment depends on the type and size of the vessel, sector of its navigation, as well as on the vessel's intended use. All equipment must be in working order and located in appropriately assigned places so it can be used efficiently.

Vessel devices are mainly auxiliary machines and other appliances, either installed or fastened to the deck.

Unlike equipment, which mainly consists of larger fixed or movable items, the ship's fittings / accessories are smaller portable objects of various general uses. All listed devices or fittings can be used for multiple purposes.

Depending on its main purpose, general equipment of a vessel includes:

- Anchoring gear and devices;
- Mooring / unmooring equipment and devices;
- Equipment and devices designed to preventing flooding;
- Fire extinguishing equipment and devices;
- Life-saving equipment and devices;
- Navigational equipment and devices;
- Radio communication and signalling equipment and devices;
- Towing and pushing equipment and devices;
- Loading / unloading and warehousing equipment and devices;
- Equipment and devices intended for maintenance of propulsion machinery and installations;
- Equipment and devices of a general purpose;
- First aid equipment.

Anchoring gear and devices: located at the bow and stern, most of which is arranged on the main deck. It consists of: an anchor winch / windlass (electric, motor or manually operated), a main anchor, a back-up anchor (80 % of the main anchor's weight), an auxiliary anchor (20 % of the main anchor's weight), anchor chains (thick, thin), a hawse-pipe, an anchor davit, auxiliary bollard, stoppers, a chain locker, etc. As a rule, the length of the anchor chain should be one and a half of the length of the anchoring vessel. The "Register of Shipping" or another state-authorised "technical supervisory body", has laid down, in its "Technical Rules", standards governing the relationships between vessel mass and anchor mass, together with the breaking strength of the anchor chain.

In general, anchors are divided into:

- Admiralty pattern anchor, which received its name from the British Admiralty that first stipulated the dimensions for this anchor type. It consists of a shank, crown, arms, flukes, blades, a moveable stock with balls and an anchor shackle. Anchors of this type have good holding power, but their chains easily get entangled around the moveable stock or arms. A drawback of this anchor is awkward handling, because of which the so-called "one-armed" mooring anchors were made, and these are used for anchoring of buoys, other fixed floating establishments and aids to navigation safety.

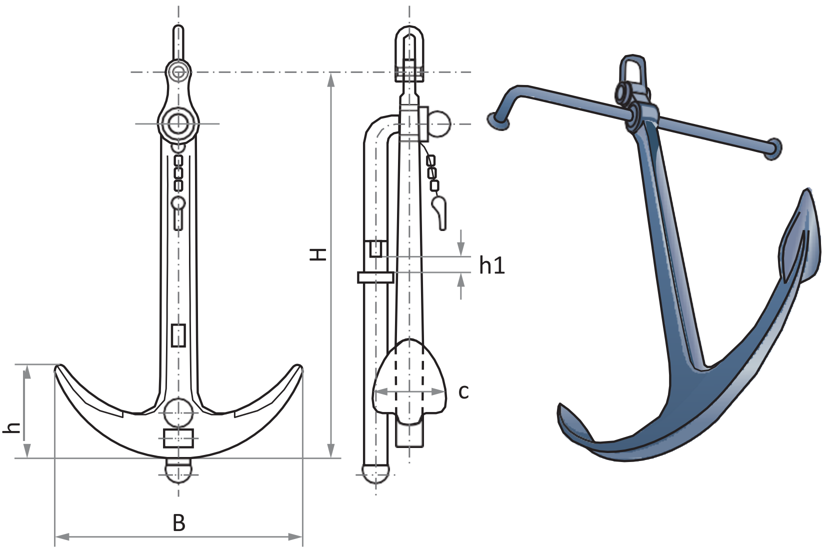


Figure 20: Admiralty Pattern Anchor

- Patent or stockless anchors: design of these anchors allows simple hauling up until they rest with the shank inside the hawsepipe. They are easy to handle and stow aboard at any moment. The best performing patent anchors are Hall and Danforth anchors.

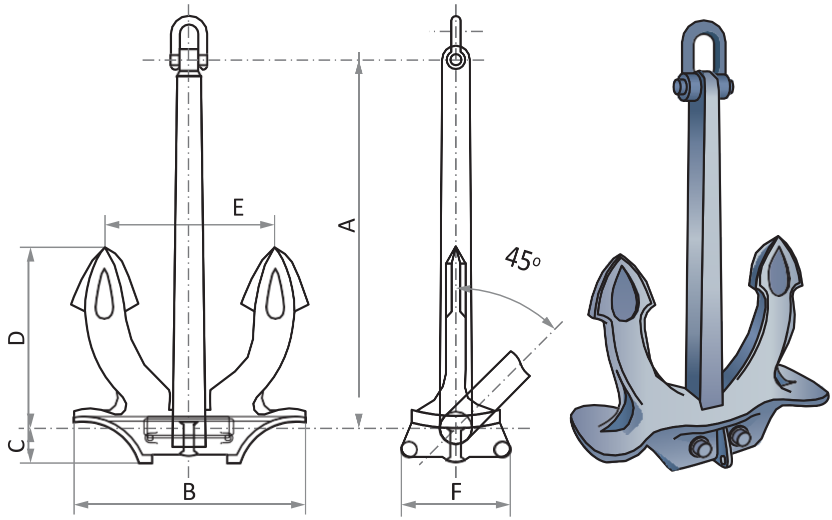


Figure 21: Hall anchor

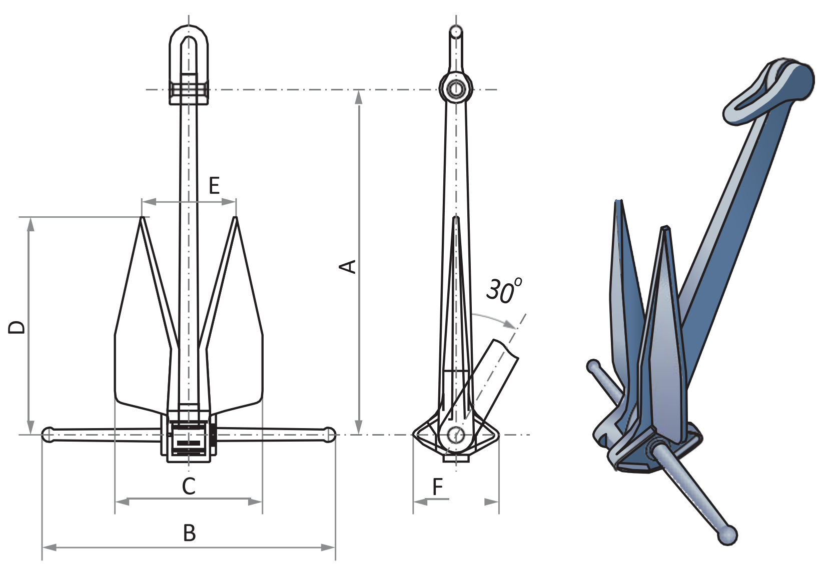


Figure 22: Danforth anchor

Mooring / unmooring equipment and devices: installed and symmetrically arranged on the main deck (at bow, stern and sides) so that the mooring operation can be carried out as safely as possible. In addition to mooring winches and capstans, lines and bollards, which constitute the basic equipment as stipulated by technical rules, this type of equipment also includes the following: throwing (heaving) line with a monkey's-fist, a rope reel, reinforced poles (*kazuk)*, mallet / sledge, reinforced mooring spacer, reinforced steel pulley, boathook fender, hitcher, shovels, coupling clamps, cross bollards (single and double), anvil bollards ("ambus"), "radla", etc.

Mooring lines can be made of steel (steel-wire ropes) and of fibre (fibre twisted or braided ropes). Each rope has its own intended use, so steel-wire ropes are used in towing, pushing, mooring, coupling etc., while twisted or braided ropes are used during mooring in ship locks and side-by-side mooring, but never during navigation – only during overnight stays.

Apart from lines, ships should have a boathook and reinforced pole – a wooden pole with a sharpened and reinforced tip (with steel), used to moor a vessel if there is no other suitable mooring structure.

Equipment and devices designed to prevent flooding: they are of great importance – they include both the equipment used for pumping the water out of a vessel (manually operated, electrical and mechanical pumps) and the equipment used for preventing water from penetrating into hull (salvage tarps, wooden wedges, calcium-based mineral grease, quick-setting cement, etc.). It should be noted that due to the particular conditions of inland navigation (small crews) and waterway infrastructure, it is very difficult to use the equipment and accessories designed to prevent flooding, so in the event of an accident pumps and stranding manoeuvres are mainly used.

Fire extinguishing equipment and devices: are compulsory for all vessels. Depending on the size and the intended purpose of a vessel, various firefighting systems are designed and installed: sprinkler systems, inert gas and foam cylinders, along with a number of portable fire extinguishers. Different fire extinguishing media are used for different classes of fires (electrical installations, oil and oil derivatives, chemical products, wood, etc.).

Life-saving equipment: it must be accessible and regularly maintained. It comprises of: life buoys and life vests, lifeboats and life rafts with appropriate accessories.

Navigational and steering equipment and devices: located on the deck or in a vessel's wheelhouse and master's cabin, i.e. in locations with high level of visibility. Main elements of this equipment are the conning console with instruments, devices transmitting information to engine-rooms, and the rudder with transmission, a rudder blade and its stock. All devices and equipment located in a wheelhouse are described in detail in Chapter 6 of this Manual, covering the navigation issues.

Radio communications and signalling equipment and devices: are located on the commanding bridge / in the wheelhouse or any suitable position on a vessel's superstructure that is easily accessible from the wheelhouse. The most important ones are: siren / horn, whistle, klaxon, a trumpet, ship's bell, ship tannoy, ship's radio station, masts, signalling and navigation lights, flags and pennants (according to the International Code of Signals), signal rockets, etc.

*Towing and pushing equipment and device*s: arranged around the vessel's main deck and its superstructure. Towing equipment is positioned on the aft-most part of a ship, while the pushing equipment is situated on its fore part.
Some of the most important devices include:

- Towing device – towing winch / windlass – compulsory for tugboats with power exceeding 200 KW;
- Towing device – automated towing hook with a safety latch;
- Steel wire rope – towline / hawser, 80 to 350 m in length, and 12 to 32 mm in diameter, depending on a tug's towing power;
- Shock cord for towlines;
- Towing ship arch fenders;
- Auxiliary safety bollard for securing towlines;
- Additional ship lights and daytime signals;
- Coupling winches.

Pulling and coupling winches can be: manually operated, motor-driven, electric, hydraulic, as well as a combination of any of these types.

Loading / unloading and warehousing equipment and devices: their arrangement depends on vessel type, as well as on the type of cargo being transported. In addition to the equipment and accessories used for manual loading (rarely seen on present vessels), today's vessels mainly use modern electrical, hydraulic and pneumatic equipment combined in accordance with their size and intended purpose. In addition to cranes, during cargo loading / unloading operations, the following items of equipment are also used:

- Pallets, boards, dunnage planks and shore legs for stacking cargo;
- Hooks and clamps (sharp and blunt);
- Grippers and clamshell buckets for bulk cargo;
- Loading / unloading pipes, chutes and funnels;
- Nets, tarpaulins, baskets, boxes, etc. for light and voluminous (bulky) goods;
- Skids, magnets, levers, etc.;
- Hand-operated, electric and motor carts, forklifts, and similar vehicles for moving and stacking cargo in the holds.

Equipment and devices intended for maintenance of propulsion machinery and installations are diverse, and are mainly related to propulsion, main and auxiliary engines, and vessel installations. The greater part of this equipment is housed in the ship's workshop, and consists of different types of tools and instruments used to measure various parameters and detect malfunctions. All vessels must have in stock a certain number of spare parts that can be used for immediate repairs.

Equipment and devices of a general purpose: include all items not listed in the above-mentioned groups, but are used on a daily basis during the vessel's operation. The most significant elements of this group are:

- A boat with a chain, oars, bailer, an anchor and a hand lamp;
- A gangplank (6 m x 40 cm), rails, joints, stands, steps – ladder;
- Refrigerator, freezer, water bucket with 6 m of rope;
- Radio and TV, receiver antennas, etc.;
- Axe, pliers, cutters, saw, screwdrivers, scrapers, snow shovel, steel brush, etc.;
- A universal tool set, an ice-breaking set (ice-pick, axe and saw);
- A cleaning set for maintaining cleanliness on the deck and superstructure (brooms, buckets, wipers, mutton cloths, etc., and paint, solvents with painting accessories);
- A cleaning set for maintaining hygiene and cleanliness in common areas (saloon, wheelhouse, corridors, cabins, etc.);
- Special sets for maintaining hygiene and cleanliness in the galley and pantry.

Several of the above-mentioned items of equipment and devices must be periodically overhauled and their serviceability must be checked, while handling of some equipment must be regularly practised so that both the crew and the vessel are constantly prepared for events of an accident or other emergency.

4.3 SHIP'S PROPULSION MACHINERY

The propulsion machinery of a vessel is the name for the power-generating installations that produce the type of energy required by a vessel during operation, and consists of:

- Main propulsion engines, providing propulsion power of the vessel – main engines;
- Auxiliary power units, providing energy for all other operations on a vessel – auxiliary engines.

The required output of main engines depends on the size and speed of a vessel, whereas the power of auxiliary engines is mostly determined by the vessel's intended purpose and equipment.

Main propulsion engines provide propulsion by means of internal combustion engines, gas or steam turbines. *Two-stroke in-line diesel engines* are most frequently used as main propulsion engines in merchant vessels. Main characteristics of the propulsion engine are:

- Ability to change the engine's rpm (revolutions per minute) over a wide range;
- Ability of safe reversing in a short time;
- Ability to work at low engine rpm.;
- Safe ignition in hot and cold conditions;
- Reliable running when the vessel is rolling or pitching.

Diesel engines are (thermal machines) in which the chemical energy of fuel is converted into mechanical work. The chemical energy contained in the fuel is transformed into heat by combustion (oxidation). Two different operating principles are always encountered aboard ships: Four-stroke diesel engines, which may serve both as main propulsion engines and as generator drives, and two-stroke diesel engines, which are generally main propulsion units.

Expansion of combustion gases acts on the piston; their reciprocating motion along the liner is converted, by the connecting-rod or piston-rod mechanism, into the rotary motion of the crankshaft. Ignition and combustion of the fuel take place, in most designs, directly in the cylinder, but in some designs in the pre-combustion or swirl chambers, which is why these engines are classified as internal-combustion engines. (Engines that burn lighter petroleum fractions — petrol / Otto engines — also belong to this group, but they will not be discussed further in the following text.)

Diesel engines can be classified by many criteria, but diesel engines most commonly used for ship propulsion have the following features: they are two-stroke, in-line, burn liquid fuel (mainly heavy fuel), are turbo-charged, employ direct fuel injection into the cylinder space, are built with a crosshead, and are slow-speed engines.

Steam turbines are thermal machines that convert the thermal energy of steam into mechanical work and they began to develop rapidly in the 19th century, although the operating principle was known much earlier. The operating principle of thermal turbines is as follows: the thermal energy of steam is first converted into kinetic energy by means of nozzles in the turbine's stator, and the working medium (steam) is then guided through the curved flow channel in the turbine rotor, creating a force that turns the rotor and results in mechanical work.

The principal — and greatest — advantage of steam turbines is that they are power plants of the highest outputs. In merchant fleets they are used mainly on tankers, where large quantities of steam are required for cargo heating, which is also the reason why steam propulsion is applied on larger tankers.

Advantages of the steam turbine are its very smooth and quiet running, operational safety, lower maintenance costs, greater durability, good torque even at low shaft revolutions, and the possibility of running with very low propeller-shaft revolutions rate. In service, the steam turbine is a considerably more flexible machine than the diesel engine.

The disadvantages of steam turbines are higher fuel consumption and the need for a separate turbine for astern propulsion, because steam turbines can rotate only in one direction. The astern turbine's output is usually 40 % of the ahead turbine's output; moreover, the time required for the propeller to start turning in the opposite direction on turbine-driven vessels is significantly longer.

The very fact that the astern turbine develops 40 % of the turbine's output (whereas with diesel engines it is 100 %) and that reversing takes much longer actually means that turbine-propelled ships manoeuvre considerably less readily than vessels driven by diesel engines.

With regard to the overall cost-effectiveness, the steam turbine becomes a serious rival to diesel engines in the range above 15,000 kW, with its advantage increasing with rising power, and it is unrivalled in terms of very large outputs. The lower economically justified limit for the application of steam turbines is 8,000 kW.

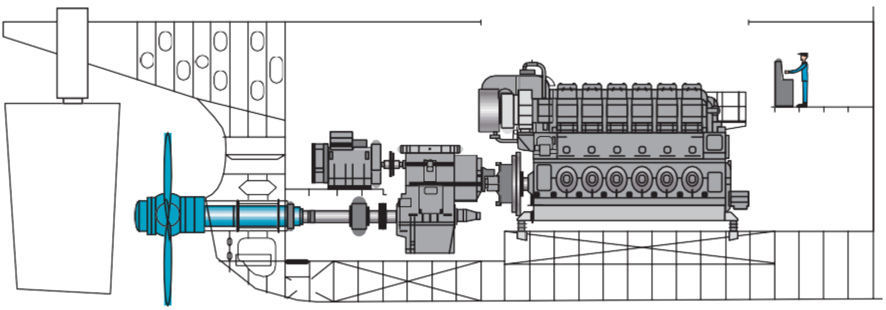
Gas turbines have not found a wide application on merchant vessels and are used mainly on naval ships in order to obtain maximum speeds and high power density, so they are often employed in combination with a diesel engine. The first usable gas turbine was built by the Norwegian engineer Elling in 1903, and the idea that gas turbines could be employed to drive turbo-chargers was developed by the Swiss engineer Büchi in 1905.

Research into jet-aircraft engines raised greater interest in maritime circles world-wide for employing gas turbines on ships. In the early 1970s, the development of systems enabled the use of diesel fuel for marine gas-turbine operation, contributing to their wider use afloat.

In brief, atmospheric air is drawn into the compressor; the compressed air passes into the combustion chamber, where fuel is injected, and after combustion the gases are led into the turbine. Before reaching the turbine, the hot exhaust gases flow through a water-cooler, and the steam generated in the cooler mixes with the combustion gases.

Of all the thermal engines mentioned so far, gas turbines have the lowest thermal efficiency. Their preparation and start-up time are relatively short, which is why they have mainly been used on previously mentioned naval crafts, where efficiency is less critical. Their auxiliary systems are the simplest — hence cheapest and easiest to maintain.

Gas turbines generally burn a higher-grade and more expensive diesel fuel and, therefore, pollute the environment less. Operating costs are high because blade erosion (burn-off) of the turbine rotor has not yet been technologically fully resolved. Because fuel burns at high temperatures, the stator blades are (air) cooled and the rotor blades are made of high-alloy steel with stellite pads brazed to the hottest part of the blade tip. Given the manufacturing cost, their service life is too short, so — apart from combined propulsion systems — they are seldom installed on ships.



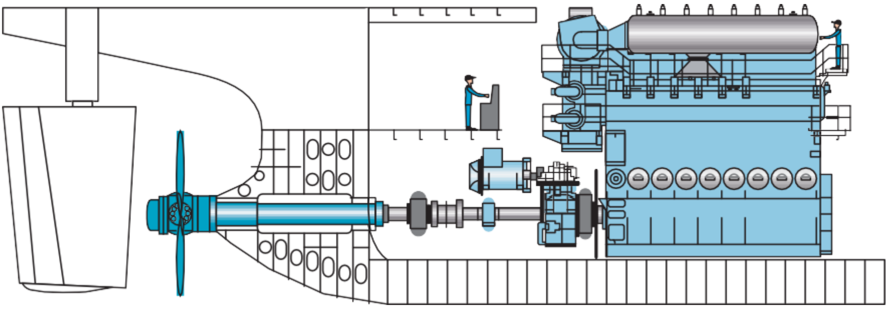


Figure 23: Arrangement of a high-speed and a slow-speed engine in the engine-room

Emerging technologies

Regulations addressing exhaust-gas emissions have become even stricter in recent years. The Regulation of the European Parliament on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery (the NRMM Regulation, Stage V) defines limit values for exhaust-gas emissions from new engines. The mandatory limits are very stringent, which will in turn demand the installation of emission-reduction technologies such as selective catalytic reduction (SCR) after-treatment and particulate filters, or the adoption of new technologies and alternative fuels.

It seems that diesel engines will remain the most common form of propulsion for inland navigation in the medium term. In the longer term, it is conceivable that gas engines and fuel-cell systems will be used, which would significantly reduce harmful emissions from vessels.

Possible effective measures for reducing the emission characteristics of marine engines include the following (viadonau, 2019):

- Reduction in sulphur oxide emissions by means of low-sulphur fuel;
- Reduction in hydrocarbon and carbon monoxide emissions by means of diesel oxidation catalysts (low-sulphur fuel required);
- Reduction of nitric oxide emissions, for instance by means of exhaust gas recirculation (requires low-sulphur fuel), humidification of engine inlet air, in-cylinder water injection or use of selective catalytic reduction (i.e. injection of a reduction agent for the effective removal of nitric oxide emissions);
- Reduction of particulate matter emissions by means of particulate matter filters (PMF).

According to the results of international research projects and experiments, such as the PROMINENT project (2015 - 2018), the most effective techniques for reduction of engine emissions and fuel consumption are:

- Engines for liquefied natural gas (LNG);
- Use of fuel with a low-sulphur content;
- Diesel oxidation catalysts;
- Selective catalytic reduction;
- Particulate matter filters;
- Fuel-efficient navigation with computer-assisted decision support systems.

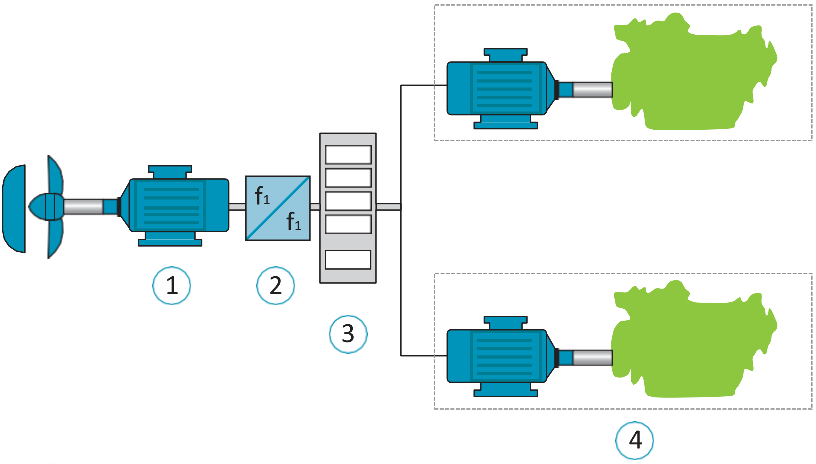
Both the PROMINENT project and the GRENDEL project (both 2019) have highlighted and discussed the most promising technologies that could be effective in achieving the greening objectives. In that sense, the most promising greening or best-available technologies have been selected on the basis of following criteria:

- Effects on energy consumption and emissions;
- Economic feasibility;
- Technical feasibility;
- Technological maturity.

A summary of the best-available greening technologies – identified on the basis of the above-listed criteria is provided it the following text.

Diesel-electric propulsion combines high engine efficiency, low noise levels and environmental sustainability due to potentially lower emissions of greenhouse gases and pollutants (GRENDEL, 2019). Any type-approved diesel engine for inland ships (NRMM Stage V) or marinized Euro VI truck engine could be used for diesel-electric propulsion. Such diesel engines combined with an electric generator are known as a generator set (genset) (GRENDEL, 2019). Depending on the respective application case, diesel-electric propulsion can significantly reduce energy consumption and related emissions because of its high efficiency: propulsion needs and power are constantly adapted to actual operational conditions.

Investment costs are currently relatively high, because electric propulsion systems are more or less custom-made, adapted to the operational profile of the specific vessel.



1. **Electric motor**:
   drives the propeller and may be with or without a clutch.

2. **Frequency converter**:
   supplies the motor with variable-frequency AC power.

3. **Main switchboard**:
   distributes power from all sources to all consumers.

4. **Genset**:
   provides AC and DC power, depending on the selection on the main switchboard and frequency converters.

Gas and gas-electric propulsion

Liquefied natural gas (LNG) is natural gas (mainly methane) that is cooled down to -162 °C and, therefore, liquified in order to ease storage and transport. LNG is mainly an opportunity for large vessels that have a high level of fuel consumption per year. In that case, high investment costs of the LNG tank and fuel system could be earned back in savings in fuel costs. LNG would allow for NOx emission reductions of at least 70 % compared to conventional CCNR II diesel engines and a reduction of up to 95 % - 100 % with regard to particulate matter (PM). CO2 emissions could be reduced by 25 %. Various European countries offer public support schemes for refitting inland vessels to LNG propulsion (France, Germany, Czech Republic) (GRENDEL, 2019).

Although bigger vessels with a high energy demand hold a relatively large share in the emissions of inland waterway transport in Europe, the number of vessels suitable for LNG is relatively limited. Moreover, investing in a 100 % LNG engine is risky because of the current uncertainty with regard to the price gap between LNG and diesel. In order to earn back additional investment costs for the transition to LNG engines (which can amount up to 2 million EUR), it is important to achieve enough savings in fuel costs. This depends on the relative price advantage of LNG compared to diesel. In the worst-case price scenario analysed as part of the PROMINENT project, there is not one positive business case for the application of LNG (Ecorys, 2018).

The latest development in inland shipping engine configurations is the gas-electric drive. The gas-electric drive is a system whereby an inland waterway vessel uses one or a number of gas engines that drive generators (gensets) that generate electricity. This electricity goes to electric motors that drive the ship.

Fuel cell propulsion

Fuel cells are energy converters that continuously convert the chemical energy of fuel, (usually hydrogen, natural gas or methanol) into electrical energy. Fuel cells allow local emission-free power generation. Fuel cell propulsion causes no mechanical stress on engine components because no fuel is burned. Consequently, there is no wear and tear, vibration or generation of noise as in conventional engines (GRENDEL, 2019). Maintenance costs are low. The downsides of fuel cell propulsion are currently the high investment costs and the limited operational experiences.

Likewise, there are also ongoing discussions on the introduction of fully electric drive systems, although this is associated with challenges concerning the power supply infrastructure, regulatory matters, storage capacity, size of the storage medium, charging time, and range of the vessel.

Auxiliary shipboard machinery comprises of all onboard machinery other than that used to generate power for the ship’s propulsion. Based on its intended use it can be classified into machinery required for proper functioning of the main propulsion engine, machinery for navigation and ship safety, machinery for cargo handling, and machinery required for the accommodation of crew and passengers.

According to location, auxiliary machinery can be divided into deck and below-deck machinery. Since the deck machinery is exposed to the effects of weather and sea water, this has to be taken into account when making decision regarding its location on board. In most cases, auxiliary shipboard machinery serves to move either solid or liquid cargo carried by the ship, or liquids or gases that need to be transferred on board. For that reason, the majority of auxiliary machinery is made up of cranes, pumps, fans and compressors. The number, size and type of auxiliary machinery items depend on the size, purpose and speed of the vessel. Sailing ships have the fewest auxiliaries — in which auxiliaries are at the same time the only engines — whereas passenger ships and warships have the greatest number of auxiliaries. The size of most auxiliary machines increases with the size and speed of the vessel. The number and size of most auxiliary machinery items are stipulated by the International Convention for the Safety of Life at Sea (SOLAS) and by the rules of classification societies.

4.4 PROPULSION

The theory of ship propulsion (or, shorter: ship propulsion) is the science dealing with the action of propulsors — devices that generate thrust and thereby set the ship in motion — and with the hydrodynamic phenomena associated with ship movement. For a vessel to travel at a given speed, a corresponding force must be applied that overcomes the ship's resistance at that speed. The energy source that generates the force required to propel the ship may lie outside the ship - as when the ship is towed by towlines or driven by wind and sails - or it may be located onboard, in which case a special device known as a propulsor, most commonly a screw propeller, converts the power delivered by the prime mover into thrust. Today, several types of marine propulsors are in use, differing widely in their operating principle, location onboard and structural design. These are: the screw propulsor (propeller) or ship's screw, the paddle wheel, the cycloidal — or Voith-Schneider — propeller, the Kirsten–Boeing propeller, and the water-jet propulsor.

Within marine hydromechanics it is customary to examine propulsion and steering separately. However, when taken together, the whole set of control devices on a vessel is referred to as the steering-propulsion unit.

In the field of propulsion there is an indescribable mess of terms (specialised terms in the English language). An azimuth thruster - AT, colloquially known as a "Schottel", is also referred to in English as: azimuthing thruster, steerable thruster, fully steerable thruster, azimuthing propeller, azimuthing propulsor, swivelling thruster, rotatable thruster, etc.

Therefore, it is not simple for people outside the profession to command the full breadth of terminology in this domain.

It is certain that, at the beginning of navigation, one device could meet both requirements for propulsion and for steering. While our ancestors, while sitting on a fallen tree trunk holding some branches in their hands, tried to sail towards their destination by rowing, they were, in fact, applying what is today known as a SPU – "a steering-propulsion unit".

Yet, we would be mistaken in thinking that this is something entirely new, since oars also represent one type of SPU. An oar, that people made by "perfecting" a branch, was also used for steering. The ancient Greek, Roman and Viking ships were steered by oars – sometimes tied with a rope. It is therefore not surprising that the German word "*das Ruder*" means both an oar and a rudder.

The oar is just one example of an SPU. They can be found on racing coxless boats, two-oared rowboats, river boats, Eskimo kayaks, Venetian gondolas, American-Indian canoes, etc. The rapid development of the SPUs is the reason why the related terminology has not yet been fully standardised. We can optionally classify them into 3 groups:

1. Propulsor and rudder combinations;
2. Steering-propulsion units;
3. Hybrid steering-propulsion units.

4.4.1 Propulsor and rudder combination

This SPU is a combination of:

a. A propulsor (that creates various extents of forward or astern thrusts, thereby enabling navigation at various speeds, vessel acceleration and deceleration); and

b. An appropriate rudder, which acts on the vessel with a transverse force and thus alters its course). This is a classic solution for large merchant vessels.

The immediate vicinity of the propulsor and the rudder results in favourable interaction: the propulsor benefits because the rudder placed in its water jet reduces the loss of rotational kinetic energy, while the rudder placed in a propeller's water jet develops a greater shear force, due to the increased velocity of the incoming stream. However, hub-vortex cavitation and, to a somewhat lesser extent, tip-vortex cavitation may cause cavitation erosion of the rudder (even more severe on fast ships). Bringing the rudder closer to the propeller has a beneficial effect in diminishing the rotation of the jet, thereby increasing propulsion efficiency. However, if brought too close to each other, they can cause intolerable vibration of the hull.

4.4.2 Steering Propulsion Unit

A steering-propulsion unit (SPU) is an integral device performing both the propulsion and steering functions of a vessel. Such devices have been in use on smaller and special vessels for a long time, but nowadays their use is being extended to vessels of a greater tonnage.

There are two sub-groups of SPUs: azimuthing SPUs and non-azimuthing SPUs.

An azimuthing SPU (ASPU) delivers a thrust force in any direction (but not of identical magnitude in all directions), i.e. from 0° to 360°. Non-azimuthing SPU (while sailing bow-first) delivers the thrust force only within the limited area of two stern quadrants.

The **non-azimuthing SPU – NSPU** sub-group includes: waterjet propulsors, semi-submerged / surface piercing propellers – SPP and steerable ducted propellers - SDP.

Waterjet propulsors (or just "jet propulsors") of various types are used in shallow waters, especially on unregulated rivers, but far more units are used on fast and very fast vessels, where their following advantages come to the fore: smooth peak resistance transition, very low susceptibility to cavitation, low level of noise and of vibrations. However, they also have some drawbacks, such as: considerable weight and the loss of displacement at the stern.

Figure 24:
Waterjet propulsor

Semi-submerged propellers **(surface piercing propellers - SPP)** are propellers of various designs that are used on very fast vessels because they adapt well to draught changes while speed-boating, achieve high degrees of efficiency (no losses due to the resistance of a shaft, struts or a propeller's hub), are not affected by cavitation, smoothly transit over the resistance peak and operate in shallow waters.

Overload protection of the prime mover in low-speed navigation, where the transom has not cleared yet, is achieved in practice in two ways. The first method is applied in hydraulic mechanisms that permit vertical movement of a propeller.

Figure 25:
Arneson drive with a partially submerged propeller at the end of a horizontally and vertically movable shaft.
The black cuff (rubber bellow) protects the universal joint.

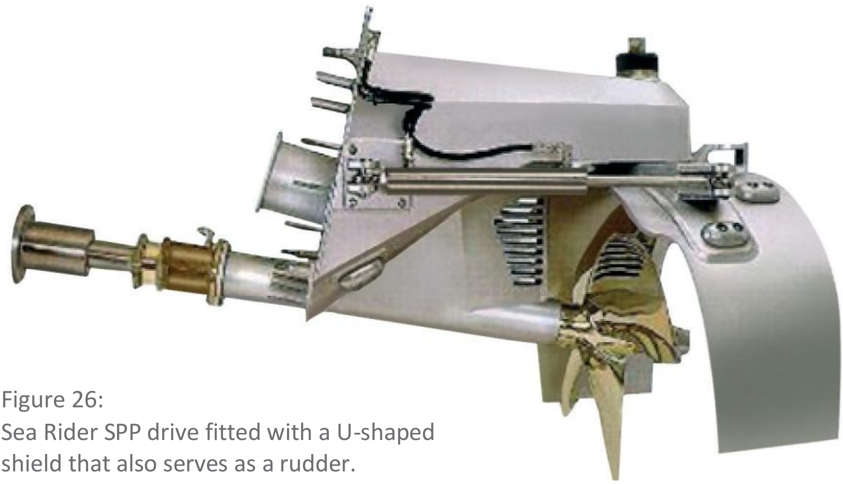


Figure 26:
Sea Rider SPP drive fitted with a U-shaped shield that also serves as a rudder.

The second method of reducing engine load is the use of a protective U-shaped shield around the propeller, acting as an exhaust gas pipe in order to cause artificial cavitation, thus reducing power absorption. A drawback of all SPP designs is the fact that they project far behind the transom and that propulsors of a U-shaped shield produce clouds of water-dust in certain operating regimes.

***Steerable ducted propellers*, SDP** – screw propellers in a steerable duct (nozzle) – are especially used on vessels with heavily loaded propellers (fishing vessels, minesweepers, ice breakers). In addition to the fact that an increase of water flow speed through the propeller reduces the propeller load, thus contributing to the higher degree of utilisation, which is the main task of the duct, it is also beneficial for the homogenisation of the incoming stream field, it improves the stability of the vessel on its course (simultaneously decreasing its manoeuvrability) and protects the propeller.

AziPod system (SPU–ASPU) contains four sub-groups, namely:

***Vertical propulsor* (VSP)** – which differs from all others in having a vertical shaft. Vertical blades protrude from a circular plate that is attached to the lower end of the shaft, (this is the reason why the VSP is also termed a “cycloidal” propulsor or “blade” propulsor), and each blade can be rotated about its own vertical axis by a system of linkages. Here, thrust variation is achieved by changing the pitch of the vertical blades around their own individual axes.

The best-known example is the Voith–Schneider propulsion unit, which — on account of its complex and costly structure — is typically installed in smaller craft such as tugs, floating cranes, ferries, naval vessels, etc. This type of propulsor offers many benefits: manoeuvring, precise and rapid execution of set thrust parameters, and direct control from the ship's bridge, eliminating the need for components such as a rudder, propeller shaft, stern tube with seals, etc. The main advantage of this unit is that propulsion and steering are integrated in a single unit.

In a VSP the propeller with a vertical shaft has, instead of a hub, a drum onto whose lower horizontal surface the blades are fastened. Each of these blades can be rotated about its own vertical axis by linkages, and thrust variation is achieved by changing the pitch of the vertical blades around these axes. In this way, a thrust vector is generated whose direction can be changed through any angle within the 360º span, resulting in excellent manoeuvrability. Consequently, with two Voith–Schneider units a vessel can even turn on the

Figure 27: Voith-Schneider propulsor

spot, and no conventional rudder is required, provided the hull in the installation area is flat. Because of its complexity, the Voith–Schneider system is predominantly fitted on vessels operating in sheltered waters, ports and lakes.

***Azimuthing or steerable or rotatable thruster* – AT** is a propulsor, also called a thruster, in which the power generated by the electric motor, diesel or petrol engine, is mechanically transferred onto the propeller mounted on a horizontal shaft. In addition to shafts, this requires use of conically shaped bevel gears with tooth-bearing faces. Propellers can be distinguished as pusher type propellers, tractor (pulling) type propellers and tandem (twin) propellers. Pusher propellers often include ducts / nozzles (ducted fans). Some manufacturers of such propulsors also use contra-rotating propellers.

***Podded propulsor* – POD** is similarly shaped as the electrically driven ATE propulsor, but with one significant difference – the electric motor is housed within a submerged, streamlined capsule-shaped body, or "pod", so that no vertical or horizontal shafts or bevel gears are needed, since the propeller is mounted directly onto the electric motor shaft.

Figure 28:
Azimuthing thruster, electrically driven with tandem propellers – SCD

Figure 29:
Azimuthing thruster, diesel driven with pushing propeller in the nozzle – SRP

Pump-jet propulsors are manufactured by the well-known German company Schottel. A pump-jet propulsor differs fundamentally from all the above-mentioned propulsors, and could be briefly described as a centrifugal pump with a vertical shaft strut, mounted at the vessel's bottom. Water is sucked directly into the pump through the intake funnel in the plate, and is expelled through the pump's (spiral) outlet nozzle, at an angle of 15° towards the bottom, so as to generate the desired thrust direction. It covers a manufactured power range from 0.05 to 3.5 MW.

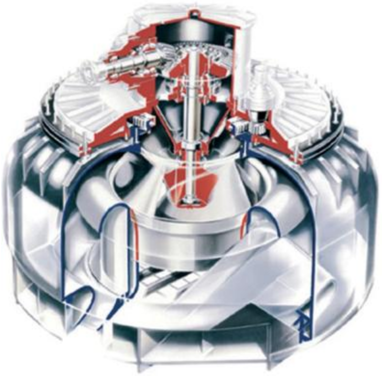


Figure 30: Pump-jet propulsor – Schottel model SJP®

4.4.3 Hybrid propulsion system (HSPS)

Hybrid SPS is a combination of any typical (regular) propulsor, a propeller, and an azimuthing SPU – most frequently *a podded propulsor* POD, but it could also be an *azimuthing thruster (steerable thruster)* AT. The essential feature is that the azimuthing SPU is coaxial with a regular propulsor, positioned immediately behind it and has contra-rotating propellers. Works on HSPS development have lately been intensified, and its widespread adoption is expected in the near future.

4.4.4 Advantages and disadvantages of ASPU and HSPS

The advantages common to all ASPUs and HSPSs, which explain why these propulsion-and-steering systems have gained such extensive application, are listed below. Some of the common qualities are:

- Excellent manoeuvrability of a stationary vessel and at very low speeds;
- Quick stop;

- Significant reduction of the ship’s turning circle at full speed;
- Absence of a rudder results in lower resistance, avoidance of rudder cavitation erosion, and lower costs and weight;
- Propeller’s positioning in a very uniformed speed field increases its efficiency and reduces harmful effects of cavitation (vibrations, erosion, noise);
- No resistance of appendages on multi-propeller ships;
- Reduced loss of power in transmission, since there is no stern tube;
- Rudder and steering device are not required, which results in lower costs and greater deadweight;
- Simple assembly (no shaft-line alignment required);
- Transverse stern thruster is not required.

Disadvantages of ASPUs and HSPSs are generally different from one design to another, and cannot be reduced to a common denominator. Therefore, they will not be discussed separately on this occasion and at this level.

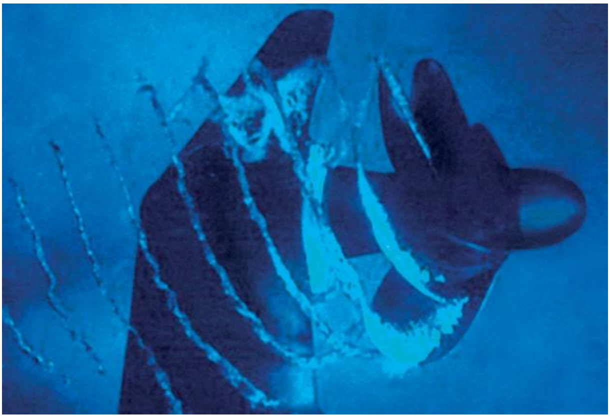
4.4.5 Cavitation

Cavitation is the phenomenon in which water evaporates and vapour bubbles are formed. It occurs at the moment when the pressure of water becomes equal or falls below the saturated-vapour pressure. When the pressure of water around the propeller blades drops to the vapour pressure of water, the vapour “bubbles” or “voids” are formed and subjected to higher pressure, where they implode (turn into droplets again). Implosion in the immediate vicinity of the propeller’s blades may even damage their surface. First damage occurs on the tips of the blades, where water currents are strongest. This phenomenon is accompanied by vibrations and noise, and its consequences are lower efficiency and damage to the propeller.

Basic forms of cavitation are:

- Sheet cavitation;
- Bubble cavitation;
- Cloud (or vapour-cloud) cavitation;
- Tip- or hub-vortex cavitation.

Figure 31:
Cavitation



The risk of cavitation is greatest with heavily loaded propellers, that is, propellers delivering very high thrust. That risk is generally lower when, instead of a single propeller, two or more propellers are mounted at the stern. Cavitation occurs above certain rotational speeds, leading to fluid breakdown and loss of thrust. Ultimately it may prevent the vessel from attaining its design speed. Prior to that, cavitation manifests as noise, whistle-like sounds, vibration and erosion of propeller blades, struts and rudders. Whereas cavitation problems once concerned only high-speed vessels, the continual rise in attainable speed and power has made cavitation increasingly significant — especially in single propeller vessels with high output — because of large velocity gradients across the propeller plane, which favours cavitation, so attention must be paid to the clearance between blade tips and the hull.

The most serious consequence of cavitation is erosion. Early observations of blade erosion were attributed to corrosion, but modern research has explained the cavitation mechanism, the effects of which, besides erosion, include other kinds of damage.

4.4.6 Summary

According to the foregoing, it could be noted that this branch of shipbuilding is perhaps the “most propulsive” one and that it has the strongest tendency to develop. In structural terms (materials, constructions, displacement...), the shipbuilding industry advances daily, but matters of propulsion and its reliability represent an area that will largely determine the future and the competitiveness of the shipping industry and commercial navigation in general.

Propulsion systems for inland-waterway vessels develop particularly quickly and are optimised in accordance with demands set for design engineers, in accordance with the development of transport and traffic technologies. Installation and use of bow thrusters in newly built inland-waterway vessels facilitates their manoeuvring and steering, and contributes to a higher degree of navigational safety, which is an essential factor under conditions of denser traffic in narrow or restricted fairways or their sections.

4.4.7 Rudder

A rudder is a device used to steer a ship in the desired direction, and to ensure that the given course is maintained.

The rudder is an essential element that, in addition to its primary purpose of keeping a vessel at the correct steering trajectory, can be an integral part of the vessel's propulsion unit. Furthermore, it is also one of the vessel's mobile appendages. Introduction of mechanical propulsion meant that all these attributes are to be shared with a propeller. The rudder, as well as all other elements of the assembly, must sustain pressures, forces and resulting torques that arise from the rotation at the vessel's maximum speed. This should include superimposing forces applied on a rudder plate in heavy weather, due to subsequent movements, i.e. yaw, pitch and roll. Modern shipbuilding trends apply a number of different rudder designs that depend on a vessel's type, size and speed. The design and shape of the rudder may also be determined by other factors – design engineer's and owner's preferences, region of navigation, water depth, etc.

A common feature of almost all of today's rudders, regardless of type, is their hydrodynamically profiled horizontal cross-section.

Single-propeller ships carry the rudder directly behind the propeller. This enables utilisation of the favourable effect of the propeller jet on rudder action.

Twin-propeller ships can have one or two rudders, but if a higher degree of manoeuvrability of a twin-propeller ship is required, then a rudder is placed abaft each propeller.

Depending on the position of the blade relative to its axis, rudders are distinguished as: unbalanced, semi-balanced and balanced rudders.

- *Unbalanced rudders* have the entire area behind the rudder's axis of rotation;
- *Semi-balanced rudders* have 10 % – 15 % of the area in front of the rudder's axis of rotation; and
- *Balanced rudders* have 20 % – 25 % of the area in front of the rudder's axis of rotation.

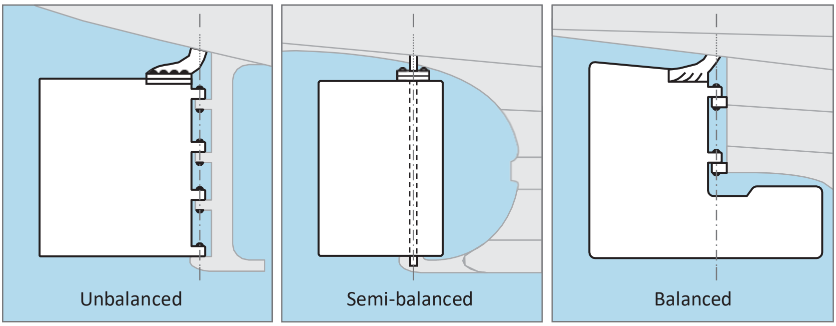


Figure 32: Rudder types, by position, with regard to axis

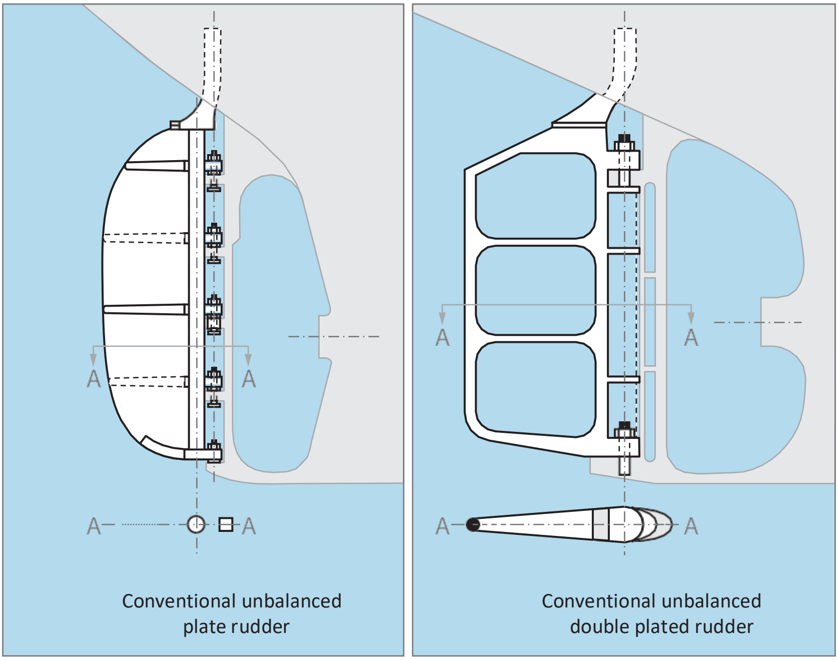


Figure 33: Rudder types, by cross-section shape

Rudder types, by cross-section shape, are divided into:

- *Plated rudders,* have a regular, flat profile cross-section and, seeing how their resistance is greater than that of double-plated rudders, they are rarely used today, and mainly on small vessels or vessels without their own means of propulsion;
- *Double-plated rudders* have a cross-section of a symmetrical double-plated profile that significantly reduces resistance, but its hollow structure causes problems with impermeability.

By the manner in which they are fastened to the hull, rudders are divided into:

- *Simple / conventional rudders*: attached to the rudder post by one or several bearings, and by the rudder stock to the vessel hull;
- *Full-spade or hung rudders:* attached to the vessel's hull only by the rudder stock; and
- *Semi-spade/ underhung rudders* – additionally leaning onto the rudder post or horn, and attached to the vessel stern with a heel piece.

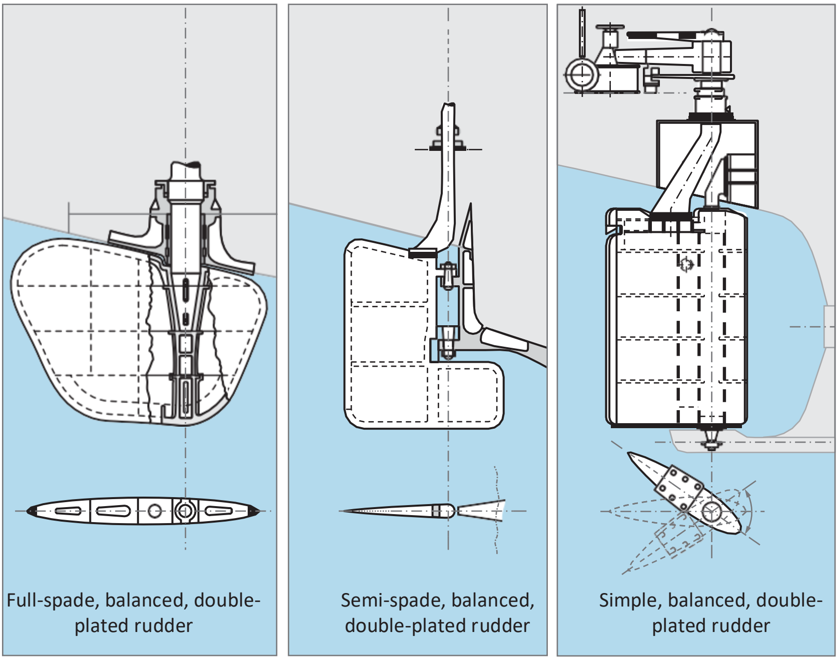
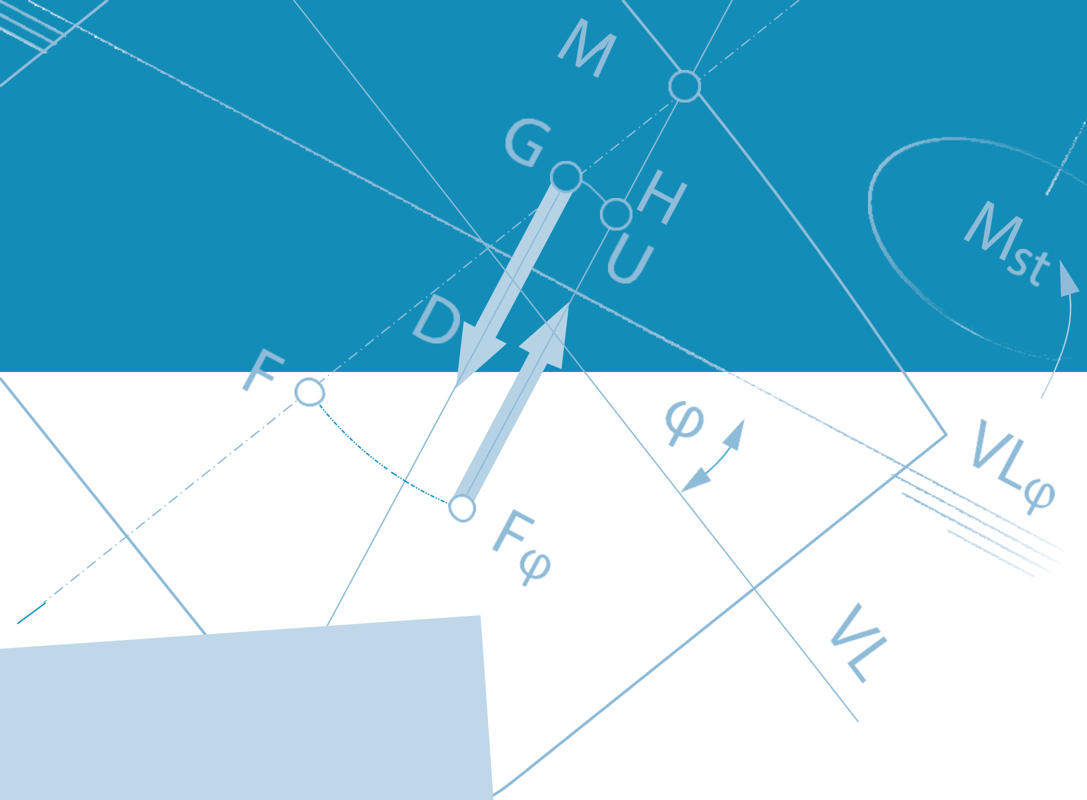


Figure 34: Rudder types, according to the way they are secured to the hull



5.

5.
STABILITY AND LOADING OF CARGO

5.1 BASICS OF SHIP STABILITY

Stability of a ship is defined as its ability to regain its upright, original position, once the external forces, which have caused the heel cease to act. Stability of a ship can be conceived as the ship's resistance to heeling. External forces capable of producing a heel are: wind, waves, unevenly distributed cargo, centrifugal forces in a turn, water penetration into a vessel's hull, an athwart-ship pull of a towline on a tugboat, lifting of heavy cargo sideways, etc. The importance of ship stability calculations is indicated by the fact that a ship without stability cannot sail at all (it would capsize), while poor / insufficient stability constitutes a hazard to the crew and cargo. A loss of stability is one of the most frequent causes of vessel loss. Majority of the greatest naval disasters resulted from capsizing caused due to the reasons cited above.

Ship stability is determined by two factors:

- *Form stability* – form of the immersed part of the hull;
- *Weight stability* – weight distribution.

Essential parameters required in ship stability calculations are the distance between the centre of gravity (G), which is affected by the downward pull of gravity (D), and the centre of buoyancy (F), which is affected by the buoyancy force (U). The position of the ship's centre of gravity (G) is defined by the distance measured from the after perpendicular, and its height above the inner face of the bottom or keel. Archimedes' principle states that any object, immersed in a fluid, is buoyed up by a force (U) equal to the weight of the displaced fluid.

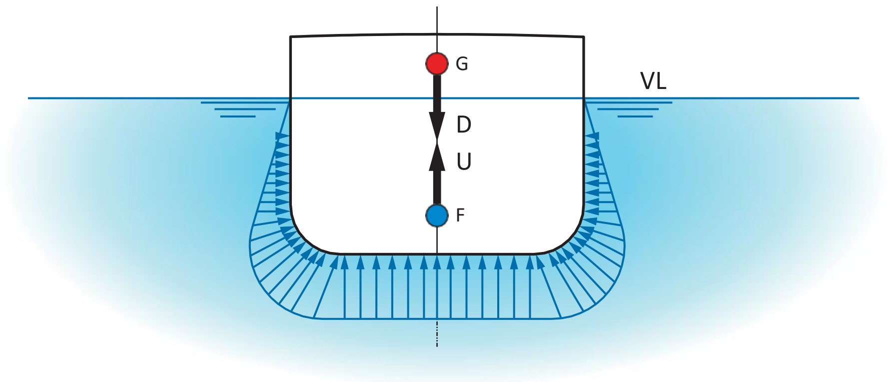


Figure 35: Main parameters required for stability calculations

Ship stability can be divided into two basic groups:

- With regard to acting moments, we distinguish: *static* stability (which, depending on the ship's form and weight distribution, can be subdivided into form stability and weight stability) and *dynamic* stability;
- With regard to direction of heeling, we distinguish: *transverse* stability (heeling about the ship's longitudinal axis - roll) and *longitudinal* stability (heeling about the ship's transverse axis - pitch).

5.2 STATIC STABILITY

Static stability is the state in which the external moments act statically, i.e. do not change over time, or change slowly and gradually. Consequently, accelerations and their resulting inertial forces arising from such movements can be neglected. Static stability can be defined as the ship's resistance to moments that displace it from a position of equilibrium.

As external forces are applied to the vessel's hull, the ship heels, emerging on one side and submerging on the other. One part of the displacement shifts from the emerged to the immersed side. The displacement does not change when the ship heels, since the weights remain unchanged. Moment generated by this shift of buoyancy creates a righting moment. When static equilibrium is re-established, i.e., the condition where the statical heeling moment (Mv) equals the static righting moment (stability moment, Mst), the heeling stops, but the ship remains inclined. When the external forces cease, the heeling moment disappears, and the righting moment restores the ship to its upright, equilibrium position.

Exposure of the ship to waves during navigation results in inertial forces that are neglected in the static condition (the static heel is assumed to last a very long time). The ship must be able to absorb the energy transferred onto it by waves, i.e., must possess dynamic stability.

5.2.1 Transverse stability

Distinction can be made between initial stability and large-angle stability. Initial stability occurs when the ship is in a fully upright or in a slightly heeling position.

Value of initial stability in the upright position is measured as the distance between the metacentre and the centre of gravity, whereas, in cases of small angles of heel, it is expressed by the initial righting moment **Mst0**. In cases of initial stability, angle of heel (ϕ) is small, ranging from 6° to 8°.

At such angles, the immersed and emerged wedges have equal volume and shape. In majority of cases, it suffices to analyse the initial stability alone.

The point Mo, where the line of buoyancy force intersects the ship's centreplane is called the initial metacentre. The distance MoG is referred to as the initial metacentric height. Initial metacentric height - MoG - is a measure of initial stability; it also determines a vessel's rolling motion.

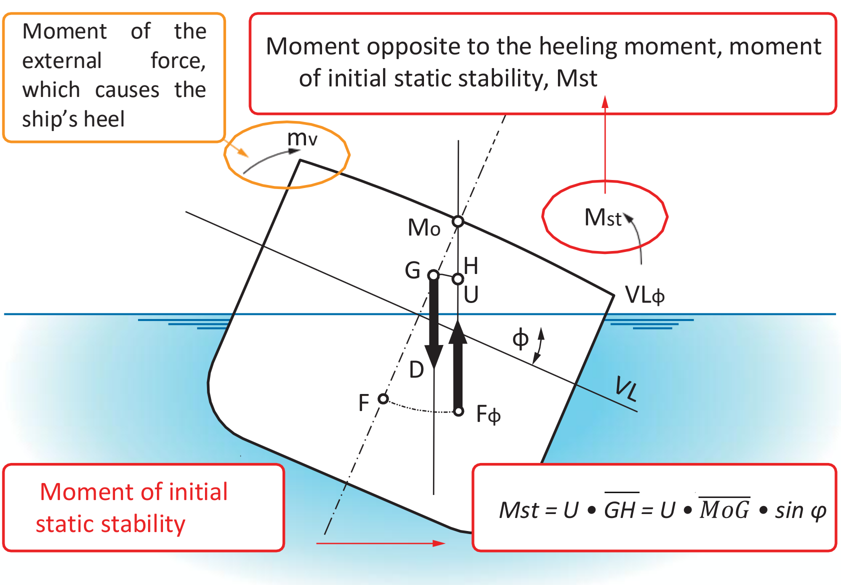


Figure 36: Transverse stability of a ship

General requirements for ship stability are:

1. The weight of an immersed ship (D) equals the upward force of buoyancy exerted by water (U), i.e.:

D = U; U = V× ρ× g	Where: V = volume of the immersed part of the hull (m³); ρ = water density (kg/m³); g = gravity / gravitational acceleration.

2. Forces of buoyancy and gravity must lie on the same straight line perpendicular to the current waterline. Otherwise, resulting coupling forces will cause the ship to heel and, in the worst-case scenario, capsize.

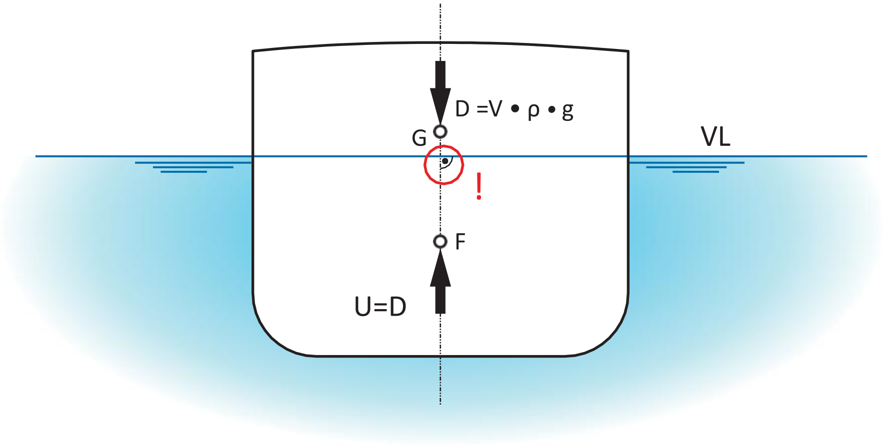


Figure 37: Ratio between the buoyancy force and mass / weight of displaced fluid

3. The metacentre (Mo) must at all times remain above the centre of gravity (G).

A ship is said to be in **stable equilibrium** if Mst (the moment of static stability) is positive. That will be the case only in the following situations: MoF>FG, i.e., the centre of gravity G, must be below the initial metacentre Mo, which is a general requirement for equilibrium of vessels. The moment of static stability acts to restore the ship into its original upright (equilibrium) position.

A ship is said to be in **indifferent (neutral) equilibrium** if the metacentre (Mo) and the ship's centre of gravity (G) coincide: MoF = FG. There is no moment of stability here, thus the ship remains heeling until some force acts to change its position.

A ship is said to be in **unstable equilibrium** if the metacentre (Mo) is below the ship's centre of gravity (G): MoF<FG. This results in a negative (righting) moment of stability (–Mst), acting to increase the angle of heel, thus causes the ship to capsize.

The position of the centre of gravity (G) is of utmost importance for the analysis of ship stability. In the majority of ships, the centre of gravity (G) lies above the centre of buoyancy (F). This position is conditional upon cargo stowage, as well as a vessel's stability characteristics. However, ships with reduced stability, such as sailboats, must have a centre of gravity (G) lying below the centre of buoyancy (F), which can be achieved with appropriate weight distribution (adding ballast).

This may lead us to conclude that a floating object is more stable if its centre of gravity G is in a lower and the initial metacentre Mo in a higher position, i.e., if the initial metacentric height MoG is greater.

Nevertheless, in practice, a vessel should satisfy two "opposing" conditions:

- Initial metacentric height (MoG) must be great enough for the ship to resist external moments;
- Initial metacentric height (MoG) must be moderate enough to ensure comfortable navigation. Otherwise, because of high inertia, these ships would shift over its initial position and roll even more violently than vessels of appreciably lesser stability.

5.2.2 Longitudinal stability

Longitudinal stability is the state that restores a ship's upright position, should it heel about its transverse axis. Difference between transverse and longitudinal stability is reflected in the fact that a ship is not symmetrical with respect to the midship section (transverse axis), whereas it is symmetrical with respect to the centreplane, and in a longitudinal sense it is very stable since it has great longitudinal metacentric height MLG.

Everything that applies to transverse stability also applies to longitudinal stability, yet two essential differences exist.

- Vessels are symmetrical with respect to a longitudinal centreplane of the ship, but are rarely symmetrical with respect to the midship;
- Moments of stability will not be equal when a vessel heels in the fore and aft direction.

Trimming, i.e. the longitudinal heeling of the ship, is of a much lesser extent, and longitudinal metacentric height is considerably greater than the transverse one. Consequently, a conclusion may be made that longitudinal stability is substantially greater than transverse stability.

5.2.3 Form stability and weight stability

A vessel's stability depends both on hull forms and on distribution of vessel mass and cargo. Distribution of cargo on a vessel must be in alignment with the ability of a vessel's form to generate a stabilising moment that will exert external forces enabling a heeling ship to regain its upright equilibrium position.

Form of a vessel affects stability in a number of ways. For small angles of heel, the most influential factors are the vessel's breadth at the waterline, and the fullness of the waterline. For every increase in breadth, the stability moment increases for that same angle of heel due to the increase in volume of the immersed wedge.

At larger heel angles, the wedges become irregular because the deck submerges or a bilge strake previously underwater emerges, creating a greater influence of the freeboard. The volume of the vessel above the waterline (reserve buoyancy) is immersed at large angles of heel. A large reserve of buoyancy provides a wide stability range, i.e., allows the ship to retain stability even at large angles of heel.

The only relevant factor in terms of form stability changes is the breadth of a vessel.

Moment of weight stability has a negative impact on ship stability. Therefore, the position of the centre of gravity (G) must be as low as possible in order to decrease the moment of weight stability, i.e. increase the total stability moment. In practice this is achieved by stowing cargo as low as possible in the cargo space, prohibiting deck stowage, and, if this should not suffice, by adding so-called "ballast" along the bottom of the hull in order to artificially lower the ship's centre of gravity.

5.3 DYNAMIC STABILITY

Sudden changes in the extent of forces or moments affecting a ship cause acceleration of masses. We then speak of dynamic action and of the ship's dynamic stability. In cases of dynamic stability, external forces act erratically, or intermittently (in impulses). In such an event, a vessel will heel to a certain angle ϕ_1, but when the dynamic force ceases it will not immediately regain its equilibrium position and will, due to inertia, continue to heel to a further angle ϕ_2. This means that a vessel will continue to heel, even after the static equilibrium has been re-established, until mechanical effects of the external force and the buoyancy force balance each other, i.e. until dynamic equilibrium is established. Stability is the property of a ship to resist forces making it heel, and its ability to automatically regain its upright, equilibrium position, when those forces cease to act. A vessel without such abilities cannot navigate at all, and a vessel without sufficient stability is not safe for navigation.

5.4 FREE SURFACES AND THEIR EFFECTS ON STABILITY

When a vessel carries liquid or bulk cargo, its holds can be filled to the top, or certain gaps can remain to create so-called free surfaces.

When a tank is completely full (water passing through the vents) it behaves as a rigid body, and as such is taken into account in stability control calculations. However, if tanks are not full, liquids follow the motion of the vessel. In such cases, cargo changes its shape and, consequently, its centre of gravity. As a result, the metacentric height will be shortened, i.e. stability will either be reduced or even completely lost. It should be noted that metacentric height shortening, i.e. reduction of stability, does not depend on the amount of cargo, but only on the moment of inertia of a free surface and the cargo's specific weight. Therefore, even the smallest amount of cargo at the bottom of the ship has the same negative effect as cargo in a nearly full cargo space. The effect of free surfaces is accounted for by a free surface correction, which is calculated using the volumetric moment of inertia of the liquid surfaces in tanks, denoted by $\boldsymbol{i}$. The moment of inertia of free surfaces in tanks is determined for each partially filled tank on board the vessel by the following expression:

$i = l \times B^3/12$	Where: i – moment of inertia of a free surface; l – distance between the transverse bulkheads; B – breadth of the ship.

From the equation for the moment of inertia of the waterline it is evident that the breadth enters to the third power, so even the smallest reduction in breadth has a significant impact on stability.

Some vessels are fitted with bilge keels, so that when they heel to the bilge keel, the waterline area increases sharply, thereby increasing the metacentric height. In small boats, if weight is shifted to the bow — which is narrower — so as to submerge it, stability falls greatly because the waterline surface area is reduced; this effect is immediately felt when people move towards the front of the boat. On river crafts the centre of gravity G lies above the main deck, but because they have a small displacement volume and a large waterline area, they remain stable due to their metacentric radius being very large.

Free surfaces are: all uncovered liquids, fuel tanks, lubricants (they must not be filled up to the top), technical water, water penetrating the ship, water used to extinguish fires, etc. In addition, grains and some other bulk cargoes are considered to be free surfaces. All free surfaces significantly reduce the initial stability of the ship, but particular danger exists on ships whose holds extend full breadth, along the entire ship length, because if the water penetrates these holds, there is a real threat of capsizing. The same applies to ferries. If the water floods the car deck because the front doors are not properly sealed, there is a risk of capsizing (not such a rare example). All precautionary measures must therefore be taken during construction of such vessels in order to prevent these adverse events from occurring. This problem can be resolved with the use of longitudinal partitions/ bulkheads in all areas where free surfaces can appear.

In every case, all free surfaces reduce the metacentric height, which is something that must be considered in all stability calculations.

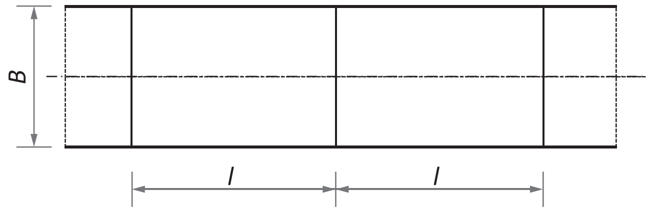


Figure 38: Transverse partitions/bulkheads on a horizontal plane

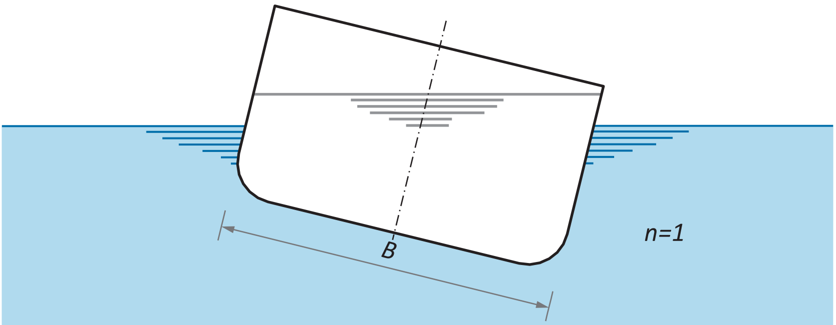


Figure 39: Diagram showing the position of cargo and free surfaces in a cargo space without longitudinal partitions/bulkheads

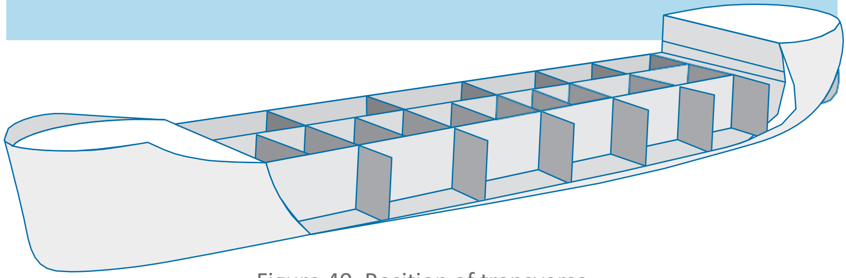


Figure 40: Position of transverse and longitudinal partitions/bulkheads on a tanker

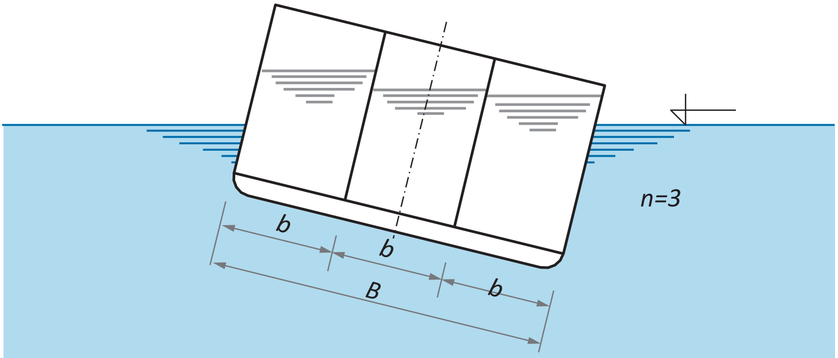


Figure 41: Diagram showing the position of cargo and free surfaces in a cargo space with longitudinal partitions/bulkheads

5.5 CARGO LOADING

Cargo loading is a particularly sensitive issue that requires excellent knowledge of the previously described ship stability. Equally so, individuals responsible for cargo loading must carefully plan and implement the entire operation, while bearing in mind and taking into account all cargo and vessel specifics. The following text deals with terms relevant for ship loading.

5.5.1 Cargo distribution on the ship

Cargo distribution, with respect to transverse stability of the ship: Transverse stability directly depends on the metacentric height, which means that greater metacentric height will ensure greater stability. This also means that the position of the ship’s centre of gravity directly affects stability, and the lower that centre lies, the higher the metacentric height and, consequently, the stability.

This leads to the conclusion that heavier cargo should be stowed as low as possible. However, it should be taken into account that an excessively large metacentric height, i.e. stability, means a more intense pitch and roll, which is detrimental to the cargo, to the vessel and to the crew. Moderate or optimal metacentric height can be achieved by loading the tween-deck. Before any cargo is stowed on the upper deck, transverse stability must first be secured (filling of double-bottom tanks with water or loading of lower decks).

Cargo distribution, with respect to longitudinal stability of the ship: Trimming, i.e. longitudinal heeling of a ship, is not extensive, which means that external and internal moments resulting from such motion are likewise small and constitute a bow-down (trim by head) or a stern-down (trim by stern) trim. Bow-down trim means greater resistance and reduced propeller efficiency, whereas a stern-down trim increases propeller efficiency and should be allowed for when planning the stow.

Cargo distribution, with respect to ship hull strength: Ship hull strength represents its resistance to deformations caused by the action of external forces. We distinguish transverse strength, longitudinal strength and local strength, which are ensured by strength of the ship’s keel, frames, bulkheads, propulsion unit base and materials used during construction (depending on a ship’s intended use).

The following simple formula is applied in longitudinal cargo distribution and loading (based largely on maritime navigation experience):

$$Qs = Cs \cdot \frac{Qk}{C} \text{ (t)}$$

Where:

Qs – mass of cargo in one ship's hold

Cs – capacity of one hold

Qk – useful deadweight; total mass of commercial cargo carried

C – total carrying capacity of all ship's holds (m^3).

Total and individual hold capacities are derived from the cargo plan, which we will address later in the text.

Cargo distribution, with respect to transverse stability:

Symmetric loading on both, i.e. port and starboard sides, is of utmost importance for transverse cargo distribution. This helps ensure that navigation, i.e. pitch and roll of a ship, will not cause movement of cargo, reduction of the ship's stability or damage to hold fittings.

Cargo distribution, with respect to the cargo loading / unloading rate:

In principle, this refers to simultaneous loading / unloading on several points in the ship while paying constant attention to stability. The process of planning of such cargo loading / unloading operations in several ports is to be approached in an organised manner that takes into consideration cargo availability for each subsequent port.

5.5.2 Heavy and light types of cargo

Cargo stowage: A key parameter for correct stowage is the ***stowage factor***. In shipping, the stowage factor is the figure that indicates how much space (capacity) is occupied by properly stowed cargo packaged for transport. The stowage factor is expressed in cubic metres, and its calculation must take into account specific cargo characteristics and packaging, i.e. protective materials required for cargo stowage.

Broken stowage: Since cargo cannot be ideally stowed, certain lost space (broken stowage) occurs with all types of cargo (to a greater or lesser extent).

It is believed that broken stowage for cargo packed in bags is approximately 7 – 10 %, for grains up to 2 %, whereas for general cargo in the range of 10 – 15 %. Broken stowage also arises from the irregular shape of the fore and after hold. In addition, installations, propeller shafts, pipelines, etc., which are located in the holds, must also be taken into consideration.

Freight (measurement) ton and freight rating: Total ship capacity divided by its useful deadweight for which a freight charge is paid is called *space per deadweight ton.* If a loaded vessel carries cargo of such a volume and weight that it fills all the vessel's hold spaces, it would bring it down to the maximum draught line. Such a vessel is said to be loaded *"full and down".*

Measurement ton is still used in maritime transport when tariffs are charged by occupied space (40 cubic feet per one ton or 1.133 m^3). For that reason, cargo is divided into light and heavy cargo.

Heavy (high density) cargo occupies less than 1.133 m^3 of space per one ton, and includes: various ores, steel profiles and sheets, copper rods, cement, etc. When loaded with heavy cargo, a ship will immerse to the maximum draught line, but its holds will not be full.

Light (low density) cargo occupies more than 1.133 m^3 of space per one ton, and these are mainly general types of cargo. In such cases, a ship's total deadweight will not be utilised even though its holds are full.

Circumstances have changed lately, since modern ships have a greater cargo carrying capacity. Consequently, a ship's capacity and deadweight can be fully utilised with cargoes occupying 1.4 to 1.7 m^3 of space per one ton. In such cases (heavy cargo), freight is paid per one ton of mass. Having in mind that freights for light cargoes are paid per measurement ton, it is evident that cargoes must be stowed as efficiently as possible.

Ship operators independently choose whether freights will be levied per freight rate or ton of mass, and this is called *freight rating.* It is common that ship operators have their own tariffs with classified types of freights. For some types of cargo, the freight is determined per m^3 or even by unit (package) – for special cargoes.

5.5.3 Longitudinal cargo distribution

Capacity factor: ratio between a capacity of each separate hold and a total capacity of all ship's holds:

$$fc = \frac{Cs}{C}$$	Where: Cs – capacity of one hold; C – total capacity of all holds.

If a ship's useful deadweight, i.e. total mass of commercial cargo for which the freight is paid, is multiplied by the capacity factor of one hold, the obtained result will be the cargo mass per one hold:

$$q = Qk \cdot fc \text{ (t)}$$	Where: Qk – useful deadweight of a ship; fc – capacity factor of one hold; q – cargo mass per one hold.

The sum of all factors must be one (1), and the sum of all masses (q) is equal to the useful deadweight of the ship (Qk). This is applied to ensure the validity of the calculation.

5.5.4 Preparation of a ship for cargo loading

Preparation of a ship for loading must be approached with utmost seriousness. These operations, to a great extent, depend on the type of ship's holds and types of cargo to be loaded. Having that in mind, we can distinguish ship holds and tween-decks. Ships specifically constructed for transport of bulk cargo and ores do not have tween-decks, as it would get in the way of grapple cranes that are used to tranship such types of cargo. Holds occupy the space between the ship's double bottom and one of its decks, and across its breadth, from one side of the ship to the other. Ships usually have several holds that are marked from bow to stern. Different pipelines and installations pass through the hold. Hatch openings that allow cargo loading and unloading are called *cargo hatches*.

Depending on their intended cargo, holds must be cleaned and dried before loading / unloading, using approved methods and preventing pollution of surrounding water. Certain types of cargo are to ventilated before and after loading / unloading. If cargo is to be stowed on deck, the same rules apply, provided that particular attention is paid to drainage channels and grilles, and that cargo does not block access to fire protection equipment, passages and doors.

The responsibility of preparing a ship for cargo loading rests with the ship's master, and, in some cases, competent inspection officers can inspect the holds. Preparing and protecting the cargo is very important and involves use of various types of mainly wooden dunnage (boards, planks, etc.), the purpose of which is to protect installations and pipelines from potential damage. The dunnage also provides boundaries between cargoes and prevents displacement of cargo due to the ship's motions.

The course of cargo loading operations is managed by a crew member in charge of the cargo and the loading procedure, who must keep continuous communication with all individuals involved in this process, whether they are on board, ashore or operating the transhipment machinery. Also, it is this person's responsibility that the cargo remains preserved from the moment of takeover, during further handling and up to the handover.

Every crew member has clearly defined duties both in the preparation phase and during loading operations.

Preservation of cargo during transport is very important. Consequently, all precautionary measures must be taken so that the cargo maintains its shape, quality and use-value. For this purpose, the cargo is *generally packaged* with various types of wrappings and packaging.

5.5.5 Monitoring of cargo during navigation

During navigation cargo must be monitored continuously to prevent any damage or deterioration of sensitive items, etc. This is particularly affected by the voyage duration, and prevailing climatic and micro-climatic conditions.

Basic measures to be undertaken for this purpose can be classified into several categories, such as:

1. Natural and artificial ventilation of holds;
2. Protection of cargo from humidity;
3. Protection of cargo from heat;
4. Protection of cargo from friction;
5. Protection of cargo from the pressure of other cargo;
6. Protection of cargo from rodents and insects;
7. Theft protection.

5.5.6 Loading, stowing and transport of various types of cargo

General (unspecified) cargo includes the widest variety of goods, such as: bags, barrels, bales, crates, boxes, bundles, cars and other vehicles, agricultural and propulsion equipment and its parts, machinery and household appliances, etc. Also, general cargo includes various types of castings, pipe profiles, planks and other building materials. Loading / unloading of such cargo is somewhat more complex than loading / unloading of bulk or liquid cargo. Manipulation of general cargo requires use of ship cranes, and of forklifts, trailers or other port vehicles ashore.

Bulk cargo refers to commodities shipped unpackaged, but which are loaded and transported in bulk, such as: coal, coke, ores, cereals, salt, sugar, sand, gravel, stone, etc. When bulk cargo is packaged, it is classified as general cargo (salt, cereals, cement, etc.). This type of cargo is mainly transported in large quantities, and bulk cargo manipulation has lately been modernised, so that time spent in ports is now shorter than in past times.

Some major types of bulk cargo need particular attention and implementation of special procedures. These include: cereals, coal ore, timber, sugar, rice, coffee, etc. These cargoes require application of special firefighting measures, protection against humidity and high temperatures. Certain commodities are liable to spontaneous combustion and require implementation of special monitoring measures.

Likewise, cargoes packaged in bales / rolls / bags, barrels and crates requires special treatment and stowage, depending on the material they are made of. Consequently, in order to achieve better economic use and utilisation of space, their stowage and safe-keeping in cargo spaces is carefully planned.

Liquid cargo is mainly transported in tanks that are specifically constructed for particular types of liquids (tankers, cisterns), and these most frequently include: oil and oil derivatives, various types of oils, water, alcohol, wine, liquefied gases, fruit-juice bases, etc. Some types of liquid cargo are transported in special metal barrels. Transport of propane, butane, water, wine and fruit-juice bases is carried out by special ships that apply specific monitoring measures compulsory for such types of cargo.

Dangerous cargoes are provided special treatment and, due to their specific characteristics, their carriage is regulated by the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN), which classifies dangerous goods.

The classes of dangerous goods according to ADN are as follows:

1. Explosive substances and articles;
2. Gases;
3. Flammable liquids;

4.1 Flammable solids, self-reactive substances and solid desensitized explosives;

4.2 Substances liable to spontaneous combustion;

4.3 Substances which, in contact with water, emit flammable gases;

5.1 Oxidizing substances;

5.2 Organic peroxides;

6.1 Toxic substances;

6.2 Infectious substances;

7. Radioactive material;
8. Corrosive substances; and
9. Miscellaneous dangerous substances and articles.

Due to importance and specific characteristics regarding transport of the aforementioned substances, special safety measures are always applied, which depend on the specific type of dangerous goods that are being transported. Measures and procedures regulating carriage of dangerous goods are defined by international (ADN) and national regulations.

Refrigerated cargo is transported frozen or refrigerated to a particular temperature, in order to stay fresh. This includes:

1. Deep-frozen (temperature up to -40° C);
2. Frozen (temperature up to -8° C);
3. Fresh (temperature in the range from -2° C to +12° C).

Deep-frozen and frozen goods are: various types of meat and fish; and fresh goods include: fruits, vegetables, eggs, milk and dairy products, lard, etc. Cooling equipment on modern ships is designed so that holds are air-cooled. Cooling systems can be either direct or indirect. These two systems differ in the way in which Freon gas (or other environmentally friendly inert gas) is used to regulate the temperature in evaporators and the way in which cooled air is directed into the holds (freezers).

Today we have special vessels, so-called "reefer ships", which have a centralised cooling system that is automatically managed and remotely monitored.

5.5.7 Most common packaging systems in modern waterway transport

The most common packaging systems used in modern waterway transport are pallet and container systems, which hold an important place in overall waterway transport due to their simple and economic handling.

Pallets typically have dimensions of 80 x 120 cm, and their cargo is loaded up to 150 cm of height. They have grooves and hooks and can be loaded with a forklift or derrick and crane. Cargo manipulation is safe and fast and risk from damage is reduced. The only drawback is reduction of useful space in holds by 10 – 15 %.

Containers appeared in the late 1950s and now represent the most advanced packaging method, accelerating and simplifying cargo handling. Drawing up stowage plans is now computerised, reducing transport costs and enhancing the competitiveness of water transport when compared to other types of transport. Many types of containers have been developed, differing in construction, insulation, refrigeration, strength, etc., so that almost every type of general cargo (except for special and bulk) can be packaged in them.

Vertical container-handling systems are increasingly robotised and automated, both on the ship and on terminals. Duration of port operations and further cargo management is maximally reduced. The most common types of containers are 20-foot and 40-foot containers.

Figure 42: 20-feet (6.1 m) ISO container equals 1 TEU

Figure 43: 40-feet container on the top of two 20-feet containers

Over the past 20 years, we witnessed the construction of large cargo vessels intended for carrying containers, so-called “mother-ships”, which are able to carry up to 24,000 TEU and move containers to major logistics hubs. From there, smaller ships (able to carry up to 3,000 TEU) distribute them to minor ports. Even though they are predominantly present on the sea, containers are increasingly finding their place in inland navigation.

RO–RO ships (Roll-on/Roll-off ships or RoRo ships) are vessels designed to carry wheeled cargo, such as automobiles, trucks, etc. (ships with horizontal handling systems). They are intended for carriage of freight vehicles or containers on their own trailers — with or without tractor units. At the moment, this type of transport is predominantly present at sea. However, its use is slowly finding its place on inland waterways. RoRo vessels have built-in ramps that allow the cargo to be efficiently rolled on and off the vessel when in port.

Cargo transport with “shipborne barges”

In maritime and river transport special cargo transport technology has been developed for carrying cargo in shipborne barges (a pushed barge designed to be carried on board seagoing vessels and navigate inland waterways[1]). These barges are routed along inland waterways to specialised barge-carrier ships. The barges, which are carried along with the cargo, on special ships, are, in their essence, containers with a deadweight of 300 to 850 tons, and are usually rectangular in shape and in most cases made of steel. Dimensions of barges are not standardised, so that they can be of various sizes, depending on the size of the ship, transport technology employed and the method of transhipment.

Ships of this type are intended for transport of barges between countries that, in addition to maritime routes, also possess inland waterways. According to the method of transhipment employed, two basic types of vessels are built: those with vertical transhipment – LASH system, and those with horizontal transhipment - SEA BEE. In the former case (lighter aboard ship (LASH) system), the barges are transhipped by overhead (gantry) cranes, while in the latter case (SEA BEE) by a large hydraulic crane capable of lifting two barges at a time. There are also two subtypes of shipborne barges: BACAT and CAPRICORN.

1 Definition pursuant to the Rules of Navigations on the Sava River Basin and European Code for Inland Waterways – CEVNI. In maritime transport they are also referred to as “barges” or “lighters”.

6.

6.
VESSEL NAVIGATION, MANOEUVRING AND HANDLING

6.1 TERM AND CLASSIFICATION

Navigation is a science devoted to computing and calculating the position and movement in space and time and guiding the ship from one point to another. Navigation is not founded solely on scientific knowledge. Instead, when dealing with navigational situations, the navigator's experience also comes into play.

Navigation is categorised into three types:

- Navigation on rivers and canals;
- Navigation on the coastal sea;
- Navigation on the high seas.

For the purposes of this Manual, we will reflect only on navigation on rivers and canals.

River navigation could be defined as the skill of guiding a vessel along the shortest and safest route by applying theoretical and practical knowledge, such as: vessel steering, the art of using various navigational aids for orientation on rivers and canals, knowledge of the rules of navigation, floating signs and riverbank marks, understanding the characteristics of the river, water currents, limans, natural and artificial obstacles on the waterway, the methods of departure, docking, mooring and anchoring, procedures in emergency situations, and similar.

Navigation on rivers, canals or other inland waterways is considered to be the simplest form of navigation, but it also represents one of the most dangerous ship handling methods.

The reasons for simplicity are strictly marked and defined fairways, a lesser need for use of electronic navigation equipment and almost no need for use of optical navigation aids. In addition, better situational awareness regarding waterways (e.g., passability) is also of great importance, as is the lower dependency on the weather conditions. The development of River Information Services has, from a navigational standpoint, significantly altered vessel and convoy handling methods, which, in turn, entails highly trained and technically proficient ship's masters and crews.

Pursuant to the aforementioned, the risk is reflected in poor knowledge of the river course, lack of information regarding signalling and marking, the limited width of fairways, fluctuating water levels, and thus variability of water depth on the fairways, reduced visibility due to frequent fogs, waterborne sediments, and similar. All of this can cause poor manoeuvring or failure to manoeuvre in the fairway, a greater risk of a collision, sinking, stranding, and damage to vessels, blocking or closure of fairways.

For reliable and proper ship navigation on rivers and canals, one must primarily pay attention to signs and marks on fairways. Regulations and rules on navigation, especially the ones prescribed by competent authorities for a particular part of the fairway, must be taken into consideration, as well as excellent knowledge of the river course.

Distance is not difficult to calculate. Monitoring of fairway kilometre markers allows easy calculation of vessel speed in relation to the distance travelled, the remaining distance and arrival time. If the speed of the water course varies on individual sections of the waterway, the calculation must include corrections, so as to obtain the most accurate result.

It is not easy to obtain maps for navigation on the river, and if you have one, it must be as a recent edition as possible because they are constantly being updated and corrected. The two main reasons for the frequent corrections are fairway passability, which depends on water level, and water course shifting, which in turn often requires changes in signalling and marking. Today, electronic navigation charts (ENCs) are made within River Information Services (RIS), updated in a simpler and faster manner and made available via the internet.

During night navigation, if there is no possibility to use a radar, special attention should be paid to the following:

- Make sure you have the navigation lights on and that other lights are turned off or dimmed so as not to interfere with vision;
- Regularly control the average speed and control the performance characteristics of each light buoy and beacon with a stopwatch;
- If a buoy or beacon is closer to the right riverbank (your right side), it must stay on the right-hand side when passing it;
- When two buoys are placed next to each other (one closer to the right and the other closer to the left riverbank), a person must pass between them. Buoys arranged in such a manner mark a bend on the river, a fairway with sufficient depth, passages under bridges and similar;
- Pay attention to other vessels and, depending on their signals, observe traffic rules and regulations;
- Regularly observe, both by eye and binoculars, the area you are passing. Optical illusions on the water are very common at night;
- If you estimate that further navigation is dangerous, be sure to leave the marked fairway. It is necessary to move away from the buoys, but in a manner that they remain in your field of view, anchor the ship and duly mark it with signalling equipment.

6.2 NAVIGATION EQUIPMENT

Modern navigation equipment is the standard of every vessel and a great aid in navigation and safe sailing. Due to the high humidity and presence of impurity, conditions for use of electronics on a vessel are unfavourable. Consequently, requirements set before the manufacturers and those in charge of equipment maintenance are quite strict. Properly fitted and used equipment is a prerequisite for reliable orientation and navigation. Navigation equipment has undergone a technological revolution, contributing to the development of so-called “integrated bridge” platforms that include multiple possible combinations of connecting navigation equipment and software packages to ensure conformity of all necessary navigation parameters. As a result, certain integrated systems can be composed of several different components. Generally, it can be said that an integrated navigation system interlinks all potentially available navigation devices on a certain vessel into one unit.

For example, the following data is collected: location data from a GPS or some other available positioning system, navigation status via a radar, movement surveillance data from a gyrocompass, data on depth via an echosounder, and speed data via a speed log.

Generally, navigation equipment includes all devices used during vessel handling, navigation, manoeuvring and orientation. Only the most important ones will be discussed in the following text.

6.2.1 Echosounder

Echosounder is one of the oldest navigation tools and the methods for determination of depth are divided as follows:

Classic methods: hydrographic or sounding rod known as "lec" in shipping.

"Sounding rod" is a wooden or aluminium rod with circular shape of 4 – 6 cm in diameter and, 4 – 6 m in length, used to measure river depths. The sounding rod is graduated with 10 cm markings alternately coloured in red, white and black, for easier reading.

Figure 44:
Sounding rod,
known as "lec" in shipping

Acoustic methods

Ultrasonic echosounder, which is widely used today, utilises three acoustic frequency bands: infrasound f < 20 Hz, audible 20 Hz < f < 20 kHz and ultrasound f < 20 kHz. Ultrasonic echosounder has been in use since 1925, and is still in use today. They are easy to use and maintain, cheap and accessible to owners of small boats. The following is used to obtain accurate depth readings:

The Doppler effect, which is applied as follows: after a sound pulse emitted from the vessel is subsequently received by a hydrophone after bouncing off the bottom, depth will be calculated (*h*) based on time elapsed, Δt.

$$h = c \cdot \frac{\Delta t}{2}$$	Where: c – speed-of-sound propagation in water (1,480 m/sec for fresh water).

Echosounder resolution represents its potential of distinguishing between the two close objects at the bottom. We distinguish vertical and horizontal resolution and errors are reduced if modern multibeam echosounders are used.

Figure 45: Ultrasound echosounder

Sonars / echosounders (sound navigation and ranging) are devices that use propagation of sound under water for: navigation, cartography, communication, detection of other ships. In recent times, the most investments have been made in their development and improvement in the nautical sector. In addition to measuring depth under and in front of the vessel (up to 400 m), it also detects shoals of fish, water temperature or objects at the bottom of rivers / seas.

The latest generation of echosounders allows obtaining of results that were unconceivable until recently. This especially refers to liquid crystal displays, which have increased the value of using “fish finders”, even of those of middle and lower product quality. For proper use of any instrument, it is crucial to initially adjust it taking into account its intended use.

Figure 46: Modern dual-frequency multipurpose echosounder – sonar

6.2.2 Radar

Radar (Radio Detecting and Ranging) is a widely used modern navigation system, used especially in conditions of low visibility, for navigation of vessels through narrow and high-traffic areas, whilst avoiding other vessels and similar. Object detection and distance measurement functions work based on radio signals. The term “radar” was first used during World War II when it was initially used for military purposes. Today, the radar is an indispensable instrument, the purpose of which is to facilitate safe vessel guidance and radar systems are automatised to such a degree that their operators are merely controllers.

Operators are free from tasks that they previously had to perform and the possibility of human error is significantly reduced.

History and development of the radar is linked to 1864 when James Clark Maxwell published equations and notes on the behaviour of radio waves. In 1866, Heinrich Hertz proved that electromagnetic waves could be reflected from solid objects like light. Then, in 1904, Christian Hülsmeyer used this property of electromagnetic waves for collision avoidance and designed and patented a type of radar (the telemobilscope). In 1922, Guglielmo Marconi invented the radio receiver, which used the principle of electromagnetic reflection of short waves. The true era of the radar began in 1935 when British physicist Robert Watson-Watt constructed a system to detect aircraft using radio pulses, and in 1939, physicist Henry Butt and biophysicist John T. Randall invented the magnetron. Further technological development, discoveries and modifications contributed to the widespread use of the radar. Furthermore, our attention will be focused on radars designed for use in navigation.

Radar operation principle: High-frequency energy is created in pulses within the transmitter and is radiated in a directed beam via an antenna. The waves travel in a straight line and, after being reflected from an obstacle, a very small portion returns as an echo towards the radar's sensitive receiver. After amplification and processing, it is displayed on the screen as a bright reflection (blip). From the position of this blip on the screen, the azimuth (direction), bow angle, and distance to the observed object are determined.

For a radar to meet the criteria for navigation, it must: detect objects at the shortest possible distance, achieve the maximum range or detection distance, effectively separate objects by azimuth and distance, and be able to eliminate interference caused by atmospheric reflection from the water surface, so that even small objects are clearly visible.

Radar system characteristics: maximum and minimum radar range, accurate measuring of angles and distances, division of objects according to angle and distance. Radars can be equipped with special computer technology that allows them to solve problems related to collision avoidance. Such systems in expert terminology are marked as CAS (Collision Avoidance System).

Figure 47: Contemporary river radar

The radar horizon, in a navigational sense, represents the greatest distance from the point of emission of EM waves to where the waves would reach the Earth's surface. This distance, apart from the Earth's geometry, depends on: the height of the antenna, the wavelength of the EM waves, the radar's pulse power, and atmospheric conditions.

Radar interference, according to its source, includes: interference caused by echoes from precipitation and the water surface, noise caused by the operation of the radar's electrical components, and interference from other nearby radars.

False echoes, depending on their origin, include:

- *Indirect echoes*, created by reflections from the vessel's own hull, larger objects on the shore, and other vessels in close proximity;
- *Multiple echoes*, are caused when a nearby object with a high reflection coefficient is near the observed object;
- *False echoes* are caused by radar waves reflected from nearby parts of the ship that are within the radar beam height or from prominent and nearby land. Two echoes appear at equal distances from the centre of the screen but in opposite directions, with the false echo being smaller and less intense than the true echo.

- *Radar interference* occurs when signals from another nearby radar device are received and interfere with the local oscillator of the vessel's radar. The result of interference are strong star-shaped or crescent-shaped disturbances that spread from the centre of the radar screen and converge towards its edge. These disturbances are most pronounced when a radar operating at a similar wavelength is nearby. They are more pronounced at higher ranges because, at shorter ranges, the time base is so fast that the bright spots blur into barely visible tonal lines. Interference from interfering signals cannot be eliminated.

Radar shadows are dark spots on the cathode-ray tube screen between reflections, although they physically belong to the same object. They occur due to the shape of obstacles, their positioning, and the inability of EM waves to reflect off geometrically shielded surfaces.

Blind sectors are circular sections of the cathode-ray tube screen where no EM waves are received, and no objects can be detected in these areas. They occur when obstacles, such as masts, chimneys, cranes, and others, are near the antenna.

Reflections from the water surface represent numerous variable and unstable point echoes, caused by reflections from the leading edges of waves at sharp angles and occurring at shorter distances. These disturbances disappear when the gain of nearby reflections is reduced using the “Anti-clutter Sea” button (*for sea interference*).

Atmospheric clutters manifest as numerous irregularly shaped point echoes on the cathode-ray tube screen, corresponding to the actual position of the atmospheric phenomenon. The common characteristics of these clutters (rain, low rain clouds, hail, snow, fog) are: stretched reflections with no pronounced edges (bristles) and a high-speed movement across the cathode-ray tube screen compared to the real echoes of objects, with a weaker reflection intensity when compared to that of real objects. These are eliminated by linearly reducing the gain over the entire operating range using the “Anti-clutter Rain” button (*for rain interference*). This weakens real echoes as well, but the interference disappears before echoes of real objects.

Radar reflections differ by: size, detection range, shape, fluctuation, sharpness, and mobility.

Characteristics of reflections from land objects include: appearance at expected locations based on the vessel's position, immobility, no fluctuation, and large, dense reflections whose relative positions do not change.

Characteristics of reflections from vessels include: movement, changes in position when compared to other reflections, unexpected appearance, fluctuation, but also permanence, narrowness, and appearance at medium distances, with one edge of the reflection being blunt and the edge in the direction of the vessel's movement always sharp.

Characteristics of reflections from small vessels include: occurrence at short distances, significant fluctuation with disappearing reflections at certain transitions of the EM beam over a wavy surface, stronger reflections than those from interferences, and shorter detection distances by 15 – 20 % during fog.

Relative motion display can be explained through two models i.e.:

- *Unstabilised (Heading Upward) Display*, where: the vessel itself is stationary and always in the centre of the screen, while reflections of all stationary objects move in the opposite vector of the vessel's speed, the heading line is always directed to the zero fixed scale regardless of course, only the right bow angles can be read using the azimuth dial, and objects to the right of the bow are visible on the right side along the centreline of the screen (the heading line); when course changes, the heading line remains in its previous position, and all echoes rotate opposite the side of the course change. This kind of display is suitable for resolving situations - problems related to collision prevention.
- *Stabilised (North Upward) Display*, wherein: own vessel position is fixed and always in the centre of display and reflections of all other fixed objects move in opposite vector of the vessel's own speed, the heading is directed toward the real course with reading on the fixed scale, the radar image of riverbank objects is oriented towards the meridian (same as the navigational charts), radar azimuth of all objects can be read with the azimuth plate, when changing the course of the own vessel the positions of the reflections remain the same while the heading rotates in the direction of the course change until the new course. This kind of display is suitable while manoeuvring for the purpose of collision avoidance.

True Motion Display shows real movement within a limited space and, in order to achieve it, it is necessary to break up the movement into N–S and E–W components, which requires continuous input of data regarding the vessel's own course and speed, as well as data from the gyrocompass and speed log.

This means that the position of one's own vessel is at the origin point from which the time-base sweep starts and that origin shifts proportionally with the vessel's own movements. The characteristics of these display modes are:

- All fixed objects are stationary reflections on the display;
- All movable objects including the vessel itself are moving in relation to the fixed objects in real courses and speeds;
- The whole picture, as well as the navigational chart, is oriented according to the meridian, which requires an additional scale for angle measurement because the fixed dial on the rim of the display cannot be used. Azimuths are measured electronically with a straight line, which appears on the display from the time-base sweep origin, and the value is read on a separate digital display.

6.2.3 Gyrocompass – gyroscope

Gyroscope is an instrument which uses certain physical characteristics of a massive rotating body (gyroscope or spinning top) for identification of a meridian. It first appeared in the first decade of the 20th century for the purpose of polar expeditions. The gyroscope is a dynamic tool that rotates freely with great speed. It is usually designed as a symmetric rotor with great peripheral speed, which is mounted in the gimbal rings.

The spinning top's spin axis is the main or primary axis, while the axes in which the gimbal rings are fastened are horizontal and vertical equatorial axis. On a spinning top with three degrees of rotational freedom all axes intersect in one point. Therefore, such a top is balanced. The spinning top displays two main characteristics: **inertia** and **precession**.

Inertia is the characteristic of a gyroscope to always retain the spin axis in the same direction in space, depending on the direction towards which the platform, to which the top with three degrees of rotational freedom is attached to, is oriented. In doing so, the top retains that direction regardless of any movement, including the movement of the Earth, which means that the spin axis keeps its direction in space independently of the movement of the Earth.

Precession is the characteristic of the spinning top to deviate its spin axis by 90° from the direction of the force acting on that axis. These two properties are used for the operation of a gyrocompass. By limiting the free rotation of the spinning top, the spin axis is set in the direction of the meridian. Gravity acts on the spin axis to position it in the horizontal position, and inertia, acting in the direction of Earth's rotation, aligns it with the meridian.

Gyrocompass error (deviation) is the total deflection of the main axis (spin axis) from the real meridian. It is positive if the gyrocompass axis is deflected towards east and negative if the same is deflected towards the west.

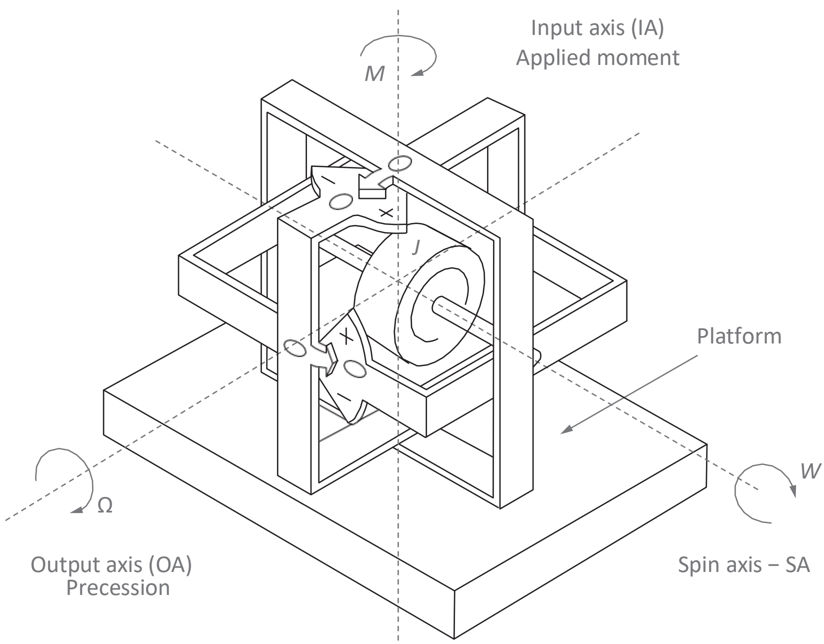


Figure 48: Gyrocompass – gyroscope

The following errors can affect deflection of the spin axis: ship movement error, latitude error, ballistic error, quadrant deviation and installation error.

The autopilot— a device for automatic steering — is the best example of gyroscope use in inland navigation. On one side, it is connected to the gyrocompass, and on the other to an electric or hydraulic steering device.

If the ship veers off the course, the steering device activates and returns it to its course. The compass repeater contains a contact that closes a circuit with either the port or starboard contact ring, depending on the direction in which the ship is turning. When the rudder starts to turn, the contact rings are activated via a feedback link, and they open the steering device circuit. By alternately engaging and disengaging it, one can maintain a ship's course in calm weather within ± 0.5°. Sensitivity of the autopilot is adjusted manually. When navigating during bad weather, autopilot sensitivity should be reduced. Automatic steering reduces losses and increases average ship speed.

6.2.4 Speed log

The speed log is an instrument that measures vessel speed and 3 main types are in use:

- *Patent log* - towed astern, and measures speed by rotating its own propeller. The information is mechanically transmitted to the indicator, and navigation speed is determined based on the number of revolutions of the propeller in a unit of time. This type of speed log is impractical, out-dated and is not in use anymore;
- *Impeller (electro-mechanical) log*, which measures speed of navigation by using a propeller attached to the hull bottom. The propeller's rotation drives a small dynamo that reports electrical value to the indicator (voltmeter gauged in knots or kilometres) in the form of electrical impulses;
- *Pitometer log* - measures speed of navigation by means of a "Pitot tube", and it measures the difference between static and dynamic pressure, which is shown on the indicator in knots or kilometres in a unit of time.

Navigation speed shown on the speed log represents the speed through water, not speed over the bottom or in relation to the riverbank, mainly due to the impact of water currents. Consequently, for example, in order to obtain the actual speed in relation to the riverbank during upstream navigation (along the river), the indicated navigation speed should be reduced by the water flow velocity, whereas downstream it must be increased by that velocity.

Speed of navigation on rivers and canals can be measured by reading the river-kilometre mark and determining the distance travelled per unit of time. For example, if a craft sails from rkm 255 to rkm 262 on the Sava River in one hour, it means that the navigation speed in relation to the riverbank is 7 km/h. For more precise measurements, when testing newly built ships, testing kilometres or miles, specially dedicated for that purpose, are used.

6.2.5 Ship barometer

A barometer is an instrument for measuring atmospheric pressure, i.e., pressure exerted by the air mass.

The first barometer was the so-called water barometer (called Goethe barometer because Goethe popularised it), which worked on the principle of an air-filled vessel submerged in water, and, when the air pressure fell, the water column inside rose (because the air column went down). The most commonly used one is the mercury barometer (column of mercury rises or falls depending on changes in air pressure). It was discovered by Evangelista Torricelli. There is also a dry (aneroid) barometer.

Figure 49: Modern metal aneroid barometers

The barometer is an indispensable instrument in meteorology. It is also useful in the so-called “folk meteorology” because it is commonly believed that an increase in air pressure is followed by sunnier weather, and a decrease by cloudier weather. The barometer forecasts the arrival of rain, clear weather, and a tendency in pressure changes due to flow of air masses (wind). Regardless of whether the pressure change is positive or negative, the stronger the pressure changes is over a short time, the stronger the wind and the severer the weather is to be expected.

6.2.6 Binoculars

Binoculars are one of the most frequently used navigational aids. It is an optical instrument composed of two small telescopes coupled so that, when viewed through (with both eyes simultaneously), they present a single image. Its advantage over a telescope is that it naturally increases the ability of human sight because both eyes (not one eye) are used.

Increasing x and the diameter of the lens: all binoculars are characterised by two figures, which are usually engraved on the housing of binoculars next to the eyepiece.

Figure 50: Binoculars/ Great Britain, 20th century, steel, glass, brass

They are shown as a product of numbers, e.g., 7 x 30, 7 x 50, 11 x 80 etc. The first figure is the magnification of binoculars, and the second is the diameter of the objective - lens in millimetres. We can freely say that the magnification is actually making objects virtually closer to the eye for the specified value. Binoculars with a magnifying rate of 8 will show the observed object 8 times larger, while the angle under which an object is being observed will be 8 times larger than to the naked eye.

The other figure (30, 50, 80 etc.) is the lens diameter in millimetres. The larger the diameter, the more light enters the binoculars and faint objects can be better observed. The “light grasp” value, or light-collecting power, depends principally on the lens diameter. Consequently, binoculars with a lens diameter of 50 mm gather 2.8 times more light than with a lens of a 30 mm diameter. Medium-power binoculars are optimal for navigation

6.2.7 Radiotelephone equipment

Radiotelephone equipment is considered an aid in vessel navigation. It is also used to receive hydro-meteorological reports and weather forecasts, which are broadcast by public radio stations on an everyday basis. Vessels in both inland and maritime traffic employ:

High-frequency (shortwave) radiotelephone devices (HF), which operate on a frequency from 1.6 to 3.8 MHz (calling frequency is 2.12 MHz). A standard type offers very long range. This HF radiotelephone device was formerly common in professional shipping - in shipping companies whose ships sail great distances.

Very high frequency (ultra-shortwave) radiotelephone devices (VHF), which operate on a frequency from 156 to 162 MHz. Their calling frequency is 156.8 MHz – channel 16 (navigational safety channel). Standard VHF radiotelephone devices have 55 channels for communication and they are intended for: radio communication on short distances, communication vessel-to-vessel or vessel-to-shore (harbourmaster's office, company, marina, harbour etc.). The range of the transmitter is 50 km, while power consumption is low, namely low enough for any ship's battery. Motor vessels (except small crafts and ferries) and technical vessels may navigate the Sava River only if they carry either two properly working radiotelephones or one set capable of monitoring two VHF channels simultaneously.

Operating procedures for a VHF device are specified in the Manual for Radiotelephone Service in the Sava River Basin, which the Sava Commission issued in accordance with the Manual used on the network of European inland waterways issued by the Rhine, Danube and Moselle River Commissions.

Figure 51:
VHF device

6.3 NAVIGATION MANUALS

Navigation manuals are of great importance for every navigator - whether a ship's master or a leisure skipper. Their primary purpose is to provide necessary nautical information both in navigation preparation and execution. Special attention must be paid to the up-to-dateness and accuracy of all manuals so as to ensure highest possible safety of the vessel, crew and other participants in navigation. Navigation manuals also include navigational publications that provide descriptions of data important for navigational safety, which cannot be shown on navigational charts. These publications are used in combination with such charts. In addition to navigation manuals, there are other publications useful for inland navigation.

6.3.1 Navigational charts

To this day, navigational charts have been the backbone of navigation and a principal navigational reference. Consequently, much attention was placed on their details, up-to-dateness and durability in navigation conditions. As a rule, it is issued by authorised state bodies, responsible for the accuracy of the information provided. Currently two basic chart types are in use:

Paper charts: Up until the late 1990s, paper charts were the only charts used. However, in the last couple of years they have been used predominantly as a back-up navigational aid. The only true navigational chart drawn-up solely for vessel orientation and handling is the “Pilot Chart of the Danube” published by the Danube Commission in Budapest. The chart is made in a 1:10000 map scale, which allows a high level of details. In addition to the fairway, this chart displays numerous information intended for vessel orientation and handling, such as: riverbank type, position of river-training structures, fairway axis, depth along the fairway axis, position of shallows, rocks, direction of river current, river-kilometre marks, floating navigational lighted and unlighted marks, riverbed between high and low navigable water levels (HNL and LNL) and navigational signs and marks used for regulation of navigation. The navigational charts for the Sava River have not been drawn-up yet. Instead, hydro-technical maps of a far lower level of detail are used and are considerably less reliable.

Electronic Navigational Chart – ENC represents a data base standardised in content, structure and format and issued for use with an Electronic Chart Display and Information System (ECDIS).

It was developed based on the standards of the International Maritime Organisation (IMO) and it is in conformity with standards S-57 and S-52 of the International Hydrographic Organisation (IHO).

Inland ENC (*Inland Electronic Navigational Chart*) was developed along with Inland ECDIS for use in inland navigation. Inland ENC is in conformity with IHO standards S-57 and S-52, but is improved with additions and explanations of those standards for Inland ECDIS purposes. Inland ENC contains all necessary cartographic information and may include further data considered useful for navigation.

Inland ECDIS is an electronic chart display and information system for inland navigation. Its purpose is to contribute to safety and efficiency of inland navigation and contribute to environmental protection. It was developed based on the findings of the European INDRIS project (Inland Navigation Demonstrator for River Information Services) and the German ARGO 2001 project, when the Danube and Rhine Commissions adopted Inland ECDIS and Inland ENC for their rivers. In 2001, the United Nations Economic Commission for Europe (UNECE) adopted the Inland ECDIS standard as a recommendation for the European Inland Waterway Network. By November 2013, inland electronic navigational charts were developed in accordance with the Inland ECDIS standard, covering almost 10,000 km of European waterways including: Rhine, Danube, Moselle, Main, Elbe, Sava and Drava in the Netherlands, France, Belgium, Switzerland, Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania and Ukraine.

Unlike paper charts that are limited to only four colours in data display, electronic navigational charts can display navigation-relevant data in a far wider colour palette and it is possible to display only those data as chosen by the user. When using Inland ECDIS, minimum data should be displayed as stipulated by the IMO and the International Hydrographic Organization (IHO).

The Inland ECDIS system requires that, on the screen, useful information is displayed together with the navigational situation, such as: position, speed, course, traffic situation in the vicinity of the vessel (vessel positions, courses, speeds) and other important data. There are two types of display, relative motion and true motion.

In the case of relative motion, as on a radar display, the vessel's position is fixed at the centre of the screen while the riverbank line (electronic chart) moves in the opposite direction at a speed equal to that of the vessel. Such a display demands high computer-memory capacity considering that large data sets must continuously be shifted over the screen.

In true-motion display, which uses a north-up orientation, the electronic chart is stationary while the vessel moves over the screen. Whenever a vessel approaches the screen edge, the picture is reprogrammed so that the chart window is expanded in the direction of travel, narrows the area opposite to the direction of movement, and the vessel's position is repositioned near the opposite edge of the screen. A special screen or a special frame on the ECDIS display is reserved for alphanumeric digital display of data regarding the vessel's course, speed, depth or position. Split-screen views of the area currently being navigated through or a view of the areas the vessel needs to enter can also be used, while the general navigational situation is simultaneously displayed on the main screen.

Figure 52:
ENC combined with a radar

Generally speaking, electronic navigational charts should meet the following criteria:

- ENC must be compatible with the inland ECDIS standard;
- Information on the ENC must be current;
- They must contain a so-called minimal data set, required for efficient and reliable use of electronic navigational charts.

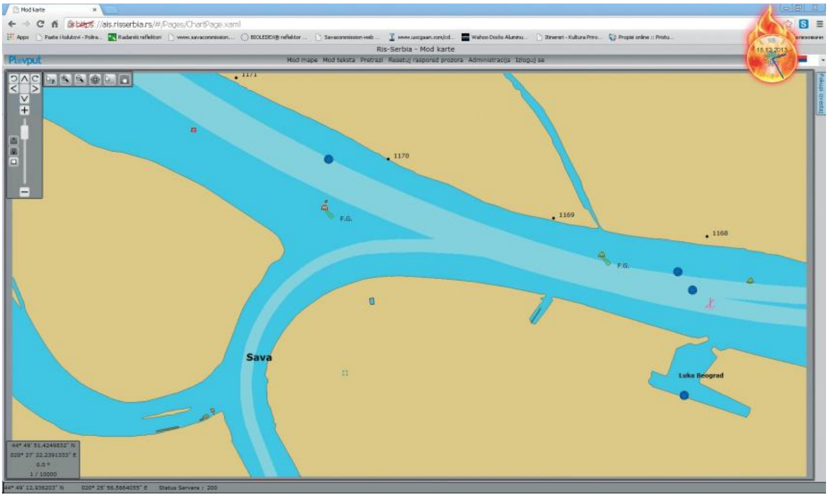


Figure 53: Example of an ENC

Along with the aforementioned mandatory requirements, it is desirable for the ENC to contain information on depths in the critical parts of the fairway. Inland ECDIS represents a standard for the display of electronic navigational charts in inland navigation, which was accepted by the Central Commission for Navigation of the Rhine, the International Sava River Basin Commission, the Danube Commission and the European Commission under Technical Directive No. 414/2007.

The primary functions of Inland ECDIS are as follows:

- It contributes to the safety and efficiency of inland waterway transport and environmental protection;
- It reduces the amount of work compared to traditional methods of navigation and obtaining of information;
- It is a reliable and accessible source of information for all subjects involved in inland navigation;

- It provides simple and reliable updating of electronic navigational charts;
- It can be used in navigation and information mode. Navigation mode means that the Inland ECDIS is used in conjunction with traffic information obtained by a radar and / or AIS. Information mode means the use of Inland ECDIS without traffic information.

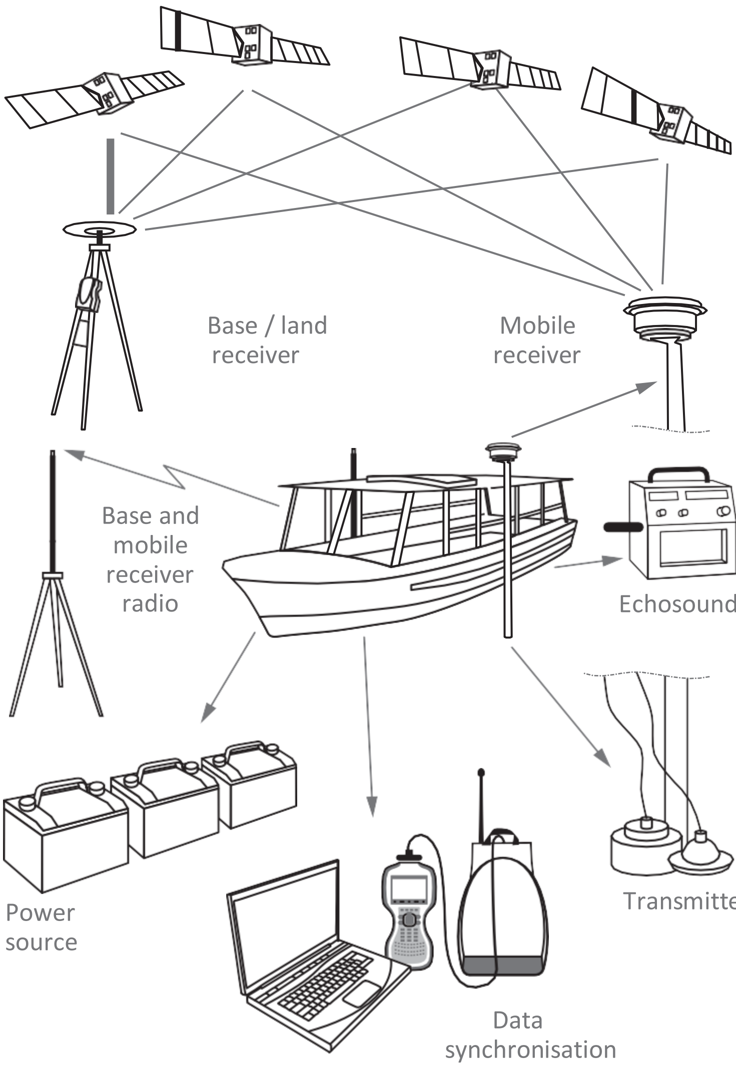


Figure 54: Integrated navigation system

Electronic navigational charts of the Sava River are made in accordance with required standards and are of good quality. A higher level of details shall be covered in updated and new issues.

6.3.2 Indicator of river kilometres

The Indicator, alongside navigational charts, is the most important source of information for vessel orientation and navigation. It lists kilometre marks, towns, bridges, river islands, hazardous places, confluences, shipyards, etc. The indicator is packed with numerous useful details and it is an indispensable manual for both experienced navigators and those with less experience and knowledge.

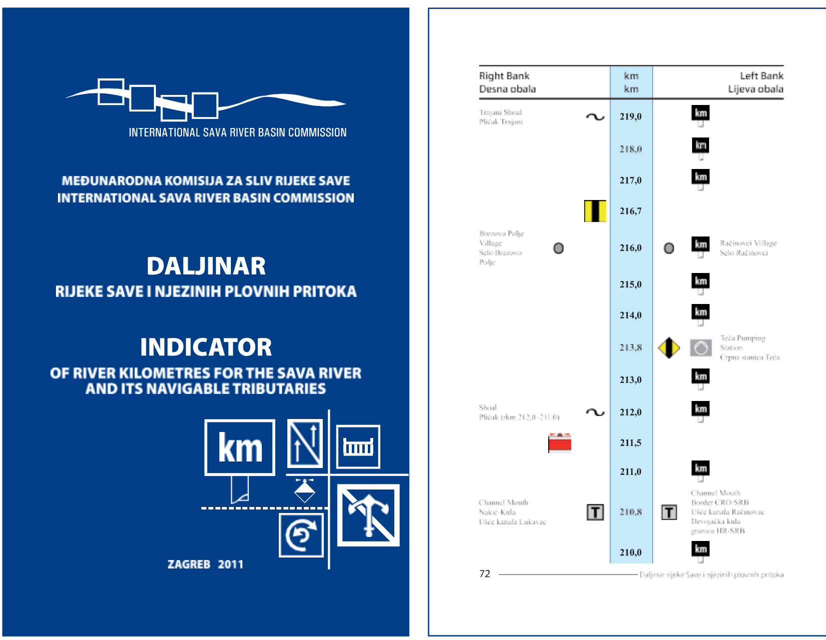
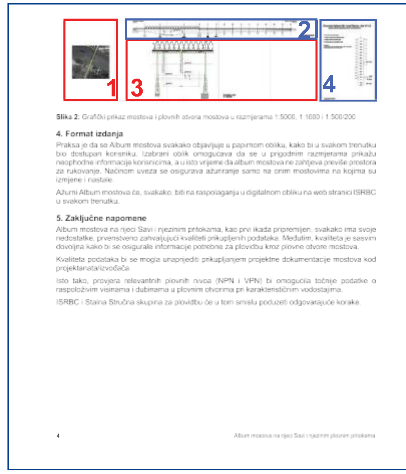


Figure 55: Indicator of river kilometres for the Sava River and its navigable tributaries

6.3.3 Album of bridges

An Album of bridges normally provides more comprehensive information for navigation, whenever a clear picture of the vertical clearance above the highest point of the vessel is required while passing through a bridge opening (navigation span). On a dedicated scale it shows the height of the navigable opening relative to the water level at the reference water gauging station.



Slika 2: Grafički prikaz mostova i plovnih otvora mostova u razmjerama 1:5000, 1:1000 i 1:500/200

4. Format izdanja

Praksa je da se Album mostova svakako objavljuje u papirnom obliku, kako bi u svakom trenutku bio dostupan korisniku. Izabrani oblik omogućava da se u prigodnim razmjerama prikažu neophodne informacije korisnicima, a u isto vrijeme da album mostova ne zahtjeva previše prostora za rukovanje. Načinom uveza se osigurava ažuriranje samo na onim mostovima na kojima su izmjene i nastale.

Ažurni Album mostova će, svakako, biti na raspolaganju u digitalnom obliku na web stranici ISRBC u svakom trenutku.

5. Zaključne napomene

Album mostova na rijeci Savi i njezinim pritokama, kao prvi ikada pripremljen, svakako ima svoje nedostatke, prvenstveno zahvaljujući kvaliteti prikupljenih podataka. Međutim, kvaliteta je sasvim dovoljna kako bi se osigurale informacije potrebne za plovidbu kroz plovne otvore mostova.

Kvaliteta podataka bi se mogla unaprijediti prikupljanjem projektne dokumentacije mostova kod projektanata/izvođača.

Isto tako, provjera relevantnih plovnih nivoa (NPN i VPN) bi omogućila točnije podatke o raspoloživim visinama i dubinama u plovnim otvorima pri karakterističnim vodostajima.

ISRBC i Stalna Stručna skupina za plovidbu će u tom smislu poduzeti odgovarajuće korake.

4 Album mostova na rijeci Savi i njezinim plovnim pritokama

Figure 56: Album of bridges on the Sava River and its navigable tributaries

Bridge sketches, compared to those in the river-kilometre indicator, are much more detailed and include additional useful data — for example, the positions of marks defining the openings through which navigation is permitted. Where two or more navigable openings exist, they are generally used separately for upstream and downstream traffic. The Album is mainly used by ship's masters of commercial vessels and convoys, but can also benefit less experienced navigators.

6.3.4 Notices to skippers

They are issued by competent harbourmaster's offices and they include all information about changes on fairways, river-training and engineering works and endangerment and bans on navigation for certain sectors. In the RIS system we recognize them as "notices to skippers / NtS", which are issued in a pre-defined electronic form.

6.4 RIVER INFORMATION SERVICE

River information services (RIS) represent a package of services based on contemporary technologies that shape and direct exchange of information among participants in inland navigation. Exchange of information is conducted based on harmonised information and communication systems. This information is then used in various applications and systems for improvement of traffic management and transport technologies in general.

This concept encompasses the following:

- Inland AIS (Automatic Identification System – AIS);
- Inland ECDIS (Electronic Chart Display and Information System);
- ERI – Electronic Reporting International;
- NtS – Notices to Skippers;
- Electronic Navigational Charts;
- Hull Database;
- Lock Management Systems.

The component most readily associated with RIS is the vessel tracking and monitoring system, which is based on Inland AIS transponders and services based upon them. A network of AIS base stations has been installed along the river and allows exchange of information with vessels equipped with AIS transponders. This two-way communication between base stations and vessel devices provides a view of the traffic situation from the shore and remote locations (through transfer of data on vessel position, its speed, course, size, type of cargo, number of crew members, destination, etc.), but also makes it possible to send information to ship's masters, such as: notices to skippers, GPS corrections, short messages, etc.

Mutual communication between transponders installed on vessels is a very important component of the vessel tracking and monitoring system. Vessel transponders collect and process data on the positions of vessels in their immediate vicinity, their size, speed, course, type of cargo etc., and thus provide the ship's master a clearer picture of the traffic situation and of other vessels in its immediate vicinity, which makes it easier to make decisions on navigation and manoeuvring. AIS transponders used in ship-to-ship communication have the unique ability to unambiguously identify optically invisible objects (other AIS-equipped vessels) at ranges of several kilometres. This also applies to the possibility of identifying vessels obscured by very poor weather conditions, which are common on inland waterways (such as fog, sleet or heavy rain).

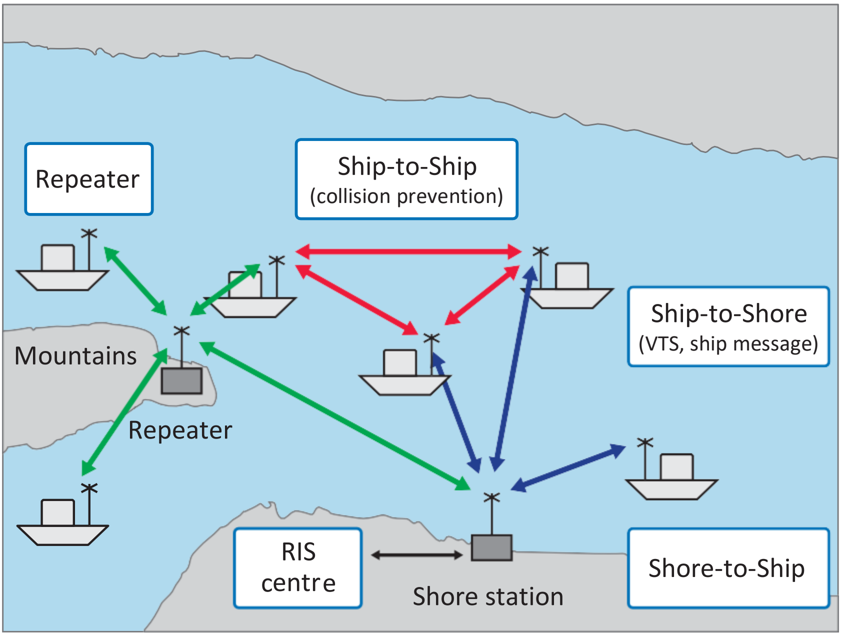


Figure 57: AIS system information exchange

Information from AIS transponders and those from the vessel tracking and monitoring system are displayed on another very significant RIS subsystem – Inland ECDIS. ECDIS shows vessel data on electronic navigational charts in real time, in both information mode and navigation mode.

In information mode, Inland ECDIS functions as an electronic atlas and serves to supply information on the fairway. Therefore, it is not planned to be used for steering the vessel. In information mode Inland ECDIS can be linked to a positioning sensor so as to automatically move the chart image and link parts of the chart corresponding to the current surrounding with the vessel position fixed at the centre of the display. A navigation regime includes the use of Inland EDCIS for vessel steering with the use of a radar. The vessel's position is obtained from a continuous-positioning system whose accuracy and precision are in accordance with the requirements of safe navigation. In addition to its principal purpose (displaying the traffic image), ECDIS subsystems are often interfaced with other RIS subsystems, such as the electronic reporting system, and system for electronic NtS.

In navigation mode, it is possible to overlay the radar image over the electronic navigational chart and AIS data display.

It should be noted that, in addition to vessels, aids to navigation (buoys) may likewise be equipped with AIS base stations — specifically AIS AtoN stations (see Chapter 3.3 “Marking the waterway / fairway”) — the use of which may benefit both navigators and the competent authorities.

In conceptual terms, an AIS AtoN is a real or virtual aid to navigation of relevance to navigational safety that is shown as an electronic symbol on the integrated shipborne ECDIS display.

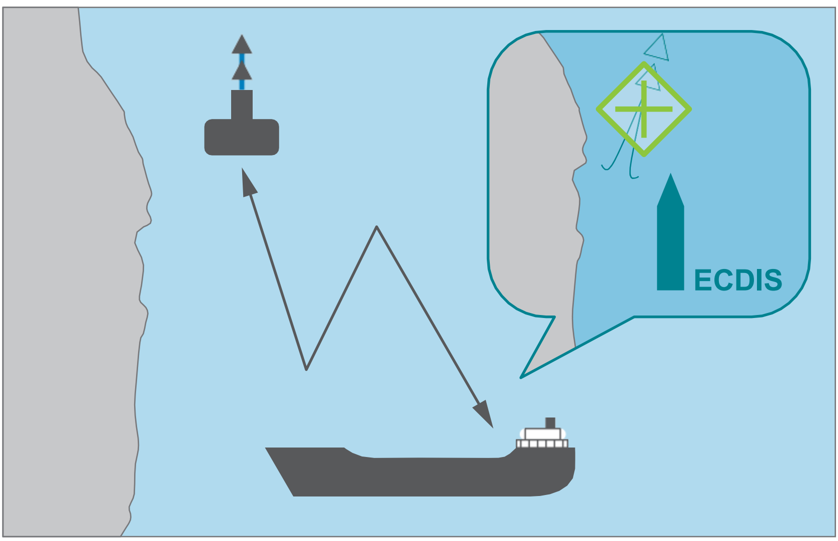


Figure 58: Inland ECDIS display of a buoy fitted with an AIS AtoN base station (ref. *IECDIS EG / VTT EG presentation 25 June 2015)*

In general, AIS AtoN units, as navigational aids, may be:

a. Real AIS AtoN – a true AIS station, i.e. an AIS station installed on a physically existing AtoN (e.g. a **buoy**);

b. Synthetic AIS AtoN – a synthetic AIS AtoN is a location for which AIS messages are broadcast from another remote AIS station;

c. Virtual AIS AtoN – a virtual AIS AtoN is transmitted as an AIS AtoN message for an AtoN that does not physically exist. It is visible only on the electronic chart, despite there being no real AtoN, such as a buoy or beacon.

The information provided by an AIS AtoN includes:

a. Monitoring AtoN status;
b. Tracking an AtoN that has drifted from its charted position;
c. Identifying vessels involved in collisions with an AtoN;
d. Collecting real-time data on the “health status” of AtoNs;
e. Remote management of AtoN parameter changes;
f. Supplying statistics on AtoN reliability;
g. Extending AIS monitoring coverage.

The Electronic Reporting International (ERI) system enables the ship's master to report in advance its voyage to the competent authorities, even when navigating through several countries. In this way, he submits a report on the details of the voyage (port of origin, destination, details on the cargo, the size and composition of the convoy, persons on board, port of landing / unloading etc.) via a standardised, language-independent, machine-readable message.

System for electronic Notices to Skippers (NtS) – enables the staff of competent authorities to distribute notices by electronic means, in standardised language-independent and machine-readable formats and, upon receipt, such notices are automatically displayed on the ECDIS screen in the vessel’s wheelhouse.

Electronic navigational charts form the backbone of RIS and are directly used in the navigation process. They belong to the group of fairway information services (FIS).

The binding element of the RIS subsystems is the so-called Hull Database, which, in the standardised format, contains all data from the ship register of every country. These data are used by other RIS subsystems and their mutual data exchange is possible.

Lock Management Systems allow the lock operator to optimise lock operation based on the information on ship positions obtained from the ship tracking and monitoring system and based on the information from the ERI system and Hull Database.

The above-mentioned subsystems are only part of those that are currently being implemented on European rivers aimed at:

- Increasing the safety of navigation on inland waterways and in ports;
- Providing essential traffic information of local and regional relevance for monitoring and managing traffic;
- Increasing the efficiency of inland navigation - optimisation of resource management in the transport chain, allowing the exchange of information between vessels, locks, bridges, terminals and ports;
- Improving the use of inland waterways - optimising provision of information on the status of the waterway;
- Protecting the environment by providing transport traffic information for an efficient reduction of navigation accidents.

In the Republic of Croatia and the Republic of Serbia RIS services and supporting systems are fully operational. Consequently, the Sava River waterway is, *de facto*, covered by RIS, and waterway users enjoy the same level of information-technology-based support as on the greater part of the European waterway network.

6.5 SHIP'S DOCUMENTS AND BOOKS

6.5.1 Logbook

The logbook is one of the documents kept on vessels (except small crafts) for inland navigation. Its content and method of keeping are laid down by certain rules / regulations. It is kept on a daily basis and, based on the entered data, one may monitor all activities on the vessel and, if required, reconstruct certain events. This is important when determining facts and analyses of accidents or other extraordinary events, and the data from the logbook are admissible in court proceedings.

When entering data in the logbook, errors must be corrected by striking through the incorrect text with two lines; after completing the entry, the person making it must sign it. Errors must not be erased, corrected with white-out, torn out, etc. Entries must be made carefully and legibly, and graphite pencils must not be used.

The logbook contains: vessel information (name or emblem, type of vessel, port of registry, total propulsion power), logbook number, date and place of issuance, name of the issuing competent authority, stamp and signature of the authorised person, information on the previously issued and completed logbook (number, date and place of issuance and the name of the issuing competent authority).

The following data is entered in the logbook:

- Hydrometeorological data relating to: weather conditions, air temperature and water level, and the relevant water gauging station based on which the vessel is oriented;
- Data on movement and operation of the vessel, including data on departure, arrival and extraordinary stoppage of a vessel;
- Composition and form / configuration of a convoy, cargo weight and vessel draught;
- Information on taking and leaving of vessels from a tow;
- Data on watch changes of crew members in the wheelhouse and engine-room in workplaces requiring certificates of competence for performing duties on board.
- Data on putting in service and lay-up of vessel;
- Important remarks during navigation, which, *inter alia*, include:
  - The measured depths of the fairway, changes to the marking system and changes in the fairway;
  - Accidents and averages of vessels;
  - Major repairs and works performed during the voyage, changes in number and the composition of the crew;
  - Outbreak of severe illnesses among the crew and passengers;
  - Information on engine operation and maintenance.

The logbook is kept during navigation and while the vessel is berthed in a port or harbour, every day from 0 to 24 hours. The logbook is not kept while the vessel is laid-up. Vessel lay-up and putting in service are considered to be extraordinary events. During navigation, a logbook is kept by the ship's master or his deputy. If a logbook is kept by other authorised persons, then the ship's master must certify the entered data on a daily basis.

In addition to the logbook, the following must be kept on board: crew list, oil record book, certificate of navigability of the vessel and other documents and books as stipulated under national and international regulations.

6.6 FORMING OF CONVOYS

The formation of a convoy can be carried out in several ways, taking into account the power of the tug or pusher, the water level, depths and obstacles in the fairway through which navigation will take place.

When forming a convoy, we use coupling and mooring.

Coupling of vessels: when two or more vessels are linked one to another, we say that these vessels are coupled. Coupling of vessels is used when forming a convoy for downstream and upstream navigation. By coupling side-by-side we can link two, three, four or more vessels.

Mooring of vessels: linking vessels one behind another is called mooring. By mooring vessels one behind the other we form a longitudinal row or string.

6.6.1 Forming of towed convoys

When towing *upstream* the barges are assembled, in order to reduce resistance, in a longitudinal row (string). The longitudinal row is formed by mooring the barges one behind the other. This arrangement reduces the resistance, because only the leading barge in the string is exposed to the greater head resistance, while the others follow in the wake it creates. The first barge, which takes the towline from the tug, typically needs to have the best manoeuvrability and the deepest draught.

Operational experience has shown that the best position for a towline during towing is when the barge is tied at 1/6 of its length, measured from the bow. In order to reduce the resistance of the convoy, the length of the towlines should be as long as possible and their length depends on the conditions on the fairway.

Nowadays towlines of 50 – 100 m are customary.

Two towlines can be tied in two ways: *straight* and *crosswise* (see Figure below). In upstream navigation towlines are rigged straight when the tow consists of more than one longitudinal row, so that the strings can be disbanded at favourable stretches to reduce resistance. In practice, depending on the type of convoy (assembly), the ship's master decides in which way the towlines will be tied.

In downstream navigation, the towlines of 3 to 5 m long, are always crossed for easier steering of the towed vessels (assembly) by the tugboat.

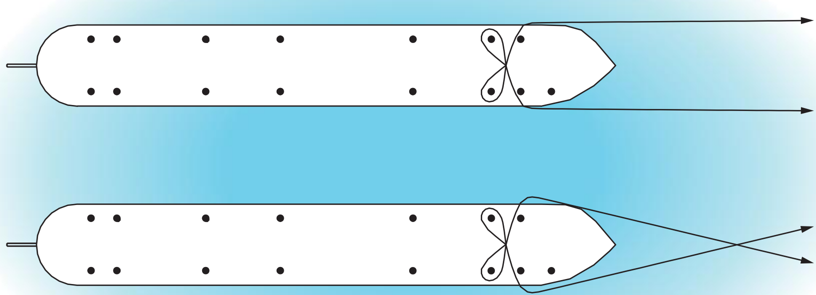


Figure 59: Straight- and cross-rigged towlines

Mooring the barges one behind another is done with secondary towlines, which are tied based on the characteristics of the sector being navigated. Depending on the discharge (current), weight and size of the convoy, number of secondary towlines amounts from one to three. We mainly distinguish three types of mooring: long, medium and short.

Long mooring is used on river sectors with a high current velocity so that each vessel can be individually towed through bends, narrows and other potential obstacles. Until recently it was used on the Upper Danube. With long mooring, the distance between barges, from the stern of the leading barge to the bow of the last vessel, amounts to three meters. As a rule, long mooring requires three secondary towlines i.e.: the first towline comes from the last barge to the front bollard (see Figure below). If mooring between barges is performed on the right-hand side, then the towline starts from the last barge, and from the front bollard on the port side to the opposite side between the second and third bollard, and from there to the barge in front.

On the second barge, this first towline goes half-around the midship bollard on the starboard side to the midship bollard on the port side, where the loop is placed. The second towline also comes from the last barge to the barge ahead, where the loop is placed on the second bow bollard on the starboard side. When mooring, the towline is led round the front midship bollard on the starboard side, where it makes one full round, then led to the to the bow bollards of the last barge where it is tied with several eight turns between the second and third bollard. The third towline comes from the first barge, it is passed under the figure-eights and the loop is placed on the second barge, and on the free bow bollard on the starboard side of the last barge.

Part of the towline on the first barge makes a full round over the front midship bollard, and several figure-eight turns over the bow bollards on the starboard side.

Before the long-mooring manoeuvre begins, one auxiliary towline is handed from the free bollards for just a short time so as to hold the second barge until the mooring is completed. When the helmsmen have each secured their towline, they heave taut so that all three lines bear equally and are equally loaded.

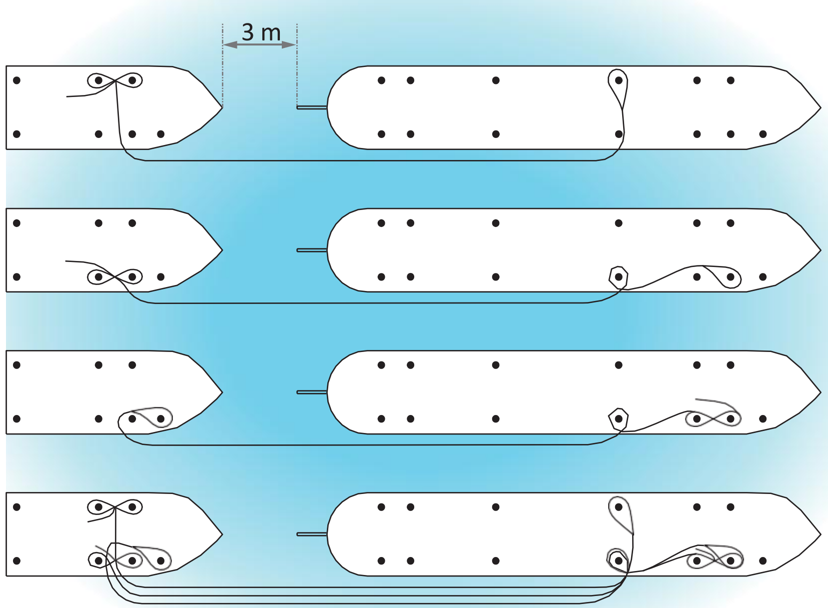


Figure 60: Long mooring

Medium mooring, is used for towing over shallows and is performed similarly as in the case of long mooring. The first barge provides one towline and the next barge two towlines (see Figure below). The first towline is led from the following barge's bow bollards on the port side to the opposite side between the second and third bollard, and from there to the first barge where it makes a half-turn round the last midship bollard on the starboard side, after which it is passed across to the barge's port side where a loop is placed on the last midship bollard on the port side.

The second towline is also led from the same barge by placing the figure-eight turns around the second and third bow bollard on the starboard side, and the towline is further led to the first barge where it makes a full turn round the last midship bollard on the starboard side, after which the loop is placed on the front midship bollard on the starboard side.

The third towline is led from the first barge, so that figure-eight turns are made around stern bollards on the starboard side. Afterwards, they are led further and a half-turn is made round the last midship bollard on the starboard side and led to the next barge, where it is passed between the second and third bow bollard on the starboard side, and the loop is placed on the first bow bollard on the starboard side.

When using long and medium mooring, distance between the vessels amounts to 3 meters.

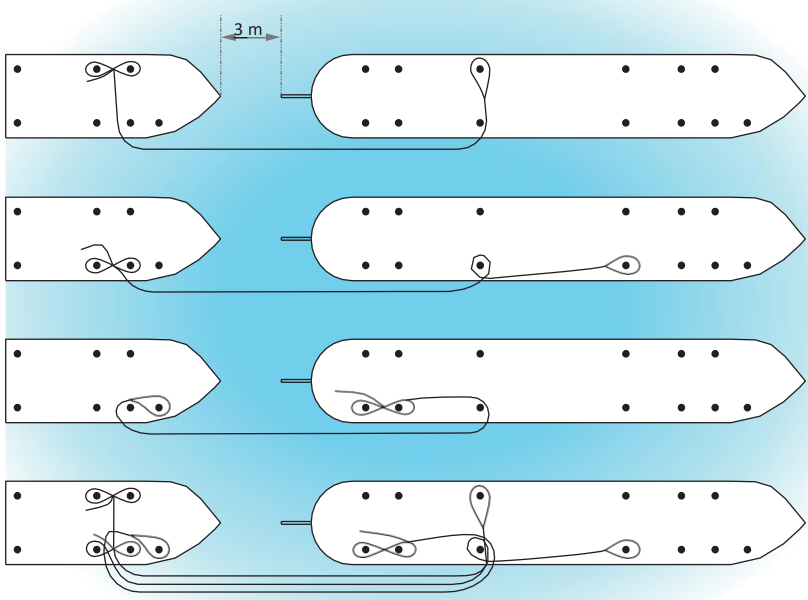


Figure 61: Medium mooring

Short mooring is used on the fairway sectors with a steady water flow i.e. Middle and Lower Danube, Sava and Tisa.

Here, two secondary towlines are led from the last barge and one from the barge in front. The first towline is led from the last barge, namely from the figure-eight to the port bow bollards and to the starboard side, between the second and third bow bollard. From there, it is led to the barge in front, where it is passed between the last bollards on the starboard side, makes a half-turn round the last midship bollard on the starboard side and is led across to the port side where a loop is placed on the last midship bollard. The second towline is also led from the last barge, by making figure-eight turns on the second and third bow bollard on the starboard side, after which the towline is led further to the barge in front, between the last stern bollards on the starboard side. Afterwards, a full-turn is made around the last midship bollard on the starboard side, and a loop is placed on the front midship bollard on the starboard side.

The third towline is led from the first barge and figure-eight turns are made around stern bollards on the starboard side, from where they are led to the next barge and passed between the second and third bow bollard on the starboard side, where a loop is placed on the first bow bollard on the starboard side. Other operations are the same as for long and medium mooring. With short mooring the distance between barges is eight metres.

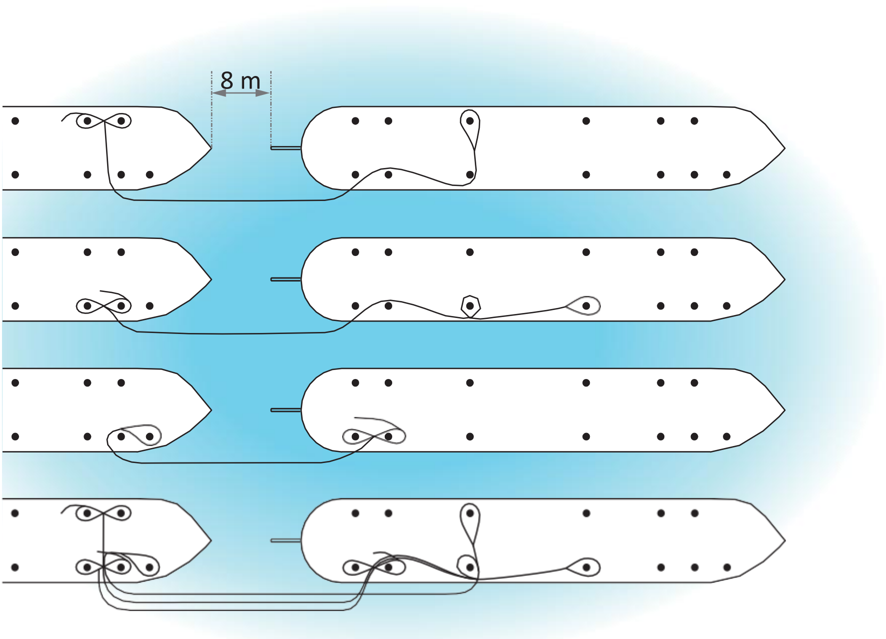


Figure 62: Short mooring

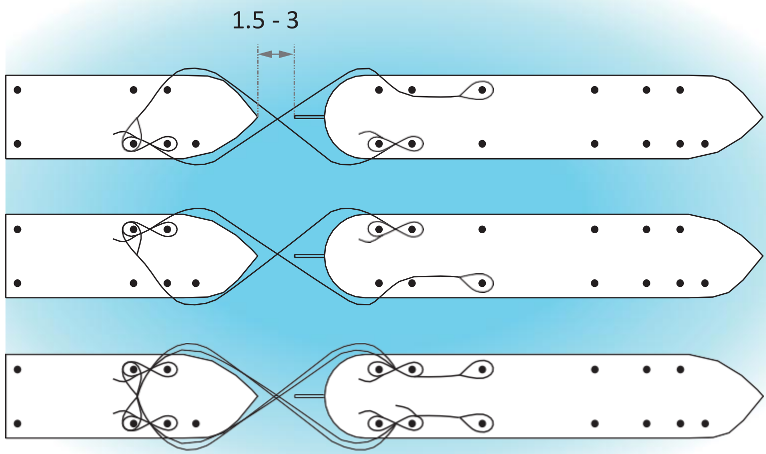


Figure 63: Short cross-mooring

Short cross-mooring is mainly used on the Upper Sava, Drava and on canals. It can be done in various ways, but the distance between barges is usually two to three metres. Details are shown in the Figure “short cross-mooring”.

Coupling of towed convoys (assembly)

In upstream navigation, longitudinal rows of vessels (strings) may be assembled or disassembled. To prevent assembled strings from disbanding, they must be coupled together. The entire convoy must be firmly coupled, starting with the barges that carry the towlines from the tug. Other barges in the convoy shall be coupled to them.

In practice, we have ordinary, tight and tight-compact coupling methods.

Ordinary coupling (figure below) is used for barges that are already at the receiving end of towlines and secondary towlines from other vessels in tow. Therefore, longitudinal coupling is not required, but only transversal and crosswise coupling.

Figure 64: Ordinary coupling

Tight coupling is used with longer longitudinal rows (string), when the same is formed of more than two transversal rows and only with light or empty vessels.

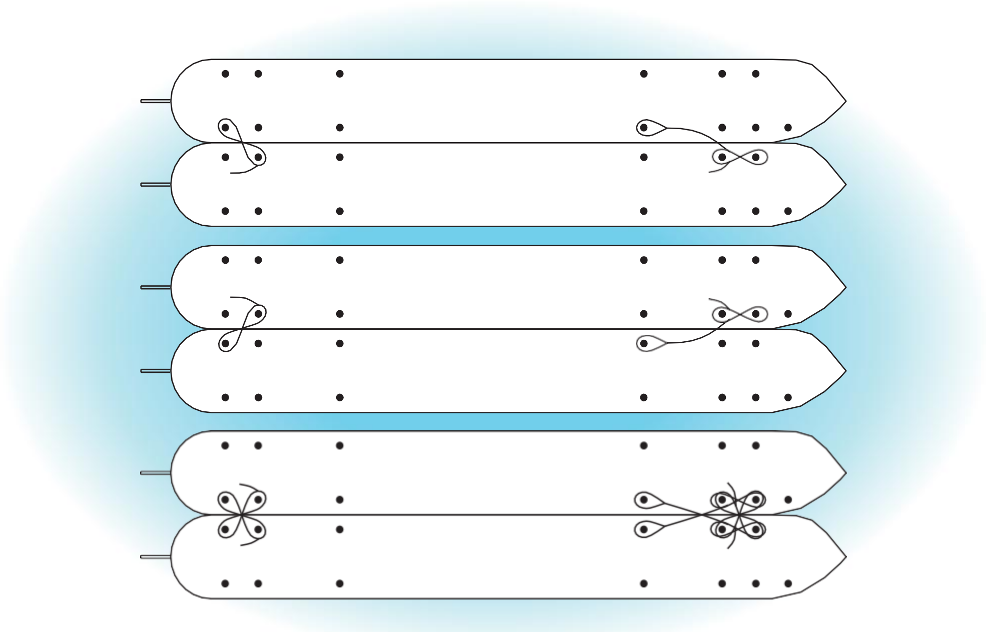


Figure 65: Tight coupling

Tight-compact coupling is used on rivers with high current velocity and for cargo vessels.

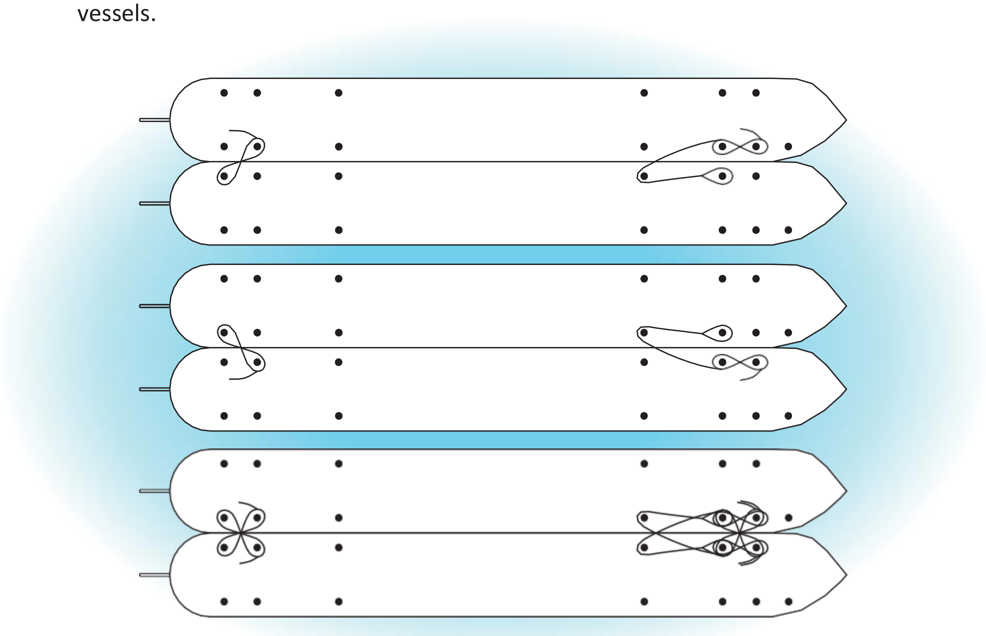


Figure 66: Tight-compact coupling

6.6.2 Forming of pushed convoys (assemblies)

The pusher vessel and pushed barges in pushed convoys, regardless of their number, load status or differing dimensions, must be firmly connected so as to practically form a single unit – "ship", which they are in terms of pushing.

To achieve this, we couple and moor the lighters by tensioning. This type of coupling and mooring is mainly used during formation of pushed convoys with the aid of mooring winches. Because our shipping companies have not yet adopted specialist terms for these joints, we use their customary names:

"*Stern-to-stern coupling*", means mooring two integrated barges so that their aft (stern) ends bear against each other.

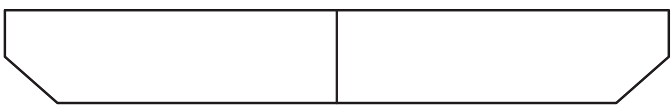


Figure 67: Stern-to-stern coupling

"Bow-to-bow (head-to-head) coupling" means mooring two symmetrical barges bow-to-bow.

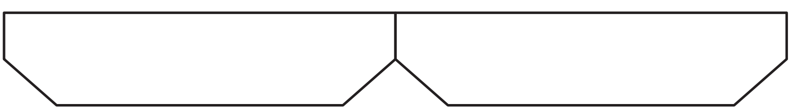


Figure 68: Bow-to-bow coupling

"Shouldering" means fastening the pusher to the barge convoy (assembly).

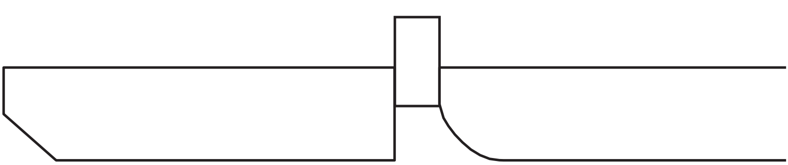


Figure 69: Barge on the pusher's shoulder

The lighters can also be coupled side-by-side in three ways:

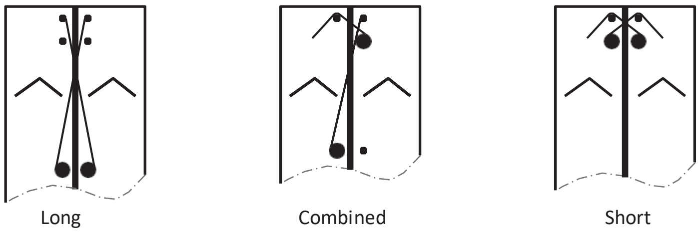


Figure 70: Side-by-side coupling of lighters (barges)

The following figures show examples of forming a pushed convoy with rope sketches.

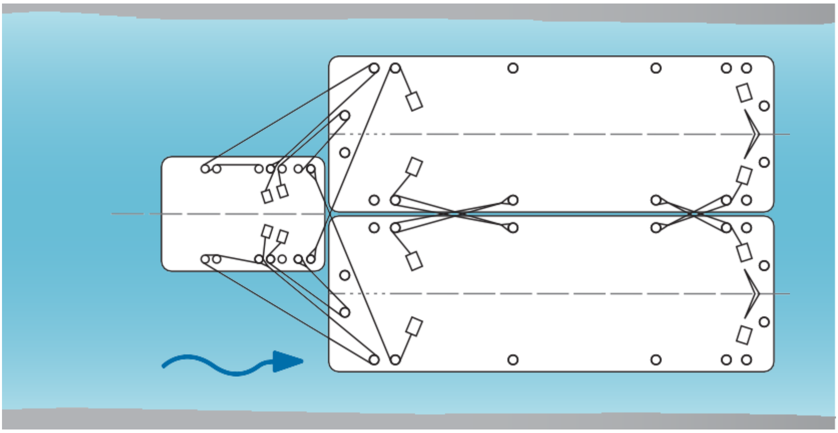


Figure 71: Downstream pushed convoy

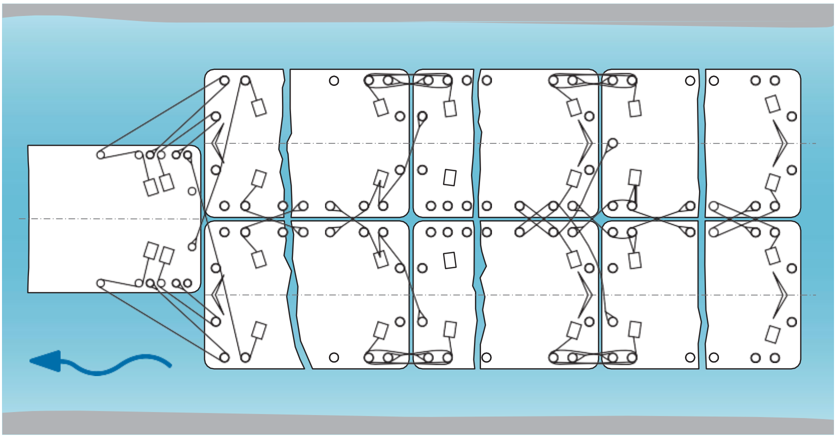
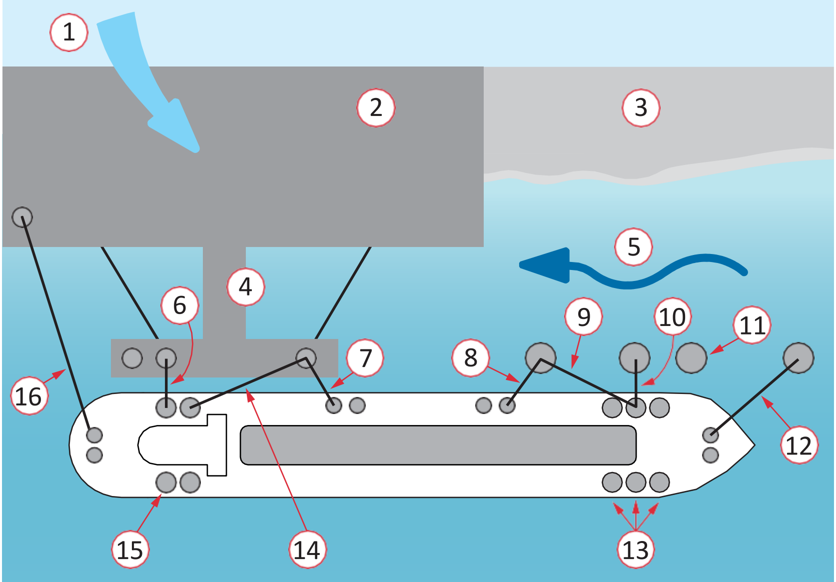


Figure 72: Upstream pushed convoy

6.7 MOORING (BERTHING)

Mooring or *berthing* means an operation aimed at making fast along the riverbank or another suitable platform. It is also employed for cargo-handling during loading or unloading, for embarking or disembarking crew and passengers, in the event of machinery failure, etc.

The figure below shows the ropes used when mooring a vessel to the riverbank or another suitable platform:



1	Wind / wind direction	9 Forward spring
2	Port (harbour area)	10 Forward breast-spring line
3	Riverbank	11 Fairlead
4	Pontoon (quay, embankment)	12 Head line
5	Current / flow direction	13 Bollards
6	Aft breast-spring line	14 Stern spring
7	Aft breast line	15 Bollard
8	Forward breast line	16 Stern line

Figure 73: Terms related to towing of inland navigation vessels

- Head line: prevents the bow from making contact with the quay / landing stage or riverbank;
- Forward breast line: prevents the bow from standing off the quay / landing stage or riverbank;
- Forward spring line: prevents the vessel from moving upstream;
- Forward breast line: like the head line, it is a load-bearing line. The entire weight of the vessel rests on the forward breast and head line;
- Aft breast line: has the same effect as a forward spring line;
- Aft spring line: has the same effect as a forward breast line and head line;
- Aft breast line: keeps the stern from standing off the riverbank;
- Stern line: prevents the vessel from moving upstream.

During longer periods of mooring, in addition to the above-mentioned lines, fenders may be placed both on the bow and stern of the vessel. In practice, all above-mentioned lines are not usually used at the same time. The previous figure shows all lines for easier recognition and to provide an explanation of their functions.

Loops of the lines taken ashore or a quay / landing stage are placed on bollards. The lines are passed ashore with the help of a heaving line. All lines specified above should be hove taut gradually and never loaded beyond their permissible working strain, due to the risk of a line breaking, which can cause serious harm to people handling the lines.

On fast-flowing waters, especially for cargo vessels, the lines are doubled. This type of line is called “doubled line” or “kec”.

6.8 MANOEUVRING

Manoeuvring is the skill of commanding a ship during: sailing out, sailing in, anchoring, mooring, pushing, towing, salvage operations, unfavourable weather condition, etc. It is based on the knowledge of manoeuvring principles and proper application thereof in practice, while taking into consideration the manoeuvring characteristics of vessels.

During navigation or manoeuvring each ship’s master must be aware of the characteristics of the vessel or convoy under his command: type of vessel (tug, pusher, self-propelled vessel, etc.) convoy size, convoy draught, and manoeuvring capabilities.

When steering, one needs to know what to expect in the course of navigation. This primarily includes all elements of the fairway, such as: width, depth, the radius of river bends and current velocity. In addition to knowing all this, the ship's master also needs to remain fully alert (steering discipline and caution during navigation and manoeuvring).

The most important manoeuvring features of a vessel are:

- Stopping capacity or "head reach" is the distance the vessel travels before stopping from the moment when the command "stop" and "full astern" is issued. Head reach is determined for every engine operating mode, and its duration is recorded. It is determined by using riverbank landmarks as reference points. Stopping distance is the distance the vessel makes from the moment the command "stop" is issued and until it stops on its own.

- The time to switch the engine from "ahead" propulsion to the "astern" mode is defined for all operating modes and is recorded along with the "head reach" duration. It is very different depending on the type of propulsion and type of propeller. Many modern vessels are fitted with a "pitch" propeller with rotating blades, which decrease this duration and do not require a reversible engine.

- The turning capacity is the size of the circle that a vessel makes when steering at constant speed and at a given rudder angle. It is defined for all operation modes and rudder angles (10°, 20°, 30° and at the maximum angle). Turning time is also recorded.

- The modern era has brought innovations in the form of bow and stern thrusters that substantially contributed to the manoeuvring capabilities of a ship, i.e., to the capacity of a ship to turn in a fixed point (pivot point).

In addition to manoeuvring characteristics, understanding of manoeuvring devices is also required, such as:

- Anchoring device, which greatly facilitates manoeuvring and makes it safer. In the event of engine failure at critical moments, the anchor may be the only means of averting an average.

- Winch / windlass and coupling / mooring devices – the ship's master and crew must be thoroughly familiar with their layout and correct use;

- Emergency steering gear - it is necessary to activate it and test periodically; and regular drills must be performed with the crew, which are then entered into the logbook;
- Onboard (internal) communication system used during manoeuvring (bridge - bow - stern; bridge - engine room - emergency steering station, etc.). On large vessels this is vital because visual communication is not possible between the bridge (wheelhouse) and all parts of the vessel with all participants involved in the manoeuvre. Wireless onboard communication is mainly used nowadays.

Steering the vessel during a manoeuvre means coordinating its precise movement in relation to the riverbank, other vessels etc. In inland navigation the process of steering a vessel consists of almost continuous manoeuvring, which includes turning, passing (overtaking and meeting), approaching the riverbank or quay, entering and leaving locks, etc.

Because a vessel is always partly in the water, it is affected by the water current, waves, proximity of the river bottom or riverbank and wind. Moreover, the vessel is affected by internal forces: propulsion, momentum, mooring-line forces and anchor cable forces. Therefore, it is necessary to understand the action of all these forces in order to use their effects during manoeuvring and reduce its adverse effects or eliminate them as much as possible. Manoeuvring skills cannot be learnt or understood through theory alone, even though it could be used as a basis, but practical work and exercise are also required.

A vessel's *inertial property* is reflected in its relatively weak connection with the environment – water, which results in very slow stopping and passing a certain stopping distance that depends on the water current direction as well as wind speed and direction. This stopping distance can be shortened by changing the engine's operating mode (used during manoeuvring) and by dosing engine power in accordance with the prevailing fairway conditions.

6.8.1 Manoeuvring features of vessels

Manoeuvring features (characteristics) of a vessel are those characteristics that allow it to change its course and speed under the influence of propulsion and steering devices. In addition to professional skills of the person performing

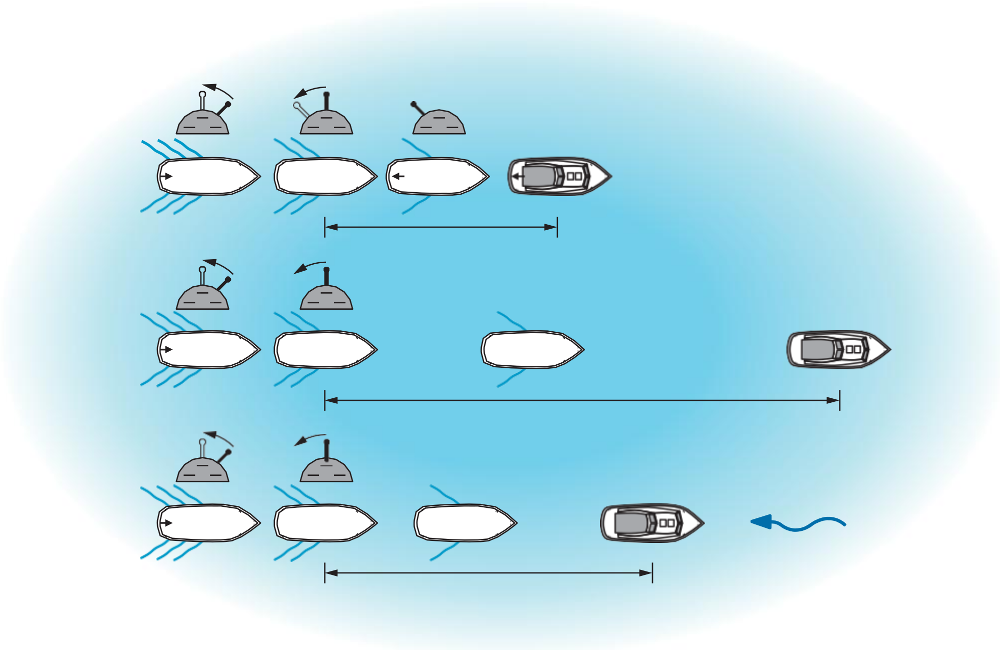


Figure 74: Operating mode from ahead to astern; from the moment the propulsion is stopped in still water; from the moment propulsion is stopped while navigating upstream.

the manoeuvre, speed and safety of the manoeuvre also directly depend on the manoeuvring features of the vessel. Some of the factors that affect manoeuvrability of a vessel include the ship's construction properties: hull length, shape and breadth, type of propulsion and steering system, etc. Besides these, manoeuvring features also depend on external factors i.e. strong crosswind.

Manoeuvring features of vessels mainly depend on the type and number of propulsors and steering gear. For example, a vessel with two propellers and an auxiliary steering device has significantly better manoeuvring features. Modern vessels have additional propulsors for lateral manoeuvres (the previously mentioned "bow and stern thrusters"), which make lateral movements safe and simple. They are installed both at the bow and stern of the vessel.

Mobility means the vessel’s speed that is achieved by the operation of propulsors.

Drifting / side-slip begins when the vessel stops moving, although it also exists while it sails, and it is compensated by changing the course. Drifting mostly depends on the current and wind, and is directly connected with the form of the hull (submerged part and superstructure). Under strong winds, ships with shallow draught and a high superstructure (planing form) will drift significantly (especially the bow section - lighter and less submerged part), whilst vessels with a deeper draught (displacement form) will drift less due to the resistance of the submerged part of the hull to the wind.

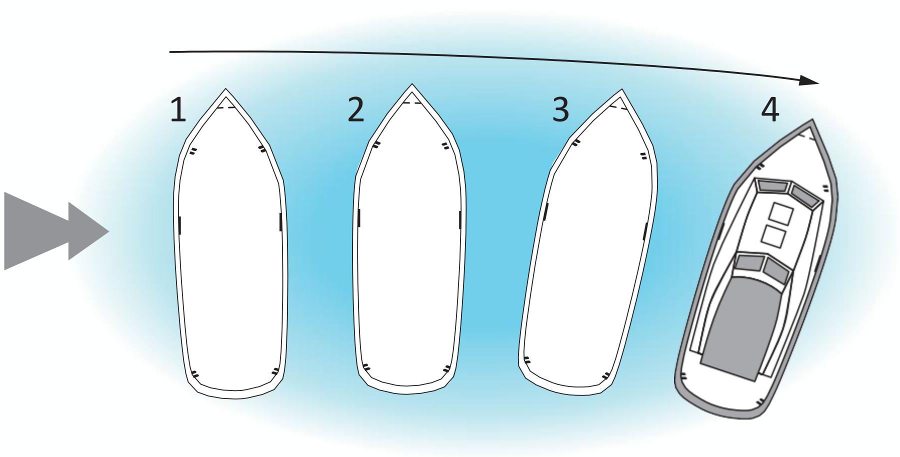


Figure 75: Drifting of a vessel under the impact of wind

Steering ability (manoeuvrability) of a vessel is its ability to keep or change the course by using a steering device. Steering ability of a vessel is characterised by the ability to change course and stability in course keeping. Ability to change course is the ability of a vessel to change the course according to the ship's master’s wish and by using steering gear. Stability in course keeping indicates the vessel’s ability to keep the determined course by counter-acting the external forces that are turning the vessel from its determined course. Stability in course keeping also means that the vessel requires 4 to 6 movements of the rudder per minute, at an angle of 2° to 3°, to keep the vessel moving in a straight line, whilst deviation of the vessel from the course should not exceed 2° to 3°.

The main reasons for the departure of vessels from the determined course are: heeling, limited fairway depth and width, wind, current and waves.

6.8.2 Meteorological and hydrological impacts

Meteorological and hydrological impacts on vessel manoeuvrability should not be underestimated and a good navigator — regardless of whether he is aboard a small boat, yacht, or large vessel —should not ignore the impact of wind on

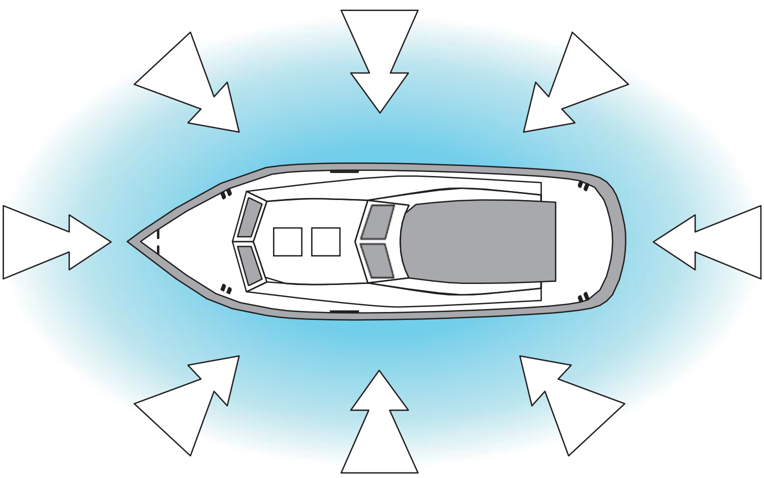


Figure 76: Wind directions and its effects on freeboard and superstructure of a vessel

the vessel’s movement. The wind can affect the freeboard and part of the high superstructure thus complicating or completely prohibiting performance of even the simplest manoeuvre. The wind has a special impact on river vessels when compared to sea vessels because they have a significantly smaller draught.

Names of winds are defined depending on the wind direction relative to the vessel: the wind blowing directly at the bow is called a “bow” or “head” wind; the one that blows astern is called “stern” wind; and the one blowing at the side of a vessel is called “side” / “beam” wind. If the wind is blowing between the bow and side, it is said to blow “at the bow quarter”, or “at the stern quarter” if blowing between the stern and the ship's side.

Any wind striking the vessel during navigation causes drifting except when it blows directly at the bow (dead ahead), thus decreasing the speed of navigation, or if it blows directly at the stern (dead astern), thus increasing speed. The wind causing sideway drifting of a vessel, which is in a still position, can set it into a “traversing” position. However, when the vessel is heading straight forward, it will be hard to move the bow from the side position windward because it is lightly immersed and the wind prevents the turn. When the vessel is moving astern, it will be easy to move it windward, because the wind quickly blows the light bow off to leeward, just like a sail. Therefore, if sailing astern under a side wind, the wind will tend to turn the stern windward and the bow downwind.

The wind is one of the most important factors when planning manoeuvring activities. If we set sail with the side wind blowing off-shore, and the vessel has a small bow draught, its influence is often stronger than the effect of backwash when sailing astern. If we wish to decrease the impact of wind to the manoeuvre, all activities must be performed vigorously and fast. The slower and more indecisive the manoeuvre is, the more exposed the vessel will be to wind action.

The Košava wind has the most unfavourable impact to sailing safety. It blows on the lower part of the Sava River and all the way up to Sremska Mitrovica. It blows from the south-east and reaches the speed of up to 100 km/h. When a navigator enters a windy sector, he should already be familiar with the characteristics of his vessel, namely: stability, manoeuvring abilities, effective power of the engine, height of the hip and freeboard exposed to the wind; and secondly, with the sailing conditions in the sector that he is entering (wind force and wave height). Given those information and experience, the navigator will decide whether he will enter the sector or wait until weather conditions improve. In case of a small vessel, the navigator must decide, based on available information, whether to continue the voyage or, at a suitable moment, interrupt it and seek shelter to leeward until the wind calms down. Navigation and manoeuvring in such cases must be performed so as to avoid direct impact of wind and waves, and berthing should be carried out windward, provided circumstances allow it.

In summer time, there are frequent occurrences of sudden changes of weather followed by strong wind, sometimes of storm strength. Severe weather cannot be absolutely surprising since it is preceded by a change of weather conditions that occurs at least fifteen minutes earlier. Air pressure drops suddenly; the sky gets dark and the air

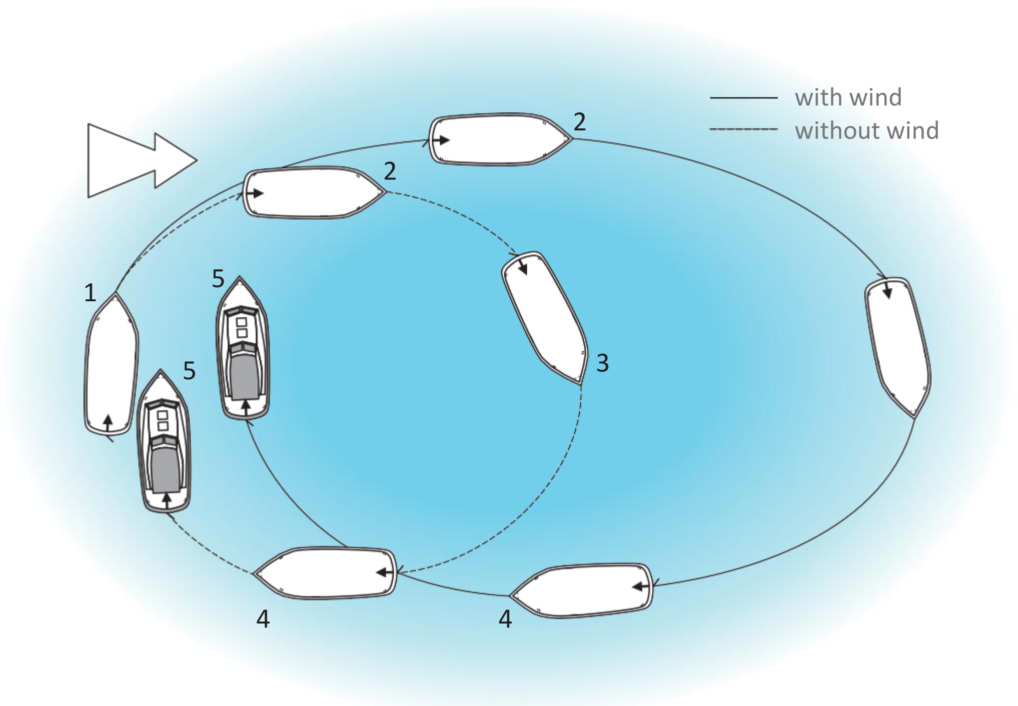


Figure 77: Drifting curve with calm weather and strong wind with constant propulsion

becomes heavy. In such cases, if the vessel is underway, it is recommended to hide under a slope at the shore or some other leeward place. After that, deck equipment that is not fixed should be secured so as to prevent it being carried off by the wind. The same shall apply to the vessel during overnight stays on an open river since storms occurring during the night can surprise even the most experienced navigator. In addition, waves made by passing vessels can also be an unpleasant surprise, especially if the vessel is moored or berthed near the fairway. River waves cannot be large as those on the sea and, therefore, they do not pose a great obstacle for navigation, with the exception of zones upstream from dams and on lakes. However, waves made by passenger vessels of great power and size, may prove to be unpleasant for a small vessel.

Impact of river currents: Manoeuvring features of vessels in a current do not change, nor does its sensitivity in a uniform current. However, it should be noted that water is moving along with the vessel. For example, if a vessel sails in still water at a speed of 10 km/h, it sails past the riverbank at the same speed, which means that its speed through water and over the ground are both 10 km/h.

In case of navigation against a 4 km/h stream, the vessel would still sail at a speed of 10 km/h, but only at 6 km/h in relation to the riverbank. During downstream navigation, flow velocity would be added and the speed in relation to the riverbank (speed over the bottom) would amount to 14 km/h. Turning circle through water and over the ground is also different. In a uniform current, the vessel behaves just as it would in calm water, as the current carries the vessel as well as the water particles around it. The circle over the ground is thus stretched downriver. The longer the turn takes, the longer the current drifts the vessel. Ship turning upstream and downstream is therefore different. Upstream turns produce a stretched turning circle arc when compared to downstream turns. The length of the turning arc depends on current velocity and the time required for the turn.

Vessel turning is one of the most important manoeuvres, which, in confined waters, often requires considerable skill, experience and knowledge. Manoeuvring, like any other skill, is perfected through practice, so successful manoeuvring requires experience. Nonetheless, skill and a good sense of space and movement can be insufficient if the ship’s master lacks the necessary knowledge and, for example, misjudges the position of the pivot point or the space necessary to complete a full-turn manoeuvre in confined waters. It is required to know that the diameter of the circle in shallow waters can more than double and that the circle can become significantly distorted and prolonged under the influence of winds (crosswind) or currents (with the current). A good ship's master must always be able to judge the position of the pivot point correctly. Many collisions and groundings occurred because the position of the pivot point, or its shift when manoeuvring in confined waters, was not recognised or was ignored.

In shipping, the word “rondeau” is often used instead of “turning”, which is a term that remained from former times along with other foreign expressions and words. During simultaneous action of winds and currents, in order to keep the vessel on its course, it is necessary to observe the principles of steering along the line of the resultant of those forces. The resultant can be approximately determined visually and the success of the manoeuvre under such conditions generally depends on the navigator’s knowledge and skill.

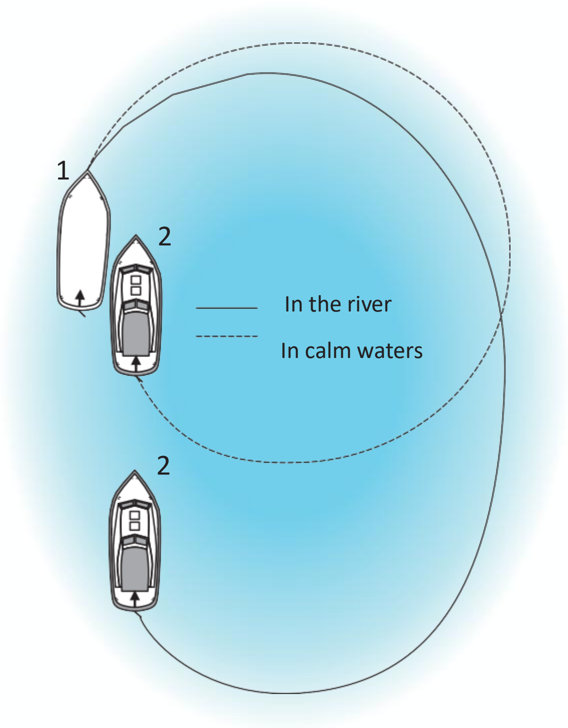


Figure 78: Illustration of a vessel's path in still water and in river currents.

The influence of shallow water is reflected by the increase in draught because, in shallow waters, there is an occurrence of *vessel skew* and *dynamic descent*. In case the distance between the vessel's bottom and river bottom is lower and speed higher, the skew is also greater. Continuation of movement in shallow waters and at a high flow velocity will increase overall water resistance and speed will fall, creating a stern wave ("the ship drags water") and submersion will reach its maximum. To counter these adverse effects, it is essential to reduce speed of navigation over shallow sections of the fairway.

6.9 SHIP HANDLING – NAVIGATION

Ship handling - navigation, requires a combination of acquired theoretical knowledge, practical skills and procedures, as well as specific preparation for each venture and, with additional years of practice, this produces a mature and experienced navigator. The process includes three phases, namely:

- Determination of current position in relation to fairway and riverbanks;
- Selection of course and speed;
- Steering the vessel on the selected course.

Depending on the fairway, navigation may take place on: rivers, canals, natural lakes, reservoir lakes upstream of a dam, as well as on some parts of the river immediately before the confluence into the sea. From a meteorological point of view, navigation can be performed under conditions of good and limited visibility (fog, precipitation, etc.), i.e. in calm or windy weather. There are generally two types of vessel conning: instrumental and visual, either separately or in combination.

1	VHF radio-station control panel	10	Radar
2	Emergency (reserve) port / starboard steering (emergency steering)	11	Echosounder
3	Wind direction and speed indicator	12	Internal communication system
4	Rudder-angle indicator	13	Height and depth measurement indicator
5	Control console for port and starboard engine units	14	VHF radio-station control panel
6	Control panel for bow and stern thrusters (transverse propellers)	15	Bow-thruster control lever
7	Steering system control panel	16	Main engine gas control handle
8	Height measurement device (e.g., display of total height from the waterline)	17	ECDIS (Electronic Chart Display and Information System);
9	Revolutions per minute (RPM) indicator	18	Rudder selector switch: manual or automatic steering mode

Figure 79: Wheelhouse technical equipment (rudder - bridge) for inland navigation vessels

The *visual method* is mostly applied when navigating on rivers, canals and reservoirs lakes. It is characterised by the fact that in conditions of clear visibility of riverbanks and navigation marks, the ship's master is able to visually determine the position by taking bearings of marks and characteristic points on the riverbank and by comparing them with the navigational chart.

The instrumental method in inland navigation is applied mainly on wide waterways (large rivers and lakes) when the riverbanks are not in sight and essentially entails integrated use of a radar, an echosounder and a speed log. It is also applied during night and under conditions of reduced visibility (fog, heavy rain, etc.) With the introduction of RIS, the instrumental method will be now applied to a greater extent on inland waterways than it was previously.

Limited navigation is carried out close to the vessel’s home berth, and for short daytrips, which is usually performed based on the user’s experience. Here, the user visually recognises the characteristic points on the riverbank and fairway, as well as hazards present on them. This kind of navigation requires information about the water level and weather forecast and the vessel will be equipped with the minimum equipment i.e.: binoculars, lenses, hook, bailer, life jackets, spare equipment and tools for the engine, etc. This way of navigation is applied by almost all owners of smaller vessels and small crafts.

Steering vessels in coastal navigation is the skill of navigating on longer sections where the fairway is only partly or little known. Therefore, prior to navigation, it is necessary to perform certain preparations in terms of familiarising oneself with the fairway and its marking system. Information about the fairway and navigation conditions is provided in navigational and hydrotechnical charts, indicator of river kilometres and other navigational aids. For certain sections, a navigator will use his notes from previous sailings, as well as notes and experiences of other navigators with greater experience.

In downstream navigation, when there are no other vessels, the navigator may sail in the middle of the fairway, in the approximate vicinity of the main current and where the river current is most pronounced. On sighting a vessel or convoy, the navigator manoeuvres to the edge of the fairway — and, if necessary, outside of it — selecting parts of the river where the current is weakest. If necessary, smaller vessels may pass on the opposite side of the floating sign, still bearing in mind that those signs are placed at points where depths are approximately 2.5 m.

By acquiring experience and fuller knowledge of the navigation sector, smaller vessels will navigate upstream outside or near the fairway, along the convex riverbank, down by the sandbars and below shoals and river-training structures, and above them when the water level allows it, as well as on all parts of the fairway where the current is the weakest. Such navigation is called "pajsovanje" (navigating outside of the main current), and smaller vessels and vessels with smaller draught are applying it with less effort.

When determining one's position, two reference points must always be taken into consideration - one ahead and one astern: a riverbank or floating sign, and on the riverbank a characteristic tree or structure. In comparison, using only one orientation point can lead vessels outside of the desired trajectory – course of navigation, e.g., between two sandbars or groynes.

Navigation in calm waters (navigation without the influence of river currents) is performed in canals (with weak, neglectable water currents), and on river parts where reservoir lakes have been created upstream of dams, i.e., where conning is simpler and easier. However, there are certain orientation-related problems on these fairways. Namely, one of the parameters for orientation is the course of the river and if the navigator is not familiar with the riverbank or river islands and there is no navigational chart, the navigator may easily become disorientated, especially after a sudden stop. A navigator may lose orientation in running waters too, when, in conditions of heavy fog, parts of both riverbanks are not visible.

The course of a vessel represents the direction of movement in relation to the riverbank, fairway or other objects that are sailing or are moored / anchored. Choosing a safe course consists in determining the most favourable direction of movement, and taking into account: the characteristics of the sector, the position of river islands, shoals, obstructions in the fairway, current strength, occurrence of limans, volume and frequency of traffic, etc.

When during navigation, the vessel veers off the given course, the reason can be as follows: subjective - error in steering, or objective - the influence of wind, waves and water currents, limans or deliberate diversion due to the arrival of a convoy, etc. The course is corrected by an appropriate engine-and-rudder manoeuvre, and, if possible, by new reference points.

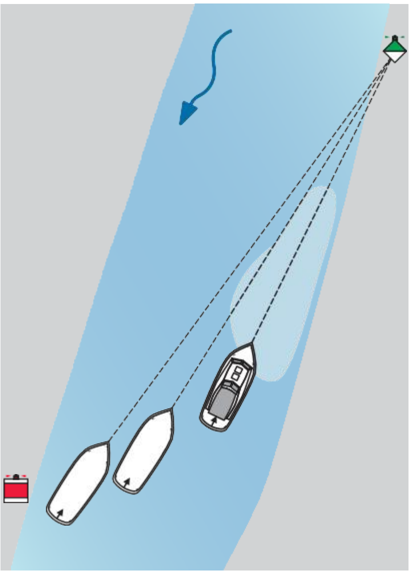


Figure 80: Unsafe navigation with one orientation point - high possibility of stranding

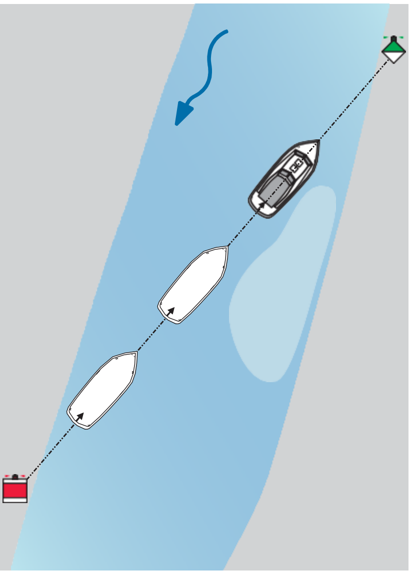


Figure 81: Navigation with two orientation points (covered direction) - safe navigation

The man overboard manoeuvre will be discussed in this chapter due to its specific manoeuvring character. It should be practised whenever circumstances permit. Lifting a person from the water is a very complicated manoeuvre, especially during navigation and at night, regardless whether that person is wearing a lifejacket or not. Regardless of the reasons and manner in which a person ended up overboard, whoever observes the person overboard must immediately throw a life jacket as soon as possible and mark his / her position. Depending on the conditions, the vessel manoeuvre, after spotting a person in water, shall be as follows:

- *Direct turn* is used by vessels able to make a full turn of a smaller diameter and stop within a relatively short distance. A direct turn is performed in such way that, immediately upon observation of a person in water, the rudder is turned towards the side on which the person was observed;
- *The Williamson turn* is performed when a person overboard is observed from a larger vessel. The vessel is then turned in the opposite direction and is often used when a ship's master is subsequently informed on a person's fall into the water;

- *The Scharnow turn* is performed under similar circumstances as those in the case of a Williamson turn. Prior to performing this turn, it is necessary to inform the engineer officer (the watch officer normally reduces speed) that manoeuvre is imminent and, before putting the rudder over the side, it is necessary to reduce the speed. This specially applies to vessels sailing at higher speeds.

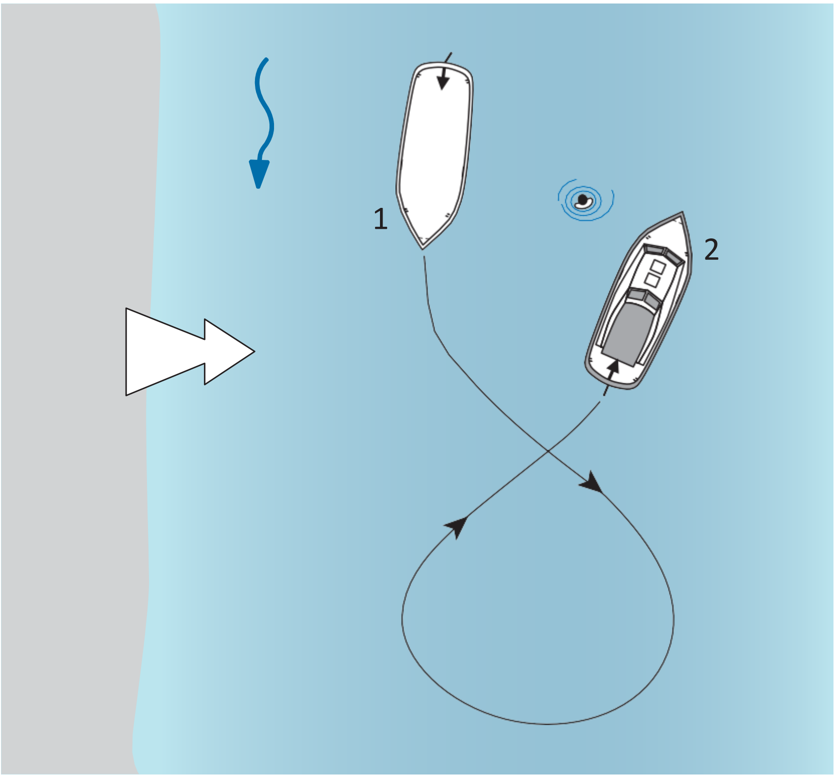


Figure 82: Man-overboard manoeuvre

Note: On a river, one needs to approach the person overboard cautiously, against the current and wind so as not to "trample" that person. The vessel is positioned, if possible, in a way that the person is in the lee (calmer water). Performing this manoeuvre at night is a lot more complex, requires more experience and skills of the crew. Nevertheless, contemporary life jackets are equipped with a self-activating lamp, whistle, etc.

6.10 MARKING OF VESSELS

Ship lights and daytime signals

Ship lights and daytime signals, given as Annexes, are part of the most current Navigation Rules applied in inland waterways, including the “Navigation Rules on the Sava River Basin”, and are particularly addressed in the International Regulations for Preventing Collisions at Sea (COLREG). These must be followed under all weather conditions. The rules regarding lights apply from sunset to sunrise, or in reduced visibility, and during this time no other lights may be shown.

Basic ship lights are defined as:

a. The term “masthead light” means a strong white light projecting an uninterrupted beam throughout a horizontal arc of 225º and placed on the ship's fore-and-aft so as to project that beam from the bow to 22.5° abaft the beam on each side;

b. The term “side lights” means a bright green light to starboard and a bright red light to port, each of these lights projecting an uninterrupted beam throughout a horizontal arc of 112.5° and placed so as to project that beam from the bow to 22.5º abaft the beam on its side; Vessels shorter than 20 meters may carry side lights in a single combined light fitted along the centreline of the vessel.

c. “Stern light” means a bright white light projecting an uninterrupted beam throughout a horizontal arc of 135º and placed as near as possible to the stern so as to project this beam throughout a horizontal arc of 67.5º along each side from the stern;

d. “Towing light” – a yellow light with properties similar to those of the “stern light”, defined under point (c) of these definitions.

e. “Light visible from all directions” means a light projecting an uninterrupted beam throughout a horizontal arc of 360º;

f. “Flashing light” – a light that flashes at regular intervals, with a frequency of 120 flashes per minute or more.

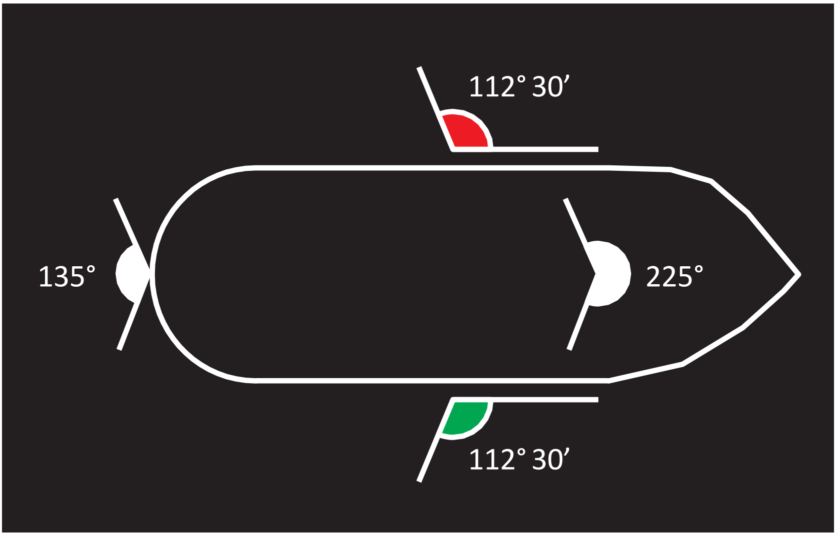


Figure 83: Basic ship lights

Pursuant to applicable regulations, a mechanically propelled vessel, when underway, must be marked as follows:

- Masthead light at the bow of a ship;
- A second masthead light aft of and above the first (vessels under 110 m in length are not required to show a second masthead light, but may do so);
- Side lights,
- Stern light.

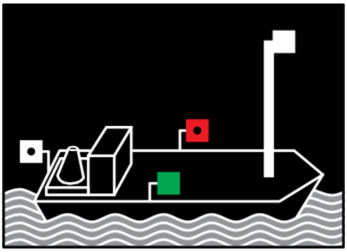
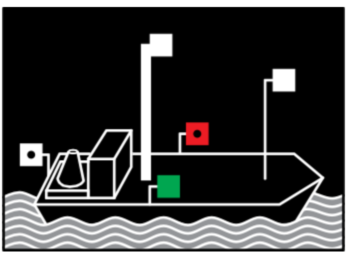
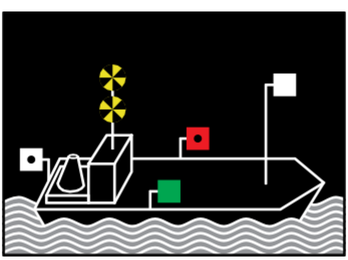
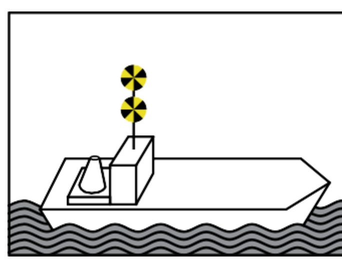
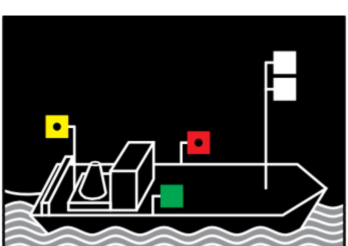
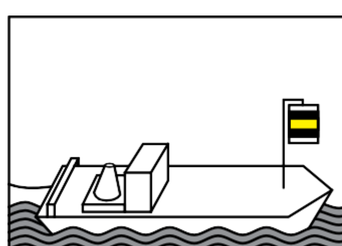
A mechanically propelled vessel, instead of the lights specified under item (a) of this chapter, is marked by:

- A white all-round light visible from all directions, and side lights.

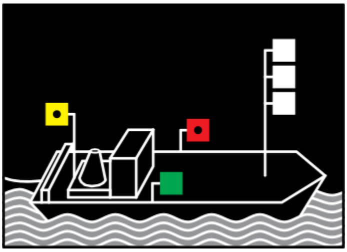
A mechanically propelled vessel less than 7 meters in length, whose maximum speed does not exceed 7 knots, is marked instead by:

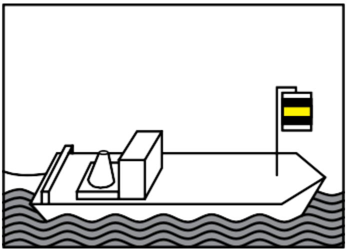
- A white all-round light, and, if possible, side lights.

In the following section, typical vessel markings are provided, considering the conditions on the Sava River fairway:

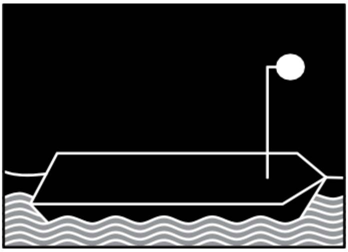
NIGHTTIME	DAYTIME
 Motor vessels proceeding alone.	
 Motor vessels proceeding alone, more than 110 m-long.	
	
High-speed vessel proceeding alone.	
	
Motor vessel leading a towed convoy - individually or as an auxiliary.	

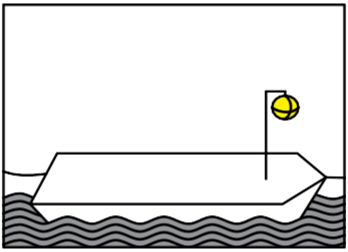
NIGHTTIME	DAYTIME



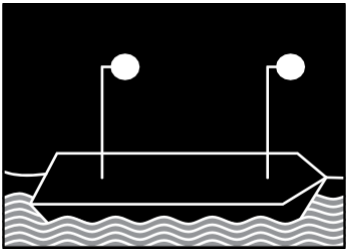


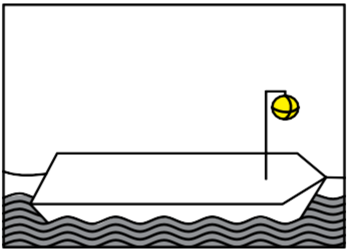
Each of several motor vessels leading a towed convoy or as auxiliaries, when several vessels are proceeding side-by-side.



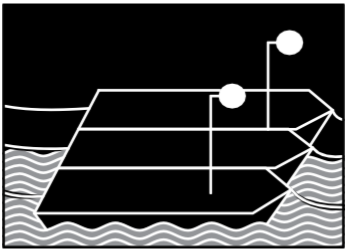


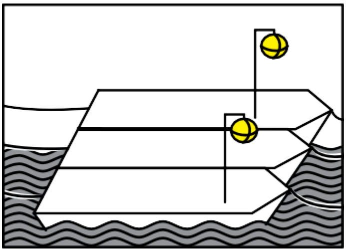
Towed convoy.





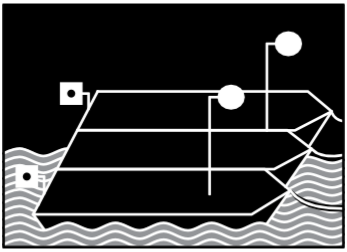
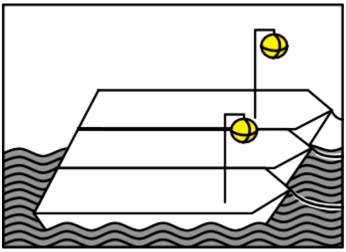
Section of a towed convoy more than 110 m-long.



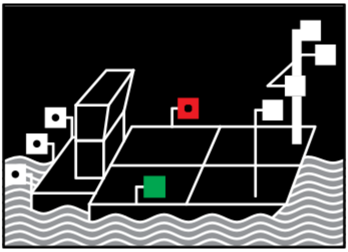


Section of a towed convoy comprising of a row of more than two vessels coupled side-by-side.

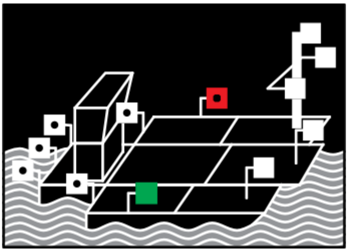
NIGHTTIME	DAYTIME

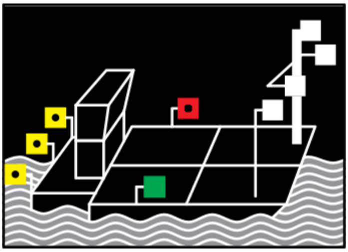
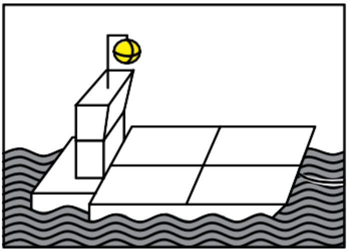
Towed vessels forming the last section of a convoy.



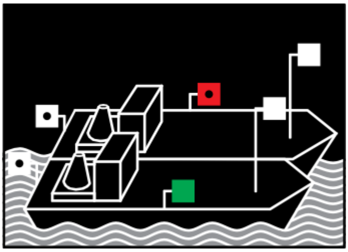
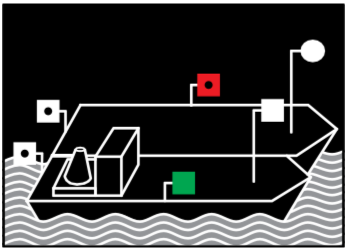
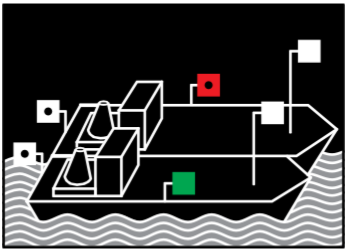
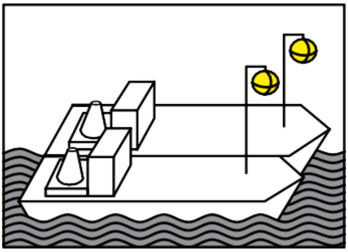
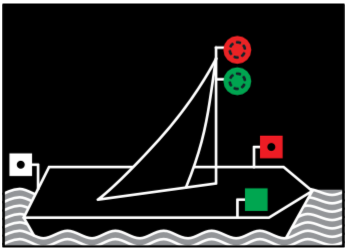
Pushed convoys



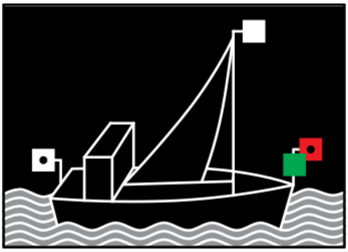
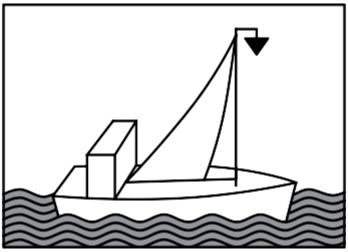
Pushed convoys, when more than two vessels other than the pusher are visible from astern over the full width

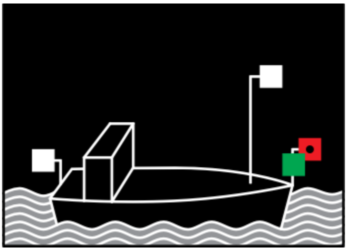
Pushed convoys preceded by one or more auxiliary motor vessels

NIGHTTIME	DAYTIME
 Side-by-side formations: two motor vessels.	
 Side-by-side formations: one motor and one non-propelled vessel.	
	
Side-by-side formations preceded by one or more auxiliary motor vessels.	
 Sailing vessels	

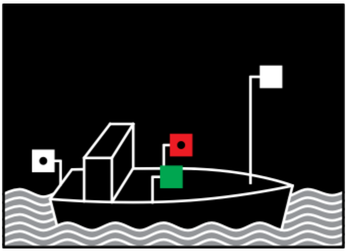
NIGHTTIME	DAYTIME

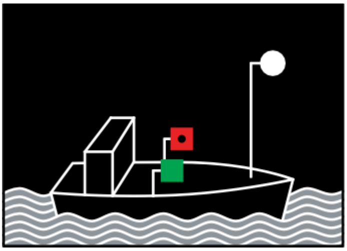
Vessels proceeding under sail and making use at the same time of its own mechanical means of propulsion.



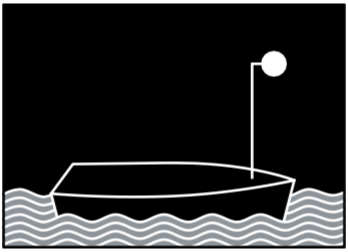
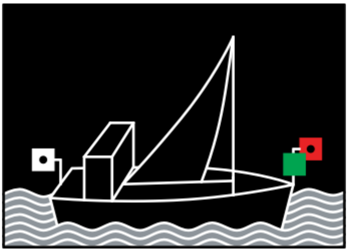
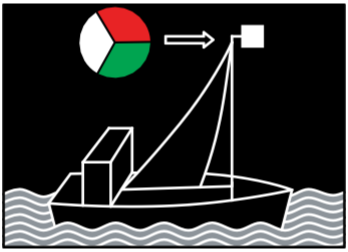
Motor small craft proceeding alone.



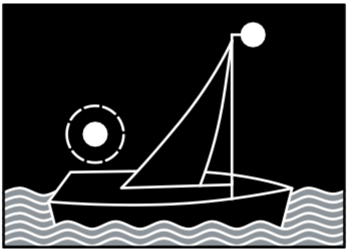
Motor small craft proceeding alone with side lights side by side or in the same lamp.



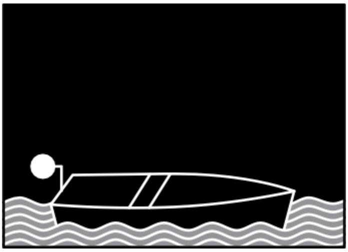
Small motor craft less than 7 m-long proceeding alone.

NIGHTTIME	DAYTIME
 Small craft towed or propelled in side-by-side formation.	
 Small sailing craft.	
 Small sailing craft, with side lights and a stern light in the same lamp near the top of the mast.	

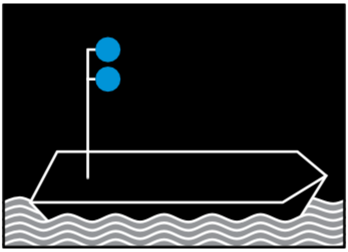
NIGHTTIME	DAYTIME

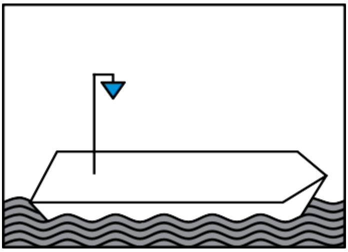


Small sailing craft less than 7 m long carrying a white light visible from all directions, and on the approach of other vessels displaying a second ordinary white light.



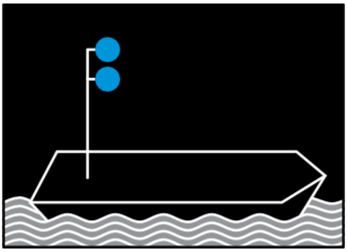
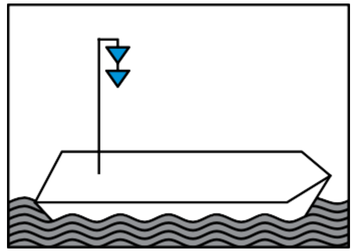
Small craft proceeding alone, neither motorised nor under sail.



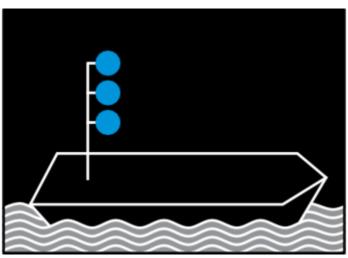
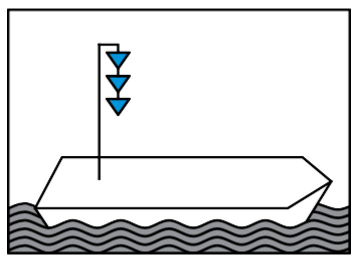


Additional marking for vessels carrying out certain transport operations involving flammable substances under ADN.

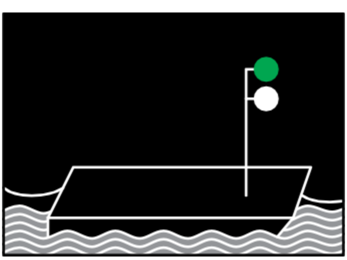
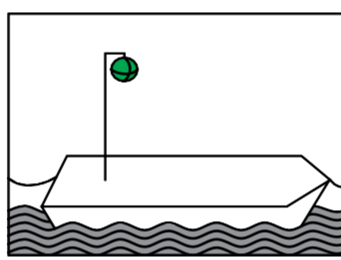
NIGHTTIME	DAYTIME

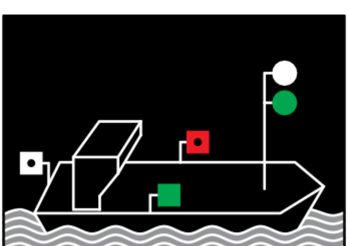
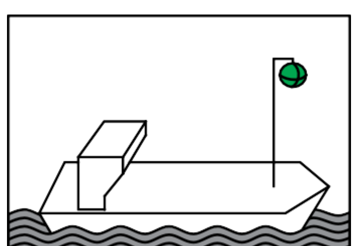
Additional marking for vessels carrying out certain transport operations involving substances constituting health hazards under ADN.

Additional marking for vessels carrying out certain transport operations involving explosives under ADN.

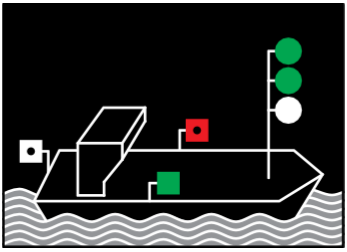
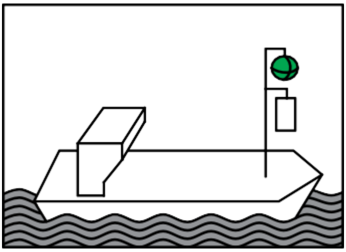



Ferry-boats not moving independently.

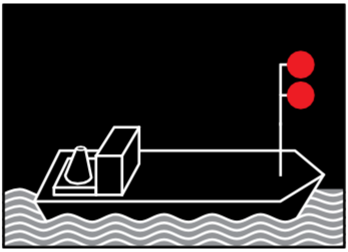
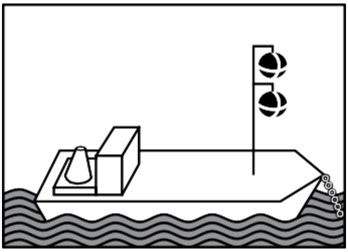



Ferry-boats moving independently.

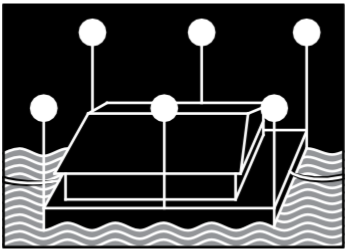
NIGHTTIME	DAYTIME

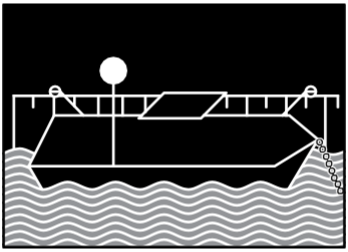
Ferry-boats moving independently and having priority of passage.

Additional marking for vessels unable to manoeuvre.

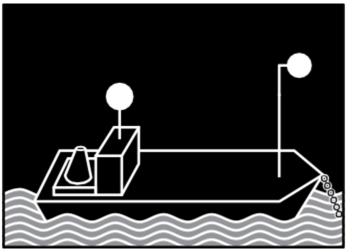
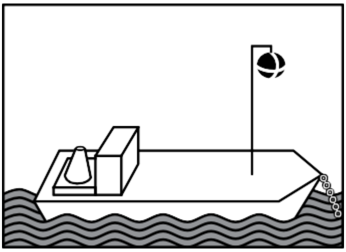


Assemblies of floating material and floating establishments under way.

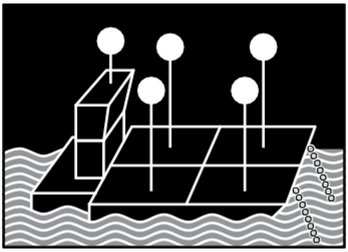
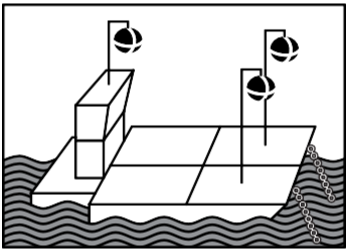


All stationary vessels.

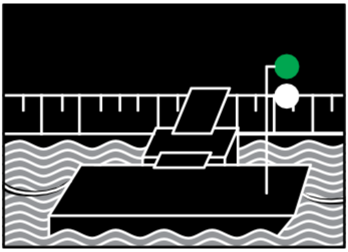
NIGHTTIME	DAYTIME

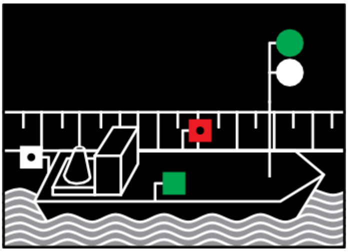
Vessels stationary offshore.

Pushed convoys stationary offshore.

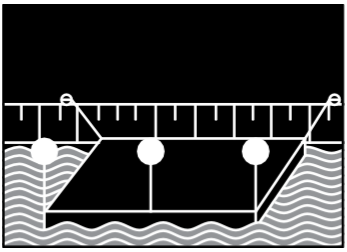


Ferry-boats not moving independently when made fast at their landing stage.

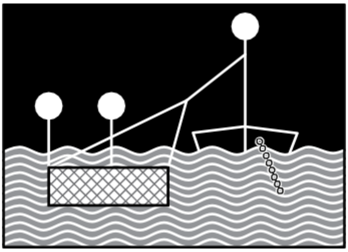


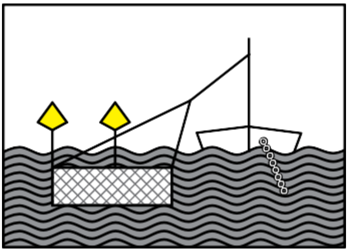
Ferry-boats moving independently, in service, made fast at their landing stage.

NIGHTTIME	DAYTIME

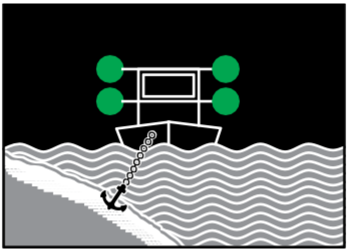


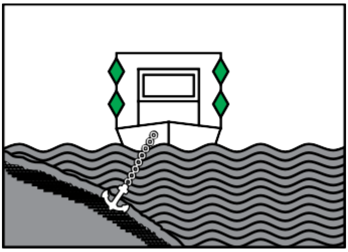
Assemblies of floating material and floating establishments when stationary.



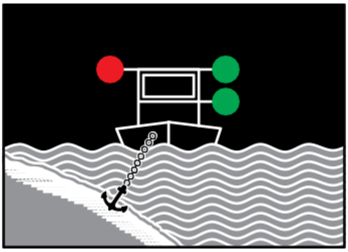


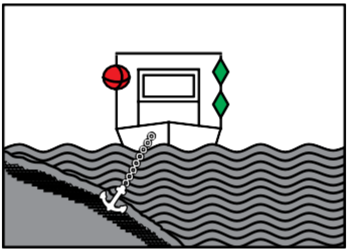
Stationary vessels engaged in fishing with nets or poles.



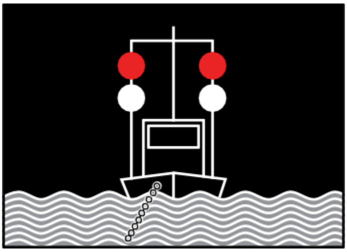
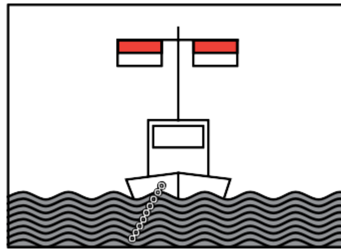


Floating equipment at work and stationary vessels carrying out work or sounding or measuring operations - fairway clear on both sides.

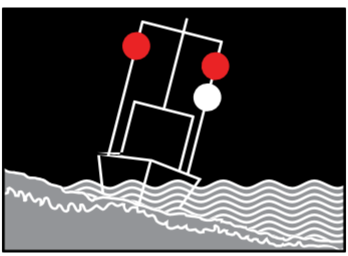
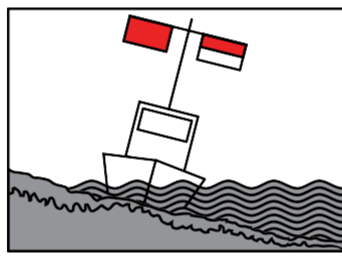




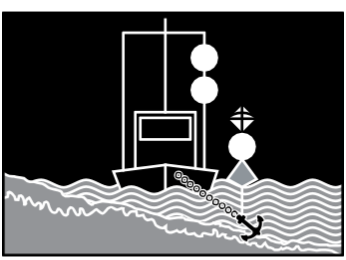
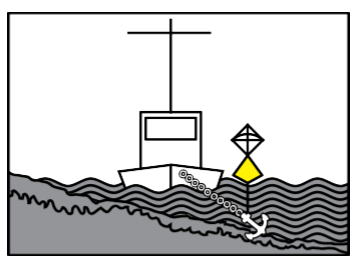
Floating equipment at work and stationary vessels carrying out work or sounding or measuring operations - fairway clear on one side.

NIGHTTIME	DAYTIME
	

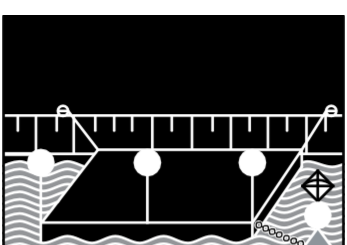
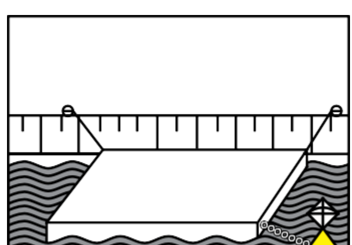
Floating equipment at work and vessels carrying out work or sounding or measuring operations and grounded or sunken vessels; protection against wash; fairway clear on both sides.

NIGHTTIME	DAYTIME
	

Floating equipment at work and vessels carrying out work or sounding or measuring operations and grounded or sunken vessels; protection against wash; fairway clear on one side.

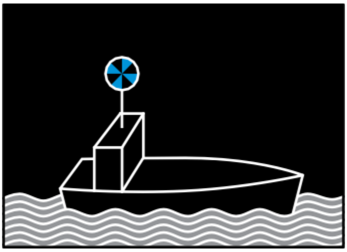
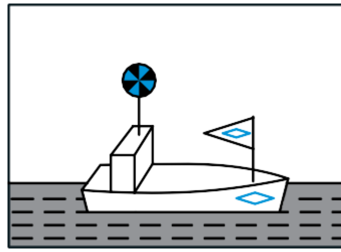
NIGHTTIME	DAYTIME
	

Vessels whose anchors may be a danger to navigation.

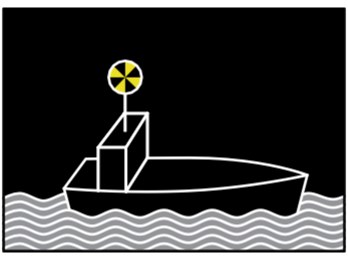
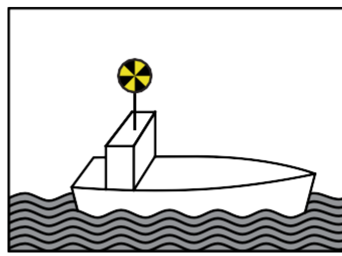
NIGHTTIME	DAYTIME
	

Assemblies of floating material or floating establishments whose anchors may be a danger to navigation.

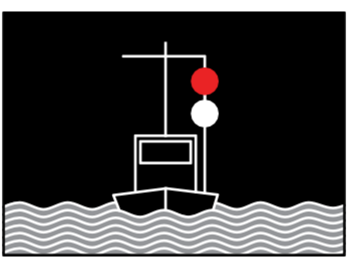
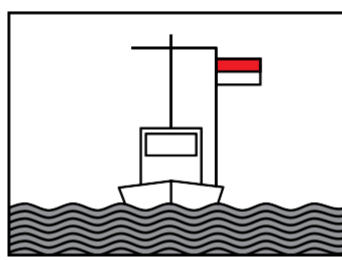
NIGHTTIME	DAYTIME

Additional marking for vessels of the supervisory authorities and firefighting and rescue services.

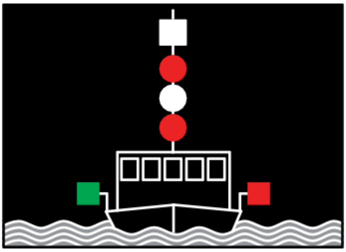
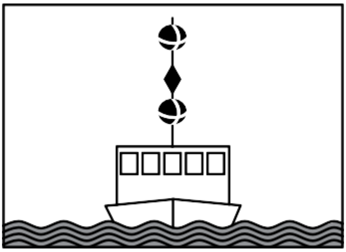
Additional marking for vessels under way carrying out work in the waterway.

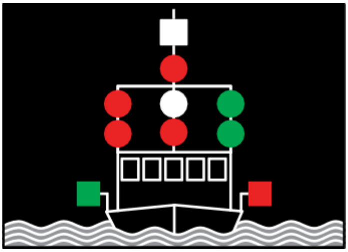
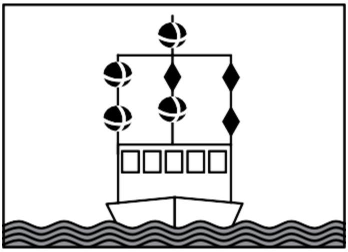
Additional marking for protection against wash.


Distress signals.

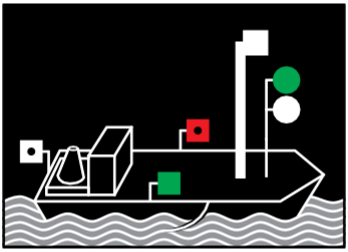
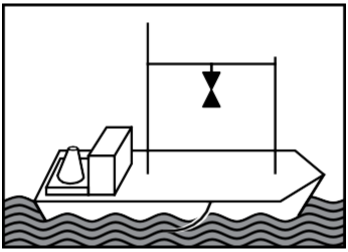
NIGHTTIME	DAYTIME

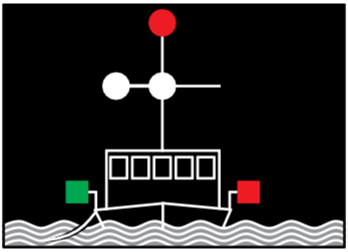
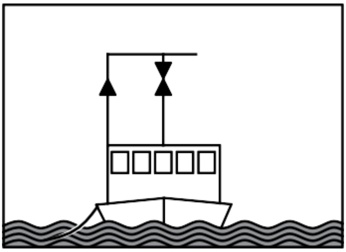
Additional marking for vessels whose ability to manoeuvre is limited.

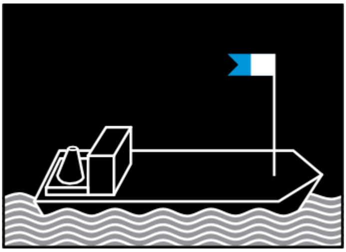
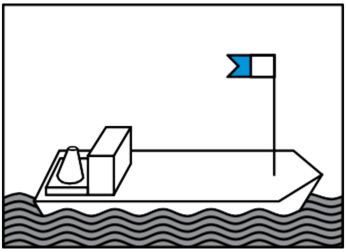
Additional marking for vessels whose ability to manoeuvre is limited; fairway clear on one side.

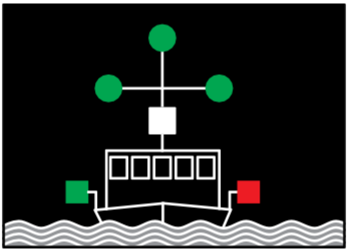
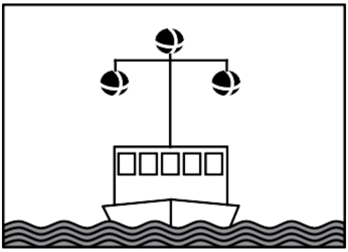
Additional marking for vessels engaged in drawing a trawl or other fishing gear through the water (trawler).

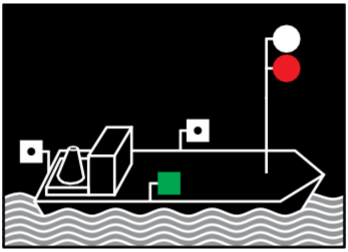
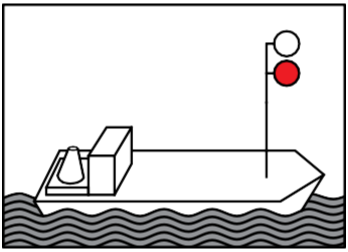
Fishing vessels other than trawlers if the fishing tackle extends more than 150 m horizontally from the vessel.

NIGHTTIME	DAYTIME
	

Additional marking for vessels used for underwater diving.

Additional marking for vessels engaged in minesweeping.

Additional marking for vessels on pilotage service.

6.11 ACCIDENTS AND AVERAGES

Navigation accident is an extraordinary event on inland waterways where death, injury or some material damage occurred.

Traffic safety, as a whole, is usually expressed by the number of extraordinary events - averages, by the number of victims and the material damage incurred. Overall, navigational safety is regulated by regulatory acts of the competent authorities (Navigation Act, Navigation Rules, Technical Rules, etc.) aimed at improving safety, and reducing the number of accidents / averages and the damage they cause.

Averages can be classified according to various criteria, but generally there are three types that are accepted, as follows:

- General (large) average;
- Particular (small) average;
- Mixed average.

The act of general average is any deliberate and reasonable extraordinary expenditure or damage, caused or incurred by the ship's master or his deputy, undertaken reasonably with the aim to save property of all participants in the same voyage from a real and common peril. Preconditions necessary for the act to be pronounced as deliberate are: that it is undertaken knowingly - in order to save lives or property, and carried out reasonably - the cost must be justified, and must result in saving and benefit.

Particular average is every accident that does not fulfil preconditions, i.e., the elements of a general average.

Mixed averages are those in which, from one initial cause, several averages occur, some with elements of a general average and some with elements of a particular average.

In cases of average, harbourmaster's offices in most countries have the task of conducting inquiries into the average, and of drawing up the stipulated documentation. The ship's master as well as any persons who witnessed the average are obligated to report the incident to the nearest harbourmaster’s office or police station and provide information on the location, time and severity of the average.

In the event of an average, the ship's master shall draw-up the following documents to be presented to the harbourmaster's office and inspection bodies:

- A statement with enclosed individual statements of crew members who were on duty at the time of the average;
- Extract from the logbook;
- Sketch of the average;
- Ship's documents.

Following the inspection of the presented documentation and determination of facts during the inspection performed on the site of average, the harbourmaster's office draws-up a report and suggests further action.

Water pollution in the waterway arising from navigation and all other activities related to navigation and navigational infrastructure is a matter of special concern for both the bodies overseeing navigational safety and the ship's masters or operators of vessels. Therefore, and for the purpose of this Manual we shall specify the primary obligations of a ship's master and the crew as well as measures and procedures intended to mitigate consequences of potential pollution made during navigation.

Ship's master and crew must undertake all necessary measures so as to prevent water pollution caused by navigation and it is necessary, for the aforementioned purpose, to implement all measures and training for carrying out suitable actions in case of pollution.

It is not permitted to discharge or spill substances, including oils, that can cause water pollution and ship's master, crew members and other persons on board the vessel must make all possible efforts in order to prevent water pollution. Furthermore, it is necessary to restrict the amount of waste occurring on board to the minimum and avoid, as far as possible, any mixing of the various categories of waste.

In case of discharge or spill of substances that may cause water pollution, ship's master shall notify the nearest competent authority without delay, indicating the position, quantity and substances of the discharge as precisely as possible. Any vessel that has caused pollution or has detected an incident of pollution of the water shall immediately by all means notify the competent response authorities and the vessels that are in the vicinity of the spill area.

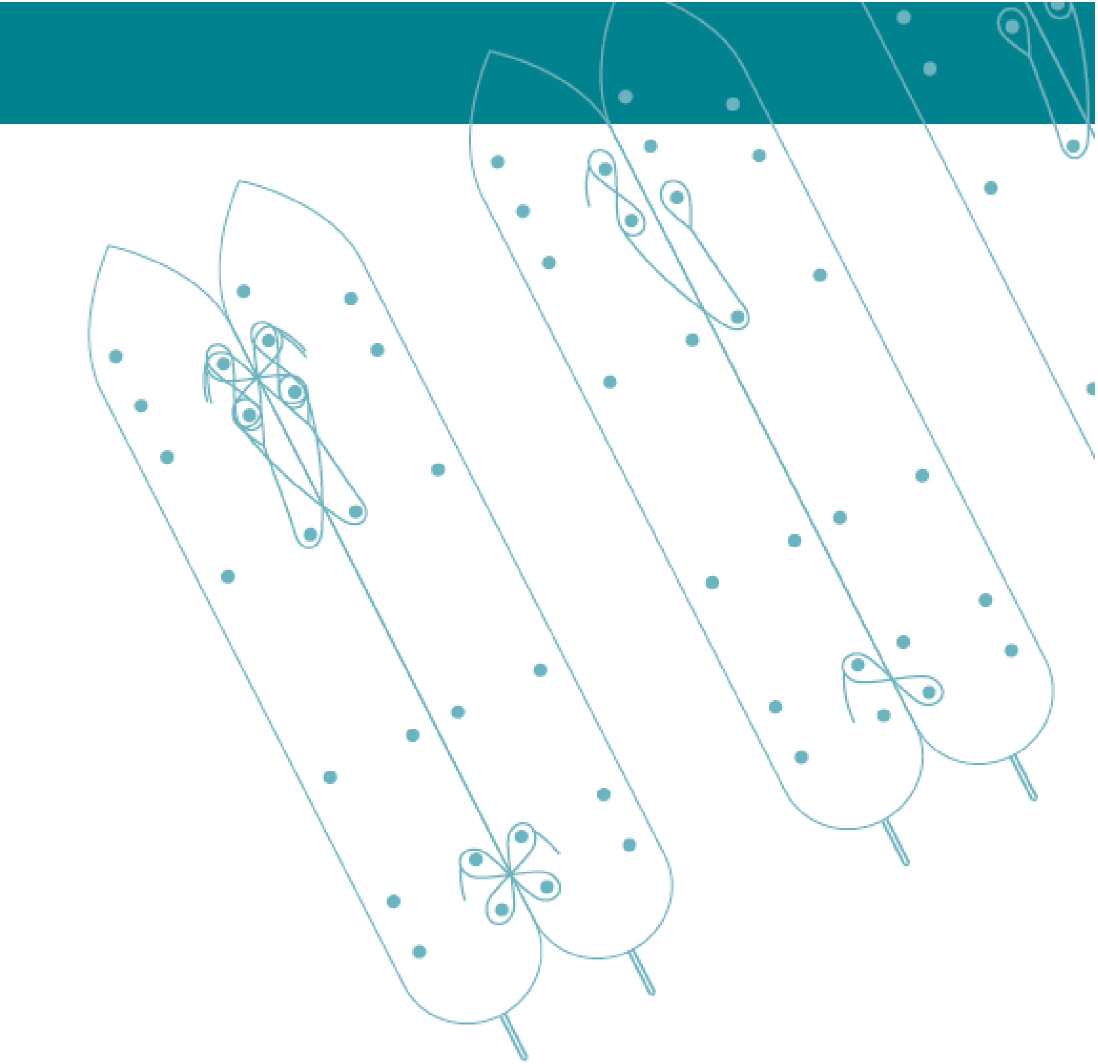
Waste occurring on board should also be collected and delivered, pursuant to the national regulations, to reception facilities at ports (if there are any) or other location designated for reception of waste occurring on board. The ship's master is responsible for keeping and updating of the "Oil Record Book" and he has to secure its availability in case it is required by the competent inspection body.

It should be kept on mind that it is forbidden to discharge oily and greasy waste in the water, and bilge water should be delivered to reception facilities. There are situations and exceptions to the prohibition of discharging water from bilge water separators into the waterway, when the maximum oil residue content after separation is consistently and without prior dilution in compliance with national requirements, and in any case, less than 5 mg/l.

It is also allowed to wash tanks and storage spaces in order to remove cargo residues from substances whose discharge into the waterway is expressly permitted by national regulations. All household waste generated on a vessel shall be collected and, when possible, after sorting to paper, glass, other recyclable materials and other waste, delivered to reception facilities.

It is generally forbidden to burn household waste, sludge, slops and special waste on board. Passenger vessels, which do not have a certified waste water treatment plant must not discharge household waste water into the waterway. Ship's masters of those vessels must keep and regularly update the "Sanitary Water Log" and they shall present it to the competent authorities upon request.

The ship's master of a vessel transporting hazardous substances shall notify the competent authorities of the country involved. In such a case, the country in question may organise an escort for the vessel or convoy during their navigations through the territory under its jurisdiction.



7.

7.
HYDROMETEOROLOGY

7.1 ON HYDROMETEOROLOGY IN GENERAL

Hydrometeorology is the science of water in the atmosphere. It links hydrological and meteorological issues within the hydrological cycle, i.e., the circulation of water in nature.

Potamology is a branch of hydrology that studies surface water flows and their regimes. It includes hydrodynamics and elements of erosion and sedimentation in watercourses. In potamology particular importance is attached to hydrography, which describes the surface watercourses, and to hydrometry, which is a technique of measuring surface and groundwaters.

Limnology is the study of lakes and still water. *The study of still waters* includes hydrological phenomena with a special emphasis on environmental impact analyses.

Cryology studies water in its solid states, e.g. ice, hail, snow and frazil ice.

Groundwater hydrology is a branch of hydrology studying groundwaters, their occurrence and movement under different conditions in the lithosphere. This interdisciplinary science mainly consists of hydrology and geology and studies the different phenomena and behaviour of water below ground. The terms hydrogeology, geohydrology or simply groundwater studies are also used, depending on the aspect to be emphasised. The most common term in our language is hydrogeology.

Therefore, hydrology is the science involved in analysing and studying the numerous influences of water, with regards to its movements and influences on living and non-living nature. It studies the water regimes in the atmosphere, on the Earth's surface and beneath it, regardless of the aggregate state of the water.

It includes observing and measuring different variables in nature and processing and analysing the collected data. Based on such data and analyses thereof, authoritative conclusions are made regarding the available quantities of water and their distribution in time and space.

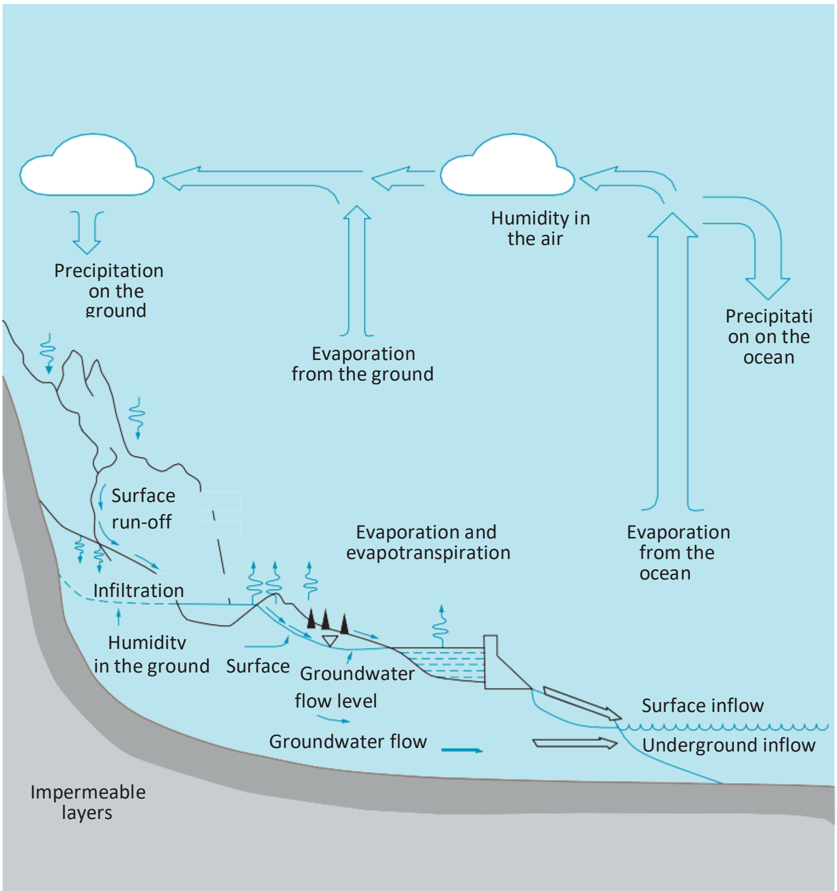
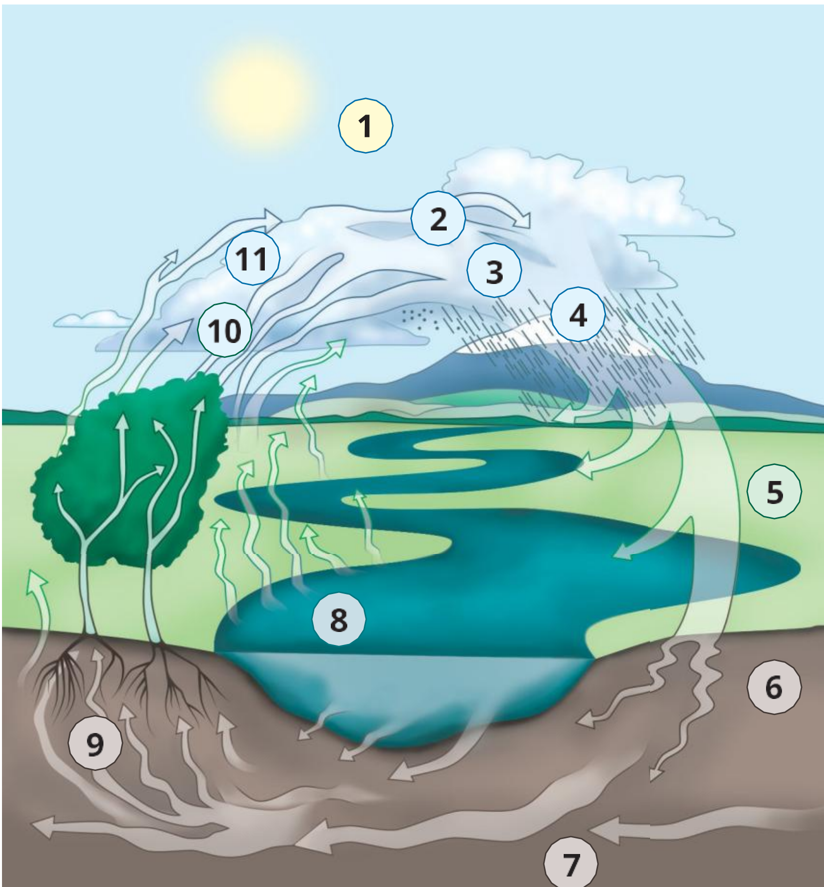


Figure 84: Water regimes in the atmosphere, on the Earth's surface and beneath it

The main difference between hydrology and other technical disciplines is that the natural phenomena studied by hydrology cannot be subjected to such strict analyses that are typical in engineering mechanics. The range of considerations in hydrology is very broad. A variety of methods are used in hydrological analyses and it is often that only the credibility of results of hydrological calculations are assessed afterwards.

Hydrological cycle takes place within the Earth's system: atmosphere, hydrosphere (on the surface) and in the lithosphere (solid component of Earth, beneath the hydrosphere). Water penetrates into the ground up to a depth of 1 km (in karst even up to 2–3 km) and into the atmosphere up to 15 km, meaning that the whole process occurs within an amplitude of approximately 16 km.



1 Solar radiation		7	Ground flow
2 Atmospheric waters		8	Evaporation
3 Water in the form of snow and ice		9	Plant absorption
4 Precipitation		10	Transpiration
5 Surface run-off		11	Condensation
6 Infiltration			

Figure 85: Hydrological cycle

7.2 WATER LEVELS / STAGES

One of the basic safety parameters for navigational safety is the river water level. It determines the dimensions of the fairway (width and depth), current velocity, etc. The water level changes continuously and depends directly on the discharge, catchment size, atmospheric precipitation, snow-melt and surface runoff (rate of runoff).

The water level / stage is the height of the water at a given moment relative to a particular reference height - “zero reference point” - at a given water gauge.

Staff gauge is a scale graduated in metric units. The scale begins with the zero reference point, so it can have positive and negative readings. As a rule, the zero reference point of a water gauge is determined using the long-term average of low water levels for the monitored location. It is fixed at a chosen elevation above sea level. In order to avoid negative readings, new water gauging stations have the zero reference point set below the lowest recorded water levels. Depending on how they are installed, water gauges can be vertical, inclined, and stepped. Modern gauges are predominantly automatic (limnographs), clock gauges, etc.

Water-level information is provided by competent state authorities and agencies and is published on national public services and hydrometeorological-service websites. Traditionally, harbourmaster’s offices inform ship’s masters about the water levels, and the harbourmaster’s offices occasionally issue their notices to that regard.

Water gauges are installed at water gauging stations that are established on the entire network covering all inland waters. In order to precisely monitor water level fluctuations, water gauges are spaced 50 – 100 km apart.

Based on the acquired data regarding water levels and their fluctuations (rising and falling trends), and with the application of theoretical and practical knowledge, a navigator will have at his disposal information such as:

- Navigation conditions, in terms of water flow velocity, submergence of river islands and sandbars with water, etc.;
- Water depth above river groynes and other river-training structures;

- Water depth at entrances to river branches;
- Possible unpleasant surprises (in a nautical sense), such as getting stranded overnight i.e. grounding, etc.;
- Whether it is safe to remain in a river branch without the risk of being entrapped due to falling water levels (water depth is usually lowest at the branch entrance).

For their own use, navigators can improvise a makeshift (staff) gauge so they can monitor water level rises and falls, as well as trends in water stage fluctuations. Such a water gauge consists of one rod or a staff driven in near the riverbank and the vessel, and for accuracy it should be sheltered from waves.

Ship's masters who keep logbooks are recommended to record water levels for the sector they are navigating if they do not keep water level notes in a separate log. This is important so that personal nautical observations and information from others can be related to a reference water level. For instance, the determined depth in certain river branch has to be referenced to the water level recorded at a particular water gauge.

From a nautical point of view, we distinguish three basic water levels: low, medium and high. Existing regulations also distinguish low and high navigable levels, which will be explained later in the text.

7.2.1 High water level

Water level fluctuations in the Sava River can measure up to a difference of 11 metres between the highest and lowest water level, which can significantly affect the appearance of the river. The adverse effects are manifested as:

- Significantly larger water masses (higher river flow velocity). This is more pronounced in the upper course and diminishes closer to the mouth / confluence,
- resulting in, among other things, disorientation owing to the formation of large water surfaces when the river overflows its bed.
- Danger to small vessels and high-speed vessels posed by the objects dislodged from flooded riverbanks.

7.2.2 Low water level

Low water level limits the dimensions of the fairway (width and depth), which has detrimental effects on navigational safety. Vessels must navigate in convoys of reduced dimensions and with reduced draughts. Consequently, passing other vessels in bends and bottlenecks can also become dangerous.

However, at low water levels the river shows all of its beauty and abundance, numerous shoals, etc. River flow velocity is extremely low, and access to riverbanks and river islands is easy, while all river-training structures are visible. This period is ideal for getting to know the fairway.

Low water level does not affect navigational safety of small crafts, provided all precautionary measures are taken. This especially applies to small crafts with large dimensions (close to maximum) and with a draught exceeding 0.5 m.

7.2.3 Water level measurement (sounding)

Water levels in rivers, lakes and reservoirs can be used directly for the forecast of inflow, designation of flood-risk areas, as well as to design structures positioned on or near the river itself.

Water levels or water stages represent changes in the level of water surfaces in watercourses, lakes or other bodies of water and are expressed with respect to a selected reference point, which can be absolute or relative. Water levels are usually measured with a precision of ± 1 cm. For special purposes the precision can be higher.

In hydrometry, several types of devices are used to measure water levels/ stages:

- Devices without automatic logging;
- Measuring devices with automatic logging (limnographs).

Devices without automatic logging are (water level indicating) staff gauges graduated at a 2 cm interval. Staff gauges are usually made of cast iron, enamelled tin, plastic, aluminium, etc. The most commonly used ones are:

- Vertical graduated staff gauge;
- Step-shaped gauge; and
- Inclined water gauge.

A large number of different types of water-level recorders (limnographs) are used today. They can be classified according to their start-up mode and recording mode.

The basic types of limnographs are:

- Float-operated,
- Pressure-operated,
- Sensor-equipped.

The usual configuration consists of a vertical pipe fixed above the watercourse and the access bridge (island type), or fixed on the riverbank and connected by a horizontal pipe to the watercourse (well type). The vertical pipe contains a float and a counterweight connected to the axle of the limnograph by a thin steel wire. The plotter is connected to the limnograph axle via multiple gears and it continuously records the water stage of a watercourse at desired time intervals onto a paper tape driven by a clockwork mechanism.

Different types of limnographs, with a gas-purge system (pressure-operated limnograph) can also be found in general use. They work on the principle that the hydrostatic pressure at a given point in the watercourse is directly proportional to the height of the water column above that point. Many devices of this type use purified nitrogen as a medium for pressure transfer. Small quantities of air or gas (nitrogen) are allowed to escape to the watercourse through a pipe, or through a special fitting at the outlet. The air or gas pressure released into the water is measured by the instrument by converting the pressure into rotation of the limnograph axle, allowing mechanical plotting of the water stage.

Figure 86: Water-level recorder (limnograph)

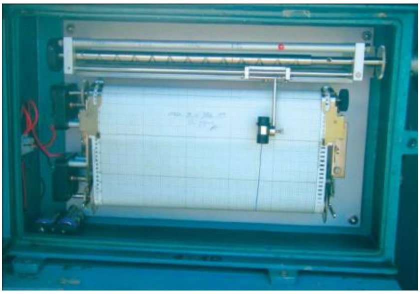


Figure 87: A plotter recording the water stage on a paper tape - limnogram

The main advantage of pressure-operated limnographs is that it does not require a vertical pipe and is not sensitive to small amounts of deposited sediment. Both types of limnographs are mechanical analogue devices with graphical recording of water levels. Recordings of water levels can be converted from analogue to digital form. Nowadays, automatic electronic limnographs are increasingly being used – these have the ability to store data in digital form. Time intervals for recording can be set in advance. Collected data are transferred to a portable computer via a special dedicated connector or a contactless infrared sensor. By means of radio waves or telemetry, the data can be transferred to desired storage locations.

All types of limnographs require the set-up of a water (staff) gauge, which is used as a reference indicator of the water level during the limnograph's operation.

7.2.4 Water gauging stations

The purpose of water gauging stations is the systematic monitoring and recording of water levels at a given point on the watercourse.

When selecting a location for a water gauging station the following criteria have to be satisfied:

- The watercourse needs to be straight at the distance of 100 m upstream and downstream of the station;
- Complete flow of the watercourse is concentrated in the riverbed at all water levels and there are no bypass flows;
- The riverbed is not prone to erosion or sediment deposition, and there is no water vegetation;
- The riverbanks are stable, high enough for cases of a flood wave, and are not covered in bushes;
- Invariable natural control feature, such as a rapid or a stable rocky riverbed for low waters or cascades, which remains unflooded at all water levels. If such an object does not exist, construction of an artificial one should be considered.
- Location for the gauging station should be set immediately upstream of the control object;

- The water gauging station has to be established far enough upstream of the mouth / confluence of the other watercourse in order to avoid the influence of deceleration;
- In addition to the above conditions, the selection of a location needs to facilitate construction of the station as well as its future operation.

In many cases it will be impossible to satisfy all the criteria, and it will be necessary to determine the relatively optimal location for the water gauging station.

No.	Type	Name	River	Mileage (rkm)	Riverbank	Elevation point "0" (m.a.s.l.)
1.	staff, limnograph	Crnac	Sava	588.2	right	91.34
2.	staff	Gušće	Sava	572.0	left	89.04
3.	staff, limnograph	Jasenovac	Sava	516.2	left	86.82
4.	staff, limnograph	Stara Gradiška	Sava	467.0	left	85.39
5.	staff, limnograph	Mačkovac	Sava	451.3	left	83.64
6.	staff, limnograph	Davor	Sava	423.8	left	82.78
7.	staff, limnograph	Slavonski Brod	Sava	371.3	left	81.80
8.	staff, limnograph	Slavonski Šamac	Sava	314.3	left	80.70
9.	staff, limnograph	Županja	Sava	267.5	left	76.28
10.	staff	Brčko	Sava	228.8	bridge pillars	76.62
11.	Automatic reporting	Gunja	Sava	228.5	left	74.32
12.	digital	Jamena	Sava	204.8	left	72.44
13.	digital	Sremska Mitrovica	Sava	139.24	left	72.22
14.	digital	Šabac	Sava	106.28	right	72.61
15.	digital	Beljin	Sava	67.53	right	69.50
16.	digital	Belgrade	Sava	0.82	right	68.28

Table 6: Review of major water gauging stations

7.2.5 Calculating depth by use of water levels

If the depth at a given sector is known at the zero reference point, and if we know the current water level at the water gauging station for that sector, we have all required parameters to calculate the depth.

Example: The depth at the “0” reference point of the Slavonski Šamac cross section, namely on the shallow sections of that sector, is 240 cm.

Example 1:	
Water level at Šamac is +50, what is the depth in the shallow sections?	
Water level	+ 50
At “0”	+ 240
TOTAL:	+ 290
Depth of shallow sections in this example is +290 cm.	

Example 2:	
Water level	– 100
At “0”	+ 240
TOTAL:	+ 140
The depth of shallow sections in this particular example is +140 cm.	

7.2.6 Determination of vertical clearance under bridges

For safe passage of vessels under a bridge or highlines stretched across a river (ferry, power line, etc.) it is necessary to know their clearance above the water surface at the zero reference point of the reference water gauging station and the height of the highest fixed point on the vessel. Highline and bridge heights are given in the Indicator of river kilometres, and the distance between the keel and the highest fixed point on the vessel is provided in the ship’s certificate. Therefore, the vessel height depends on its draught.

Height of the vessel’s superstructure may obstruct passage under a bridge, and the most characteristic obstructions are:

1. The height of the mast;
2. The height of the radar antenna;

3. The height of the highest fixed point (of ship's equipment or superstructure) with a lowered mast. This point can be movable, i.e. can be removed, for example – the wheelhouse can be dismantled, steering wheel can be lowered in some vessels, etc.;
4. Overall height (OAH) / height of the highest fixed point (F.P. - "fikspunkt"). This point is an integral part of the vessel's structure and cannot be removed, such as a radar antenna stand.

When the height of a bridge construction (at "0" reference point of the particular water gauge) is subtracted by the actual water level at the moment of a vessel's passage, the resulting value will be the vertical bridge clearance. Vertical clearance is used in deciding whether a vessel can pass under the bridge and what needs to be removed for safe passage thereof.

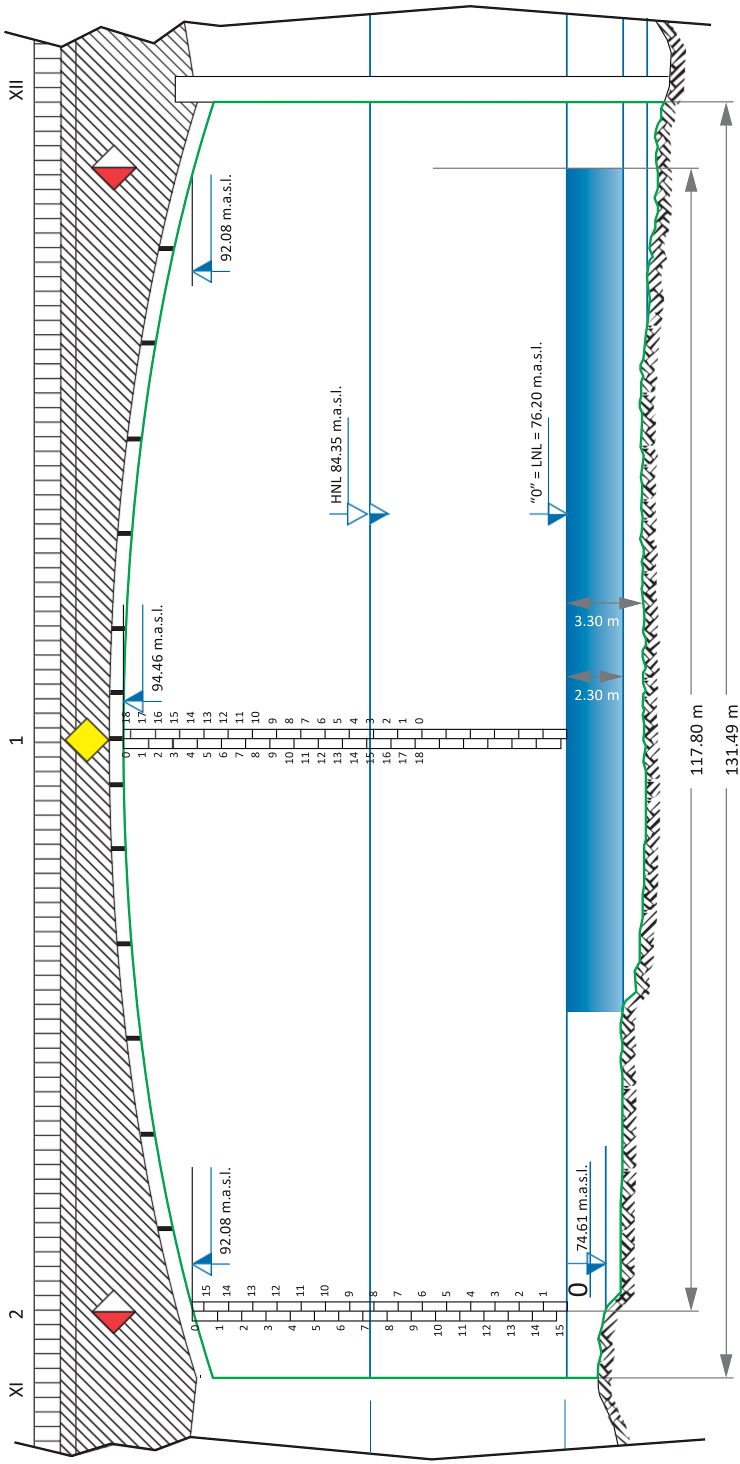
For better understanding of the text above, we will deal with a concrete example:

Vessel "Učka" should pass under the bridge in Belgrade, the height of which is 12.62 m above the "0" reference point. On that day, the water level on the Belgrade water gauging station is +550 cm. OAH / highest fixed point measured from the hull bottom is 7.06 m. At the moment of passage under the bridge, draught of the loaded vessel is 150 cm.

Available clearance at the "0" level of the reference WGS	12.62 –
Belgrade	5.50
Clearance under the bridge	– 7.12
OAH / highest fixed point (Hm)	7.06 –
Draught (T)	1.50
OAH / fixed point height at the moment of vessel passage	– 5.56
Clearance under the bridge	7.12 –
OAH / fixed point height at the moment of vessel passage	5.56
Free space	**1.56 m**

The last figure shows the height between the OAH and the bottom edge of the bridge structure, which means that a vessel can pass under this bridge because there is still 1.56 m of free space.

Figure 88: Album of bridges – navigational opening presented in a form suitable for calculation



Passing under bridges requires extreme caution. Changes in draught and water level values must be allowed for with a margin, because these data cannot always be calculated with full precision. Draught readings could be misread due to waves or ship movement, while water levels can change significantly between readings due to greater discharge of water. In addition, data on height of some bridges is not fully reliable.

If for any reason we are unsure whether the vessel can pass under a bridge, a clearance check can be conducted on the spot. It is done from the bridge itself or by observing the vessel. If access to the bridge is clear, the height of the bridge above the water level is measured by means of a rope with an attached weight (usually thrown with a heaving line). This measure is usually taken when a vessel is stationary near the bridge, so that, in case of a negative result, preparations for a vessel's passage can be abandoned.

The check on board a vessel is conducted as follows: when navigating upstream, a vessel approaches the bridge at reduced speed, stops in its vicinity and remains stationary with use of ships main engines.

Vertical clearance can be determined by sighting over the highest fixed point and another point of equal height on board, aligned on the bottom edge of the bridge structure. A second, safer, method involves the use of a vertical lath (sounding rod or boat hook), where the height is measured from the forward part of the ship located under the bridge.

In downstream navigation, a vessel should first turn upstream just before the bridge, and then, carried by the water current, position itself at a distance required for measurement. If the water current is too strong, the vessel must first anchor upstream of the bridge, and then be brought to the distance required for measurement with the use of anchor chains and engines. Understandably, this manoeuvre is conducted without towage. In case of a vessel arriving in a convoy, the convoy must be detached and anchored by the riverbank.

If a ship's fixed point is higher by a few centimetres than the vertical clearance under the bridge, a vessel could be loaded with ballasts (heavy objects or flooding bottom tanks) in order to increase the vessel's draught to the point that allows its passage under the bridge.

7.3 METEOROLOGY AND GENERAL METEOROLOGICAL PHENOMENA

Air temperature: is a measure of how hot or cold the air is and it is measured by thermometers with mercury or alcohol confined in a tube, placed in a dark space 2 m above the surface. The Celsius 100-degree scale (°C) is used here for common temperature measurements, with its zero point 0 °C being defined as the melting point of ice, and +100 °C being defined as the boiling point of water at normal atmospheric pressure.

Horizontal distribution of temperature depends on solar heat and the composition of the Earth's surface. Temperature distribution is significantly affected by land and sea, i.e., while the sea reduces the extent of periodic temperature fluctuations, the land increases them.

Air temperature decreases with altitude up the troposphere, and then changes become insignificant. Sometimes, in some layers, temperature rises with altitude (inversion) or remains constant (isothermy). The variation of temperature with change in altitude is called the vertical gradient, mean value of which is 0.65 °C for each 100 meters of altitude.

Atmospheric pressure: is the pressure exerted on a unit of horizontal surface area, equal to the weight of the air column above the ground, up to the upper edge of the atmosphere. Atmospheric pressure measurements are most frequently taken with mercury barometers in which the height of mercury column is balanced with the weight of the air column, and are expressed in millimetres of mercury (mm) or millibars (mb), the latter being the standard modern unit for atmospheric pressure.

The standard (normal, reference) pressure, also called physical atmosphere, is provisionally balanced by the weight of a mercury column 760 mm high, 1 cm^2 in cross-section, at a temperature of 0 °C and at 45° north latitude, where gravitational acceleration at sea level equals 980.655 cm^2/sec, corresponding to 1,013.27 mb. Due to air compressibility, the atmospheric pressure decreases as altitude increases. This change occurs more rapidly closer to the ground, and more slowly at higher altitudes. The vertical distance within which atmospheric pressure changes by 1 mb is called a barometric step. It depends on the pressure and on the temperature. It decreases with increasing pressure and decreasing temperature, and increases with increasing temperature and decreasing pressure. Up to the altitude of 3,000 m, barometric step is approximately 10 m.

Atmospheric pressure has a horizontal variation as well. The value which defines this change is called the horizontal pressure gradient and it is directed perpendicular on the isobar in the direction of pressure decrease. It is measured in millimetres or millibars at a distance of 100 km.

Air density: is the ratio of air mass per unit volume of air. Air density can be calculated as a function of pressure and temperature (if both are known). Air pressure increases with decreasing temperature and increasing pressure, and vice versa.

The International Standard Atmosphere (ISA) – represents a provisional distribution of mean values of basic physical parameters measured at sea level and a latitude of 45°, temperature = 1 °C, pressure = 760 mm, and air density = 1.125 kg/m^3. In ISA, temperature decrease equals 0.65 °C per each 100 m until the height of 11,000 m. From 11,000 m to 25,000 m, temperature is constant, i.e. -56.5 °C.

Atmospheric / weather front: is a boundary zone between two air masses possessing distinctly different physical properties. In synoptic charts, weather fronts are plotted at the intersection of the frontal surface with the Earth's surface. Weather fronts are plotted with lines of designated colours called weather front lines. There are two main types of weather fronts:

Cold front: forms when the cold air advances towards an area of warm air, whereupon warm air is displaced and replaced by cold air. This front brings colder weather conditions.

Warm front: forms when the warm air advances towards an area of cold air, whereupon cold air is displaced and replaced by warm air. This front brings warmer weather conditions.

There are also so-called *complex fronts or occluded fronts* that form when warm and cold fronts meet. A cold occlusion occurs when the air behind the occluded front is colder than the air ahead of it. A warm occlusion occurs when the cold air behind the occluded front is warmer than the air ahead of it. Meteorological conditions along these fronts can be very complex during their formation phase, while during further displacement of warm air aloft occluded fronts disperse.

With regard to geographic distribution of air masses, weather fronts are classified as:

Arctic front - separates Arctic and polar air masses;

Polar front - separates polar and tropical air masses; and

Tropical front - separates tropical and equatorial air masses.

Cirrus, cirrostratus and altostratus, and finally nimbostratus clouds occur along the warm front, at 800 – 1000 km ahead of the front line. Cirrus and cirrostratus clouds range in thickness from 1 to 2 km, and altostratus clouds from 2 to 4 km, while nimbostratus clouds have considerable vertical extent. Moderate to severe icing occurs in nimbostratus-type clouds, especially those with a high liquid water content and low temperatures.

The precipitation zone occurs along the weather front line, over an area of 200 - 300 km in summer, and up to 400 km in winter. Fog is sometimes formed ahead of the approaching front, ranging in width of up to 200 km.

Cyclone and anticyclone: uneven distribution of atmospheric pressure contributes to the development of pressure (baric) systems. Two main types of pressure systems are:

A *cyclone*, or an area of low atmospheric pressure, and

An *anticyclone* or area of high atmospheric pressure.

The air pressure in cyclones is lowest at their centre, but gradually rises towards its periphery. It is characterised by inward spiralling air that rotates counter-clockwise in the Northern Hemisphere. The air pressure in anticyclones is highest at the centre, with outward spiralling air that rotates in a clockwise direction.

In addition to these main types of pressure systems, there are secondary ones as well:

- *Trough*: elongated segment from the centre of a cyclone, positioned between two high-pressure areas;
- *Ridge*: elongated segment from the centre of an anticyclone, positioned between two low-pressure areas;
- *Col*: pressure area situated between two crosswise-arranged cyclones and anticyclones.

The air pressure constantly changes in time and in space, thus causing the pressure systems to alter, relocate and change their intensity.

Cyclones and anticyclones move at an average speed of 30 – 40 km/h, and last 1 – 2, or at most 7 days. Atmospheric fronts form in a cyclone, meaning that weather in a cyclone is largely governed by frontal cloud systems and precipitation.

***Air humidity**:* can be considered as absolute and relative.

Absolute humidity: is the quantity of water vapour contained in 1 m^3 expressed in grams.

Relative humidity: the ratio, expressed as a percentage, of the current quantity of water vapour in the air to the maximum quantity of water vapour the air can hold at that specific temperature and pressure. In dry air it is 0 %, and in saturated (moist) it is 100 %. Relative humidity is a measure of air saturation with water vapour.

The air temperature at which the actual content of water vapour saturates the air and turns into liquid is called the dew point temperature. The most important characteristic of water vapour is the transition from one to another aggregate state, i.e.:

- Transition to the liquid state or condensation; and
- Transition to the solid state or sublimation.

The main cause of these phenomena is cooling of the air saturated with water vapour.

Wind: is the movement of air in an approximate horizontal direction, characterised by its direction and speed. The wind direction is determined in terms of the cardinal direction from which it originates, expressed in degrees. For example, 360° wind direction means that wind originates from north. Wind speed is expressed in metres per second (m/sec) or kilometres per hour (km/h). Surface wind speed is measured with anemometers and electrical wind vanes, and on higher altitudes with weather balloons and radiosondes. Due to the actions of deflecting forces, friction, gravity and centrifugal force, surface winds blow at a certain angle in relation to isobars, turning toward areas of low atmospheric pressure.

One of the main characteristics of winds is gustiness. Especially in the friction layer, winds blow erratically (in gusts), with speeds varying within 1 – 2 sec by up to 50 % to one or another side of the mean value. A whirlwind-type of air movement is called turbulent movement.

Clouds: are divided by international classification into 10 types, namely: Cirus (Ci), cirrocumulus (Cc), cirrostratus (Cs), altocumulus (Ac), altostratus (As), nimbostratus (Ns), stratocumulus (Sc), stratus (St), cumulus (Cu) and cumulonimbus (Cb).

Clouds are vertically divided into three étages / levels: high-, mid- and low-level clouds:

- High-level clouds: cirrus, cirrocumulus and cirrostratus;
- Mid-level clouds: altostratus and altocumulus;
- Low-level clouds: stratocumulus, stratus.
- Vertically developed clouds are: Cumulus, cumulonimbus and nimbostratus.

Cloudiness or the fraction of the sky obscured by clouds is expressed in eights. For example, 8/8 means that the sky is fully covered by clouds, 4/8 means that the sky is covered 50 %, etc. Low heights of clouds (50 – 200 m) are observed on atmospheric fronts and in precipitation zones. Areas between clouds are very different and exposed to frequent changes.

Precipitation consists of water particles falling from clouds to the ground, and can be:

- Long-term, if falling out of nimbostratus and altostratus clouds;
- Drizzling, if falling from stratocumulus and stratus clouds, and
- Showering, if falling from cumulonimbus, and frequently followed by storms.

Atmospheric precipitation that falls from clouds caused by weather fronts is called frontal precipitation, and the one falling fall from clouds that develop within homogeneous air masses is called air-mass precipitation.

Precipitation is divided into solid, liquid and mixed, and most commonly occurs as:

- Prolonged moderate rain, with middle-sized droplets;
- Rain shower with large droplets, of high intensity, sudden onset and cessation;
- Drizzle with very small droplets, falling very slowly;
- Prolonged snow in the form of flakes of moderate intensity;
- Snow shower in the form of large flakes, of high intensity, sudden onset and cessation;
- Wet snow in the form of mixed rain and snow (sleet);
- Freezing rain in the form of transparent ice pellets, 1 – 3 mm in diameter;
- Snow grains falling in the form of white granules, 2 – 5 mm in diameter; and
- Hail in the form of ice balls or irregular lumps of ice of various sizes.

Fog is a visible mass consisting of the tiniest water droplets or ice crystals suspended in air at or near the Earth's surface, reducing horizontal visibility to less than 1 km. If visibility is in a 1 – 10 km range, this is called haze or mist. Fogs form when the ground air cools down to the dew point temperature, which causes condensation. Thickness of a fog layer varies from several meters to several tens of meters. Most frequently it occurs after midnight or in early morning hours, and breaks up before noon.

Air masses are huge volumes of air covering vast areas in which meteorological elements uniformly change in the horizontal direction. Based on their origin / source, they are classified as continental and maritime. By general characteristics, they are classified as:

- *Cold* air masses, which are those moving towards warmer areas and bringing cooler weather conditions;
- *Warm* air masses, which are those moving towards colder areas and bringing warmer weather conditions, and
- *Local* air masses, which are those that remain in their source region, but, once in motion, can become either warm or cold.

According to geographical classification, air masses may be *Arctic, temperate, tropical or equatorial.* Each of these air masses may be maritime or continental, depending on its region of formation / origin.

Thunderstorms and strong gusts of wind are atmospheric phenomena associated with cumulonimbus clouds, accompanied by electrical discharges in the form of lightning, with thunderclaps and showery precipitation.

Thunderstorms result from:

- Uneven heating of the lower air layer;
- Rapid uplift of warm air or the arrival of cold air in an atmospheric front; and
- Lifting of air along a mountain ridge.

Lightning is an electric discharge between electrically charged regions of opposite polarity, generated by cumulonimbus clouds when the charge of an electric field reaches the value of 10,000 V per 1 cm^2. Actual discharge can occur between different clouds and their parts, or between a cloud and the ground.

Electrical discharge can be in the form of a line or ball lightning.

Thunder occurs when the air in an electrical discharge channel expands rapidly due to rapid heating. The thunderclap can be heard up to 35 km away, or sometimes even up to 50 km away.

7.4 METEOROLOGICAL AND ASTRONOMICAL PHENOMENA RELEVANT FOR INLAND NAVIGATION

Wind is one of the factors adversely affecting navigation. Depending on wind strength and direction (with exception of sailing under certain circumstances), navigation with small vessels can become uncomfortable both for the crew and for the passengers, especially in conditions of heavy rolling. During extremely strong winds, the stability and navigability of small vessels can be seriously endangered.

The most frequent winds on the Lower Sava section are Košava – an east to south-east wind - and Sjeverac – a north-east wind. Winds are less pronounced on the upper course, while in summer months and in extreme conditions occasional cyclonic storms of hurricane force may occur.

Information on winds and their intensity can be obtained from the hydrometeorological services, shipping companies, navigating vessels and harbourmaster’s offices.

Limited visibility: Fog, drifting snow, very poor visibility (haze), showers and other causes create conditions of limited visibility. The most difficult of them is fog, which can reduce visibility to the extent that a vessel’s bow cannot be seen from the bridge.

Experience has proven, and the navigation rules require, mandatory use of a radar during fog, while convoys navigating downstream are, in case of fog, forbidden to continue navigation. Before the radars was invented, navigators used to say: “Fog falls – the ship stalls”.

Despite all modern equipment, navigation during fog requires implementation of enhanced precautionary measures. Navigation of small vessels is not recommended if visibility is reduced to less than 10 meters. In such weather conditions, the sense of orientation can be lost, i.e., sometimes it is impossible to determine if a vessel is moving upstream, downstream or towards a riverbank, meaning that smaller vessels may suffer an average by running into river-training structures, navigating or stationary convoys, bridge piers, etc.

In conditions of limited visibility, especially during fogs, skippers of small crafts must not underestimate the unfavourable navigation conditions and must implement appropriate precautionary measures. When making a decision for a vessel to depart, the minimum condition should be that the opposite riverbank is visible, and during navigation, at least one riverbank must be visible. If fog “closes the way” and both riverbanks are lost from view, an immediate stopping manoeuvre must be undertaken and the vessel brought outside the fairway. If a vessel has an anchor, it must be dropped at the earliest suitable moment and, when it holds, the vessel should be brought into an upstream position. The position can be determined more accurately by listening for sounds from the riverbank or establishing contact with someone ashore. Only then can very careful manoeuvres be made in order to correct the position, i.e., to move closer to the riverbank.

Night navigation is additionally complicated due to reduced visibility, particularly when there is no moonlight, and the weather is overcast, rainy, snowy or misty. Fairway and ships are marked with distinctive luminous marks. Search-lights are used only occasionally, in order to check the distance from riverbanks or any other obstacle. Navigators who lack experience in navigation and sufficient knowledge about the river should avoid navigating on their own after dark.

Ice is one of the greatest obstacles to navigation in general. However, even though occurrence of ice on the Sava River is very rare, the phenomenon is discussed here for general nautical awareness and general knowledge purposes. Although sporadic formation of drifting ice (10 – 15 %) does not pose a risk for larger vessels and convoys, the same does not apply to vessels of a more fragile structure, floating houses, river restaurants, landing stages, smaller vessels and boats.

Before each upcoming winter season, preparations must be carried out for the vessels to be moved into winter harbours or winter shelters (river branches with calm water) without a direct inflow of river water.

Immediately before drifting ice appears, the river marking system (floating signs) should be removed so as to protect it from destruction. Navigation is then more difficult and vessels navigate only with the aid of luminous and non-luminous signals set on riverbanks.

Figure 89: Drifting ice

Depending on its form, strength, shape and other characteristics, following forms of ice can be distinguished:

Clear ice or *"vedrac"* is the ice that first forms on calm waters, canals, closed ports, winter harbours and along the riverbank where currents, as a rule, are weaker. This ice is characterised by purity, strength, a smooth surface and transparency. In exceptionally long and severe winters, its thickness can exceed 50 centimetres, thus must be constantly broken in winter harbours and around vessels. Breaking the ice around vessels creates air vents that prevent damage that expanding ice could inflict to a vessel's hull or other vital parts (propulsors, stern, sensors, etc.).

Frozen snow ice or "snježanik" forms when river-surface temperature approaches zero simultaneously while snowfall continues for a long period. Consequently, the river surface becomes covered with grey streaks with white edges. That is a first signal that ice is about to form. Experienced navigators used to say that "cream was forming". On contact with a riverbank, the resulting "slush" of snow, ice and water captures rocks and soil, which at low temperatures turns into ice boulders very hazardous for navigation.

Ground ice or "podnac" (ice on the riverbed, "grundajs") forms when frozen water particles carried by river currents lock onto the riverbed, where they attach to coarse sediment and create ice shoals very hazardous for navigation.

Ice floes (*"sante*") form through the agglomeration of drifting ice masses, resulting in creation of large ice forms. As the floes grow and the current acts on them, forces develop that endanger vessels, transversal and parallel water-training structures, river dams, bridges, etc.

When drifting ice carried by water currents arrives to a narrowing on a riverbed, a bend, shallows, submerged structures, bridge piers or other obstacles, it stops. Arrival of other ice floes creates great pressure that causes them to override one another and creates an ice jam that can be several meters high. This situation leads to a step in water level, i.e., to a rapid decrease of water levels downstream, and increase of water levels upstream of the jam. As a rule, this is followed by a dyke failure and floods that threaten upstream areas. This phenomenon is also called a "white flood".

In order to prevent this, special vessels – ice breakers, are on call on critical points, to prevent formation of ice jams, or, if it they have already formed, to break them as soon as possible. Once the jam is broken and freed ice masses start drifting again, the resulting force is such that it sweeps everything in its way.

8.

8.
THE SAVA RIVER FAIRWAY GUIDE

8.1 SECTORS AND SUB-SECTORS

From a navigational point of view, and with reference to the characteristics of the fairway, dimensions of convoys and other navigational requirements, the Sava River can be divided into 3 sectors with their sub-sectors:

- **Upper Sava sector:**
  Sisak (rkm 594) – Gradiška (rkm 467)
  + Kupa (rkm 0 – rkm 5).

- **Middle Sava sector:**
  Gradiška (rkm 467) – Sremska Mitrovica (rkm 139) with the following sub-sectors:
  - Gradiška (rkm 467) – Slavonski Brod (rkm 371);
  - Slavonski Brod (rkm 371) – Brčko (rkm 228);
  - Brčko (rkm 228) – Sremska Mitrovica (rkm 139);

- **Lower Sava sector:**
  Sremska Mitrovica (rkm 139) – Beograd (rkm 0).

8.1.1 Upper Sava sector (rkm 594 – rkm 467)

At the confluence with the Kupa River, average water discharge of the Sava River is 680 m^3/sec. Total length of this sector, including the Kupa River, is 132 km, and for the major part of the year, it has unfavourable navigational conditions. This section is characterised by numerous sharp bends (small bend radii), a relatively narrow fairway (due to numerous shallows, especially during periods of low water levels, i.e., +/- “0” and lower indicated on water gauging station Crnac), and insufficient depths of the fairway that occur during periods of low water levels. All these factors adversely affect the navigational safety and call for cautious navigation that must take into consideration vessel draught and convoy size.

The Sava River tributaries on this sector are: right - Kupa (rkm 591) and Una (rkm 515), and left – Lonja (rkm 554), Trebež (rkm 547), Veliki Strug (rkm 475) and Mali Strug (rkm 470). The Sava River receives an average water intake of 298 m^3/sec from Kupa, and 250 m^3/sec from Una. These two rivers contribute significant amounts of water to the Sava River. Reference water gauging stations used for planning, calculations and navigation management in this sector are: Crnac ("0" reference point is at 91.34 m.a.s.l.) and Jasenovac ("0" reference point is at 86.82 m.a.s.l.).

The most favourable water stages for navigation in this sector are: Crnac +100 and above, and Jasenovac +250 and above.
At these water levels, the depth of the fairway would be approximately 4 m and more.

The main river current is very strong during periods of high water levels, which increases the dangers for navigation, especially for convoys navigating downstream in river bends, where tows may "stack up" (run aground) on the concave riverbank.

Risks emerging during periods of lower water levels ("0" or lower indicated on water gauging station Crnac) are insufficient depth and width of the fairway.

Shallows are locations where depth decreases sharply and the fairway narrows significantly. Some shallows stay in good condition for years after maintenance, but some of them are prone to silting and require occasional clearing. A certain number of such sites must be cleared more frequently due to rapid silting, while some must be regulated by various hydro-engineering works in order to ensure their navigability. This sector of the fairway has many shallows that need to be carefully studied for navigational purposes, while results of such analyses should be applied when sailing at low water levels. Such experience is valuable and should be passed on to everyone navigating on this extremely difficult sector.

Fairway depths depend largely on the difference in water levels between water gauging stations in Crnac and Jasenovac. In normal conditions, the water level is 120 cm higher in Jasenovac (meaning that the water level at water gauging station Crnac is +120 cm. This should be noted since there is a possibility of heavy inflow of water from the Una River into the Sava River, which can raise the water level in water gauging station Jasenovac, whereas the water level in Crnac remains unchanged. This results in greater depths of shallows upstream of Jasenovac, and even in Lonja, which is currently the most problematic shallow in the entire upper sector.

Location - Name	Rkm	Location - Name	Rkm
Goričica	590 – 589	Lonja	554 – 552
Blinjski Kut	584 – 581	Puska	542 – 540
Lukavac	579 – 578	Krapje	534 – 531
Gušće	573 – 570	Višnjica	524
Bistrać	564 – 562	Jasenovac	517 – 516
Bobovac	560.3	Mlinarice	504 – 503
Donji Bobovac	558	Javička Greda	501
Strmen	556 – 555		

Table 7: Overview of shallows in the Upper Sava sector

Bends are the main feature of the Upper Sava sector. Some of them are very sharp and of a small radius. Their main attribute is that they follow one another so closely that, on leaving one bend, vessels immediately enter the next. For that reason, navigators often refer to navigation on the Upper Sava sector as to "a slalom run". This manner of navigation requires constant vigilance and manoeuvring in both directions of navigation, while passing or overtaking is practically impossible.

Location – Name	Rkm	Location – Name	Rkm
Goričica	590 – 589	Žabarski Bok	543
Čigoč	568 – 567	Cvijetni Vir	538
Gornji Bobovac	561	Brest	536
Donji Bobovac	558	Kraplje	533
Strmen	556	Bumbekovača	529
Ivanjski Bok	551 – 550	Mlaka	492
Savički Dol	549	Strmac	487 – 486
Trebež	547		

Table 8: Overview of bends on the Upper Sava sector that are dangerous for navigation

The most demanding bends, from a standpoint of navigational safety and manoeuvring requirements, are: Upper Bobovac, Žabarski Bok, Trebež and Cvijetni Vir, due to their small radii of curvature, swirling flow patterns, rock revetments on the concave riverbanks and poor terrain visibility. Moreover, and as a rule, the fairway in such bends becomes narrower, which is especially the case during periods of low water levels. This calls for extreme vigilance, frequent manoeuvring, waiting for vessels and convoys navigating downstream, etc.

Bridges, in a navigational sense, always represent an obstacle on the fairway; hence, navigation under bridges requires particular attention. Since bridges have already been addressed in Chapter 6 of this Manual, this section will only give a brief overview of bridges on this sector of the Sava River.

On the 5 kilometres of fairway on the Kupa River, there are three bridges:

River (rkm)	Bridge name	Navigation opening width (m)	Navigation opening height (m)		Reference WGS “0” (m.a.s.l)
			At reference point “0”	At HNL	
Kupa (4.68)	Road bridge – new bridge Sisak	34.25	15.51	8.60	Crnac (91.34)
Kupa (3.40)	Road bridge – old bridge Sisak	37.0	5.48 – 13.98	7.02	Crnac (91.34)
Kupa (2.10)	Railway bridge Sisak	21.50	14.11	7.32	Crnac (91.34)

There are five more bridges in this sector of the Sava River:

River (rkm)	Bridge name	Navigation opening width (m)	Navigation opening height (m)		Reference WGS “0” (m.a.s.l)
			At reference point “0”	At HNL	
Sava (593.7)	Road bridge Galdovo	49.0	12.56 – 12.91	5.39 – 5.74	Crnac (91.34)
Sava (587.7)	Road bridge Crnac	67.80	13.57 – 14.50	6.67 – 7.60	Crnac (91.34)
Sava (517.2)	Railway bridge Jasenovac	41.0	14.38	6.17	Jasenovac (86.82)
Sava (515.6)	Road bridge Jasenovac	110.0	13.49 – 15.34	5.35 – 7.20	Jasenovac (86.82)
Sava (470.0)	New road bridge* Gradiška	91.00	17.57	7.00	Davor (82.89)
Sava (466.8)	Road bridge Gradiška	89.0	18.26 – 18.62	7.36 – 7.72	Davor (82.89)

* The new Gradiška road bridge is still under construction, and the bridge structure has been installed.

Turning and anchoring points: Depending on water levels on this part of the Sava River, turning and anchoring points are: Crnac on rkm 586.5, Jasenovac on rkm 514, Košutarica on rkm 511 and Stara Gradiška on rkm 468. In addition to the aforementioned official turning and anchoring points, turning of some convoys and tugs, in case of emergencies and under favourable hydrological conditions, is also possible in the following locations: Lukavec on rkm 579, Gušće on rkm 570, Bistrać on rkm 563, Lonja on rkm 553, Trebež on rkm 547 and rkm 546, Puska on rkm 541, 539, Kraplje on rkm 534 and rkm 532, Drenov Bok on rkm 526; when water level recorded in Jasenovac is above +100 cm - in Javička greda on rkm 499, Strmac on rkm 486, Jablanac on rkm 485, Dugi Put on rkm 481, Gaštica on rkm 480 and Veliki Strug and Mali Strug on rkm 475 and 470 respectively.

The dimensions and forms of the convoys on this sector are specified under the Navigation Rules on the Sava River Basin, in Chapter XI “Additional local requirements”.

8.1.2 Middle Sava sector (rkm 467 – rkm 139)

The Middle Sava sector is the longest sector and stretches from Gradiška to Sremska Mitrovica, in a total length of 328 km. Based on navigational and sailing conditions, this sector is divided into the three previously mentioned sub-sectors:

This categorisation is a result of navigational possibilities conditional on its right tributaries, the most important of which are:

- Vrbas – it empties into the Sava River on rkm 427 as its right tributary. With its length of 253 km, it extends over a drainage basin area of 5,570 km^2;
- Ukrina – 128.7 km long, it empties into the Sava River on rkm 381.5 as its right tributary;
- Bosna – it empties into the Sava River on rkm 314.5 and is a very important tributary with a length of 306 km, a drainage basin area of 10,460 km^2 and an annual water inflow of 5.5 billion m^3;
- Drina is the largest tributary of the Sava River, joining it on rkm 178, with an approximate annual water inflow of 12 billion m^3. Apart from water, Drina also carries great amounts of sediment into the Sava River, negatively affecting the navigational conditions on this sector and limiting the size and form of towed and pushed convoys;

- The Bosut River, emptying into the Sava River on rkm 162.5 on its left bank, also affects the navigational conditions on this sub-sector. This reach is, from a navigational standpoint, important for vessels moving upstream, to which speed and complexity of navigation through this section provide a basis for assessing the possibility of clearing the Rača sector without disassembling of convoys.

By the quantity of sediment and water carried into the Sava River, rivers Vrbas, Bosna and Drina have the greatest influence on the deformation of the Sava riverbed gradient, the velocity of its current, meandering, etc. All of this negatively affects navigational conditions, convoy size and configuration, as well as their draught. Based on these characteristics, the Middle Sava sector was divided into three sub-sectors.

Sub-sector Gradiška – Slavonski Brod (rkm 467 to rkm 370)

This sub-sector, with a length of 97 km, is in an overall better condition than both the preceding sector and the following sub-sector. The reference water gauging station for this sub-sector is in Slavonski Brod. At water level: Sl. Brod "0" cm, depth of shallows in this sector is approximately 160 cm, whereas the average width of the fairway ranges from 40 to 50 m.

The best-known shallows on this sub-sector are:

Location - shallow name	Rkm	Location - shallow name	Rkm
Gradiška	466 – 464	Kobaš	402 – 401
Mačkovac	453 – 452	Osavica	398 – 397
Dolina	450 – 448	Grlić	395 – 394
Gornje polje	431 – 430	Dubočac	390 – 387
Davor–Toka	427 – 425	Zbjeg–Ukrina	385 – 383
Radinje	420.5	Sijekovac–Migalovci	378 – 377
Kaoci	416 – 415	Refinery Brod	375 – 374.5

Table 9: Overview of shallows on sub-sector Gradiška – Slavonski Brod

Bends on this sub-sector are of proper radii, ranging at approximately 400 m, which allow passing of larger towed and pushed convoys in both directions of navigation. Overview of major bends on this sub-sector is given in the following table:

Bend – Name	Rkm	Bend – Name	Rkm
Pivare	462 – 461	Krst	442
Trnava	457	Gaj	434
Kopanik	454	Hercegov Dol	420
Mačkovac	452	Motajica	412

Table 10: Overview of bends on sub-sector Gradiška – Slavonski Brod

Here, major navigational problems are the bend of Hercegov Dol, because of the Radinje shoal positioned directly before the curve, and the Motajica bend, due to whirlpools (limans) occurring along both riverbanks after the bend. Passing in these bends should be avoided because there is a high probability that one of the convoy's segments will enter the liman and almost certainly cause the towline to break. Due to poor visibility conditions in bends, navigation therein requires compulsory use of all available navigational tools and radio communication devices.

Turning and anchoring on this sub-sector is possible in specifically assigned locations: Davor on rkm 428.5, Kobaš on rkm 400, Slavonski Brod on rkm 370.1.

Upstream - downstream towed and pushed convoys

In this sub-sector upstream towed convoys, depending on the water level and tug power, can tow six vessels in three transversal rows - two vessels in each row. Towlines and secondary towlines used for the vessels in a convoy should be set crosswise.

If water levels allow, convoys towed downstream can be composed of six barges set in two transversal rows.

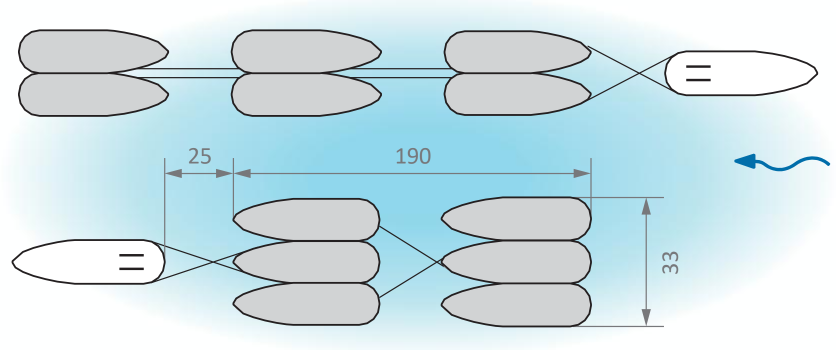


Figure 90: Upstream and downstream towed convoys – Middle Sava to Slavonski Brod

At favourable water levels, convoys pushed upstream can consist of four pushed barges set in two rows (two pushed barges in each row), and ordinary convoys pushed downstream consist of three pushed barges set in one row.

Figure 91: Upstream pushed convoy

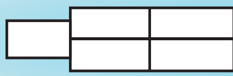
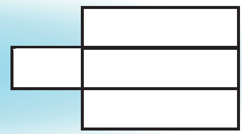


Figure 92: Downstream pushed convoy



Special attention in this subsector must be paid to the passage under the Brod bridge, because of its navigational opening (span), which is misaligned with the fairway. This especially applies during downstream navigation when the fairway shifts from the right to the left riverbank just before the entrance (approximately 300 m), where the navigational opening of the bridge is also located.

Sub-sector Slavonski Brod – Brčko (rkm 370 to rkm 228)

With the exception of some minor sections, this sub-sector of Middle Sava is very difficult for navigation, especially during periods of low water levels. The length of this sub-sector is 142 rkm, and its reference water gauge stations are Slavonski Brod, Šamac and Brčko. This sub-sector encompasses a 33 km long section between Novi Grad and Domaljevac, the so-called Šamac sector, known as the most demanding one on the Sava River in terms of navigation. Navigation on this section of the fairway is performed according to the data obtained from the reference water gauging station in Šamac.

When navigating downstream from Slavonski Brod, the first major obstacle is the Vijuš bend and shallow (rkm 367), which causes problems at low water levels, mainly because of the shallows on the concave riverbank formed by so-called "dead gravel", but also because the bend is quite sharp (note that towed convoys in two-row configurations are permitted in this sub-sector).

Shallow Oprisavci is located on rkm 337, and it also represents an obstacle to navigation due to its very narrow passage during periods of low water levels.

Apart from these shallows, this stretch includes significant bends dangerous for meeting of vessels, namely: Vijuš km 367, Moclek km 358 and Ugljara km 343.

Section Novi Grad – Domaljevac (rkm 333 to rkm 297)

A very big shallow extends from rkm 329 to rkm 322 – Novi Grad. Canals of different widths had to be dredged in order to allow navigation on this section. However, these canals are not parallel with riverbanks, which makes orientation difficult.

This section could be called a starting point of the Šamac sector. Lower part of this sector, on rkm 321, is called Jaruge, in which, according to the conceptual design, the entrance / exit of the multipurpose Danube – Sava canal should be located.

The Bosna River discharges into the Sava River on rkm 314, on the right riverbank, bringing huge amounts of sediment and depositing it immediately below the confluence, forming the so-called Šamac sector on this longitudinal profile of the Sava River. From a navigational point of view, the most unfavourable parts of this section, from Jaruge on rkm 321 to Domaljevac on rkm 297, are shallows listed in the following table:

Location and name of shallow	rkm	Location and name of shallow	rkm
Šamac ispod Klaonice	313 – 312	Klenić	305 – 304
Savulja	311	Nevjerica	303 – 302
Vrbanja	309	Dubočica	301
Vučjak	308	Domaljevac	297

Table 11: Overview of shallows in the Šamac sector

For orientation purposes: on this section, at the “0” reference point indicated on the water gauging station Šamac, water depth is 2.40 m.

Disbanding of towed or pushed convoys requires full engagement of all crew members. Disbanding is necessary from the Jabuka turning point on rkm 316 (at lower water levels and with two-row convoy configurations, it is better to turn on rkm 320 because of the shallow located on rkm 317, which is too narrow for navigation when the “0” reference point is indicated on water gauging station Slavonski Šamac) to Domaljevac on rkm 297. When the water level on water gauging station Slavonski Šamac is at the “0” reference point or lower, disbanding is required from Svilaj on rkm 333.

At favourable water levels, downstream navigation of convoys usually includes disbanding from Jabuka to Klenić, and at low water levels, from Jabuka to Domaljevac. If water levels are extremely low, it is recommended to remain in a disbanded formation all the way to Tolisa, i.e. Županja.

Towed convoys: Downstream navigation of towed convoys is allowed with maximum three barges in a tow, of which only two can be loaded and the one on the starboard side empty. This is because of the Savulja shallow, where the tow has a tendency to swing to starboard, and the fact that, if the lighter is loaded, grounding may occur.

Upstream navigation is performed one barge at time, depending on a draught. At the entrance to the Savulja shallow, which is the most critical point due to its funnel-shape and drop, towlines may slacken, causing loss of steerage. In addition, if the crew is not prepared for this situation, there is a risk of grounding or, with a sudden increase of forward power of the tug, even of rupture of the towlines. Towlines should be as short as possible, both in downstream and upstream navigation. In navigation, it is best to sail slow as possible so as to be able to increase speed at a proper moment and straighten the barges in tow.

Pushed convoys: As regards to downstream and upstream navigation of pushed convoys, it is possible to sail with two pushed barges of maximum length and width not exceeding 110 m X 23 m when the water level is at the “0” reference point of the water gauging station Šamac, or higher. At water levels lower than that, dimensions should be 110 m x 12 m. At the water level of +150 indicated at water gauging station Šamac, navigation is possible even with three pushed barges with dimensions of 110 m x 35 m. Parameters of these convoys, both towed and pushed, depend on water levels, vessel draught and the power of the tug or pusher. All these convoy-related standards and limits are to be used for orientation purposes only, and the harbourmaster's office in Slavonski Brod should be consulted before every arrival to the sector regarding changes in current sector conditions.

Apart from shallows on the Šamac sector, other main obstacles to navigation are sharp bends with insufficient radii: Vučjak on rkm 307, Dubočica from rkm 301 to rkm 300, and Domaljevac on rkm 295. This sub-sector of the Middle Sava, from Slavonski Brod to Brčko, is rightfully categorised as the most demanding on the entire fairway of the Sava River.

Location – Name	Rkm	Location – Name	Rkm
Vijuš	367	Niškovo Polje	295 – 292
Oprisavci	337	Rastovica	286
Novi Grad–Jaruge	329 – 321	Štitar	284
Gornja Jabuka	317	Suvo Polje	282 – 278
Jabuka	315 – 314	Tolisa	277 – 274
Klanica	313	Repovac	272
Savulja	311	Orašje	263 – 262
Nevjerica	303	Vučilovac	246 – 244
Dubočica	302 – 301	Rajevo Selo	235
Domaljevac	297 – 296	Brčko	230 – 229

Table 12: Overview of shallows on sub-sector Slavonski Brod – Brčko

Due to poor visibility conditions, the possibility of meeting other vessels and an insufficient bend radius, particular attention must be paid, not only to shallows, but also to all bends given in the following table:

Bend – Name	Rkm	Bend – Name	Rkm
Vijuš	367	Domaljevac	295
Moclek	358	Štitar	285
Ugljara	343	Tolisa	277
Vučjak	307	Vidovica	255
Dubočica	300	Rajevo Selo	235

Table 13: Overview of bends on sub-sector Slavonski Brod – Brčko

Turning and anchoring points: Depending on water levels on this part of the Sava River, turning and anchoring points are: Ruščica on rkm 364 and rkm 362.2, Jaruge on rkm 319, Šamac on rkm 312.5, Domaljevac on rkm 299, Županja on rkm 268.7 and Brčko on rkm 228.

Bridges

There are 6 bridges on this sub-sector:

River (rkm)	Bridge name	Navigation opening width (m)	Navigation opening height (m)		Reference WGS: "0" (m.a.s.l)
			At reference point "0"	At HNL	
Sava (374.8)	Product line of Brod refinery	104.30	24.05 – 25.45	16.47 – 17.87	Sl. Brod (81.80)
Sava (371.5)	Road bridge Brod	66.30	15.03	7.64	Sl. Brod (81.80)
Sava (311.8)	Road - railway bridge Šamac	65.30	14.52	8.16	Sl. Šamac (80.70)
Sava (329.1)	Road bridge Svilaj	91.00	18.58 – 16.48	8.56 – 9.46	Sl. Šamac (80.70)
Sava (261.6)	Road bridge Županja	117.80	15.80 – 18.18	7.85 – 10.23	Županja (76.28)
Sava (228.8)	Road bridge Gunja – Brčko	47.50	16.42	7.62	Gunja (74.32)
Sava (226.8)	Railway bridge Gunja – Brčko	120.00	18.31 – 18.38	9.58 – 9.65	Gunja (74.32)

Bridges that can represent obstacles for navigation are:

- **Slavonski Brod / Brod – road bridge** on rkm 371.5 links the two cities of Brod; at favourable water levels it does not represent an obstacle to navigation, but at lower water levels it does. This is because of its piers that are misaligned with the fairway, and, therefore, must be taken into consideration.
- **Šamac – road / railway bridge** on rkm 311.8 has suitable dimensions, but in some situations the pillar of the old bridge can represent an obstacle to navigation in both directions. Due to the irregular entrance into the bridge opening and the sudden turning of convoys in a short distance from the right to the left riverbank, vessels navigating downstream are exposed to the danger of hitting a pillar of the previously demolished bridge located in the immediate vicinity of the opening of the new bridge.
- **Gunja – Brčko road bridge** on rkm 228.8 is very unsuitable for navigation at low water levels. Due to its irregular entrance, navigation is made difficult especially for vessels navigating downstream, so larger convoys must be disbanded. The entrance into this bridge is made harder by shallows causing sudden turning of convoys navigating downstream from right to the left riverbank in the immediate vicinity of the bridge.

Forms and composition of towed convoys navigating upstream and downstream primarily depend on water levels and the power of tugboats. Downstream towing is possible for convoys formed of two transversal rows with compulsory disbanding on the Šamac sector regardless of water levels.

Depending on the power of tugboats, convoys towed upstream can be formed in one or two strings by using towlines and secondary towlines suited to the convoy configuration.

Downstream pushed convoys may be composed of two transversal rows, taking the same precautionary measures as for towed convoys, along with necessary disbanding.

Pushed convoys navigating upstream can also be composed of several vessels, depending on the power of pushers and water levels. Towed convoys gating upstream can comprise of six vessels forming two or three transversal rows.

Unlike towed convoys that can “break” in bends, pushed convoys - being compact - must manoeuvre much more when passing through bends in order to avoid ramming into the concave riverbank.

Similar manoeuvring techniques should be applied when navigating through narrow sections of the fairway, especially when correcting the trajectory in order to ensure safe passage under bridges.

Sub-sector Brčko – Sremska Mitrovica (rkm 228 to rkm 139)

The length of this Middle Sava sub-sector is 89 km. Two major tributaries discharge into the Sava River on this part of its course – Drina from the right and Bosut from the left side.

Main feature of this sub-sector is the diversity of navigational conditions, ranging from very favourable to very limiting. During periods of low water levels, numerous shallows occur on this stretch of the fairway, which must be taken into account when navigating in both directions. These shallows are listed in the table below.

Location - Name	Rkm	Location - Name	Rkm
Gunja	223 – 221	Visoča	191 – 189
Brezovo Polje	220 – 217	Bela Crkva	185 – 184
Devojačka – Nakić Kula	213 – 210	Sremska Rača	178.5 – 177.5
Jamena	205 – 203		

Table 14: Overview of shallows on the Brčko – Rača section

Section from rkm 179.5 to rkm 172.6, better known as the Rača sector, stretches over approximately seven kilometres and its regulation began back in 1892. Major river-training works had never been carried out in a professional and planned manner, which reflected negatively on the dimensions of the fairway.

After World War II, water-training and sand exploitation works successfully managed to restrain the restless and rapid waters of this sector, thus ensuring sufficient depths of the fairway. Old water-training structures had been repaired, and the new ones additionally narrowed the riverbed, which contributed to stabilisation of depths in this still navigationally demanding section of the river.

The most unfavourable point to navigate through is on rkm 177, where the fairway width is very narrow during periods of low water levels, due to the longitudinal river-training structure built on the right riverbank, and groynes (transversal river-training structures) built on the left riverbank.

The longitudinal river-training structure appears at a water level of approximately +230 cm, and transversal groynes at +330 cm indicated on water gauging station Sremska Mitrovica. Downstream from the transversal water-training structures a shoal was form, which is the narrowest and the most critical point to navigate on this river section.

Convoys navigating downstream and upstream must be disbanded from Rača on rkm 179.5 all the way to just before Poloj on rkm 172.6, although it is not a rare case with large convoys to remain disbanded all the way to just before the Bosut bend on rkm 162. Convoys navigating downstream at low water levels can be formed of maximum three vessels in one transversal row, whereas the size of convoys navigating upstream depends on the power of tugboats / pushers. If these convoys manage to pass this bend without major difficulties, then they can also pass the Rača sector. However, if passing through this bend is slow, disbanding should be performed.

This sub-sector of the Sava River is characterised by bends, which can represent obstacles to navigation for convoys of maximum dimensions. In the past, the Rača sector had three, and then only two, signalling stations, making sure that only one convoy can proceed through the sector. Signalling stations were first located in Rača, at the confluence with Drina and near Poloj, and later only in Rača and Poloj, but entailed compulsory use of “loco-pilots”. Today, thanks to modern communication devices, use of signalling stations and pilots is abandoned.

Bends on this sector are big and sharp, thus representing obstacles to uninterrupted navigation. Their overview is given in the following table:

Bend – name	Rkm	Bend – name	Rkm
Rača	179 – 177	Ravnje	155.5
Bosut	163 – 162	Manđelos	153

Table 15: Overview of shallows in the Rača sector

With the exception of the Rača sector, where the dimensions of convoys are limited, convoys of maximum dimensions can navigate through other bends and obstacles in both directions.

Turning and anchoring points on this sector are important, and their overview is given in the following table:

Location – Name	Rkm	Location – Name	Rkm
Brezovo Polje	216	Bosut	161
Bela Crkva	184.5	Ravnje	156
Rača	180	Laćarak	143.5
Poloj	171	Sremska Mitrovica	139

Table 16: Overview of locations suitable for turning and anchoring on the Rača sector

Bridges on this sector are:

River (rkm)	Bridge name	Navigation opening width (m)	Navigation opening height (m)		Reference WGS (elevation in m.a.s.l)
			At reference point "0"	At HNL	
Sava (183.3)	Road - railway bridge Rača	140.00	17.23	---	Jamena (72.44)
Sava (139.25)	New pedestrian bridge Sremska Mitrovica	100.00	14.59 – 16.52	8.37 – 10.30	Sremska Mitrovica (72.22)

As already said, towed and pushed convoys navigating upstream and downstream may be formed of several vessels, with applicable disbanding / limitations in Rača sector, where convoys navigating upstream depend on the power of tugboats / pushers, and convoys navigating downstream can have only one transversal row.

8.1.3 Lower Sava sector (rkm 139 - rkm 0)

This sector has all the characteristics of a lowland river. The river course is more tranquil and with mild bends, while the riverbed is wide and with greater depths. It also features many river islands and river branches with different navigational characteristics. The greatest depth on this sector is 25 m, near the village of Hrtkovci on rkm 121. The river width near Šabac and Ostružnica is approximately 600 m. The major river islands are: Mišarska ada, Vitojevačka ada, Velika Grabovačka ada, Miloševa ada, Skelska ada, Kolubarska (Barička) ada, Ada Međica and Ada Ciganlija.

Major tributaries emptying into the Sava River on this sector are: Vukodraž on rkm 62.0, Kolubara on rkm 27.6, Barička river on rkm 26.5 and Topčiderka on rkm 4. These are all right tributaries that have no major influence on discharge and the magnitude of the total water amount. Kolubara has a pluvio-nival water regime, with expressed fluctuations throughout the year. In addition to its minor discharge, it carries a great amount of sediment into the Sava River, especially at high water levels, which negatively affects the dimensions of the fairway during periods of low water levels.

River-training works carried out on the Lower Sava sector did not provide the desired results. Dredging of certain sectors of the fairway extended the width and depth of its riverbed, while building longitudinal and transversal river-training structures resulted in the accumulation of water from the wide cross-sectional river profile. However, despite all implemented measures, at low water levels this sector does not offer the best navigational conditions, which is particularly evident on the section from rkm 111.7 to rkm 82.3, the so-called Šabac sector, and its stretch from rkm 89.0 to rkm 82.3 (known as Kamičak).

Section rkm 111.7 – rkm 82.3 (known as the Šabac sector) extends from former Drenovačka Ada to Vrbica, in a total length of approximately 30 km. It is characterised by an absence of sufficient fairway depths and widths, which are consequences of a great dispersion of water in a wide riverbed. Back in the period from 1924 to 1935, major dredging works were carried out on this section, namely from Vitojevačka ada on rkm 95.3 in the length of 18 km in the downstream direction, which included digging of canals with a width of 50 - 80 m.

River training of the waterway downstream of Mišarska Ada was carried out with combined use of longitudinal and transversal river-training structures, and in 1994, a partition was built on the top of Podgorička Ada on rkm 86.8 along the right riverbank, closing the former fairway and shifting the navigation to the left riverbank.

During periods of extremely low water levels, convoy formations are disbanded from rkm 113 to Vrbica on rkm 80. Convoys are navigating downstream in only one row, while number of pushed barges depends on their draught. If convoy dimensions allow passage through the major part of this sector, disbanding is conducted only from Široke njive on rkm 90.0 to Vrbice on rkm 80. Due to limited fairway width and depth on this section, towed and pushed convoys must navigate with extreme caution, complying with all navigational norms.

Any deviation from experiential and relevant standards may cause dangerous stranding, closure of the fairway and averages with grave consequences. This section must also be navigated with caution in limited-visibility conditions, when water levels change, and especially when the marking system is either removed or incomplete for any reason (during winter season).

Locations suitable for turning on this sector are: Jarak on rkm 124, Hrtkovci on rkm 121, former Drenovačka ada on rkm 113, Šabac on rkm 105, Široke njive on rkm 90, Ada Vrbica on rkm 80. Reference water gauging stations for this sector are in Sremska Mitrovica, Šabac and Belgrade. Status indicated on water gauging station Šabac is very important for navigation, both at low water levels for assessing fairway depth, and at high water levels because of the limited clearance at the old railway bridge in Šabac. Status indicated on the water gauging station Belgrade is an important reference for the vertical clearance below the old railway bridge in Belgrade. Reference point "0" on the water gauging station Sremska Mitrovica is at 72.22 m.a.s.l., on the water gauging station Šabac at 72.61 m.a.s.l., and on the water gauging station Belgrade at 68.28 m.a.s.l. Navigation on section from Barička ada on rkm 27 to rkm 25 is a one-way section, going around the river island. Vessels navigating downstream use the old fairway along the right riverbank, while vessels navigating upstream go between the left banks of the river and the river island.

Location and name of shallow	rkm	Location and name of shallow	rkm
Šabac – before bridge	113 – 107	Široke Njive	92 – 89
Šabac – after bridge	107 – 104	Kamičak	89 – 82
Mišar	103 – 101	Orljača	76 – 72
Mrđenovac	98 – 95	Kolubara	27.5 – 26.5

Table 17: Overview of shallows in the Lower Sava sector

Bridges on this sector represent a huge obstacle to navigation during periods of high water levels. Therefore, all changes in water levels must be closely monitored. The bridges on this sector are:

River (rkm)	Bridge name	Navigation opening width (m)	Navigation opening height (m)		Reference WGS (reference point, m.a.s.l)
			At reference point “0”	At HNL	
Sava (136.6)	Road bridge Sremska Mitrovica	150.0	15.44 – 17.32	9.30 – 11.18	Sremska Mitrovica (72.22)
Sava (106.96)	Railway bridge Šabac	75.0	11.26 – 11.48	6.46 – 6.68	Šabac (72.61)
Sava (104.53)	New road bridge Šabac	80.0	14.13	9.42	Šabac (72.61)
Sava (42.53)	Heat pipe bridge Obrenovac	80.0/120.0	17.84 – 17.97	11.01 – 11.14	Belgrade (68.28)
Sava (15.43)	Railway bridge Ostružnica	2 x 75.0	14.44 – 14.52	8.41 – 8.49	Belgrade (68.28)
Sava (15.0)	Road bridge Ostružnica	150.0	16.58 – 18.22	10.56 – 12.2	Belgrade (68.28)
Sava (3.8)	Road bridge Belgrade - Ada Ciganlija	150.0	21.02 – 21.62	15.33 – 15.93	Belgrade (68.28)
Sava (3.0)	New railway bridge Belgrade	120.0	21.72	16.06	Belgrade (68.28)
Sava (2.73)	Old railway bridge Belgrade	90.0	12.62	6.96	Belgrade (68.28)
Sava (2.52)	Road bridge “Gazela” Belgrade	200.0	16.52 – 21.06	10.87 – 15.41	Belgrade (68.28)
Sava (1.43)	Old road bridge Belgrade	90.0	15.89 – 16.48	10.27 – 10.86	Belgrade (68.28)
Sava (1.0)	Road (Brankov) bridge Belgrade	100.0	15.55 – 16.36	9.94 – 10.75	Belgrade (68.28)

Forms and types of convoys

- *Towed-pushed convoys navigating upstream*, at favourable water levels and depending of the power of tugboats, may be formed of several vessels of various forms and purposes.

In locations with limiting conditions (Šabac sector), at low water levels, these convoys must adjust to the prevailing conditions of the fairway on this sector.

- *Towed-pushed convoys navigating downstream* can also be formed of several vessels, but fully respecting limitations set for the Šabac sector and in formations not exceeding two transversal rows.

Exceptions are the dimensions of convoys navigating on the sector Confluence of the Sava River from rkm 0 to rkm 11, and these are specified under the Navigation Rules on the Sava River Basin, in Chapter XI “Additional local requirements”.

8.2 DIFFICULTIES IN NAVIGATION ON THE SAVA RIVER DUE TO HYDROMETEOROLOGICAL CONDITIONS

These difficulties in navigation on the Sava River occur as consequences of hydrological, hydrographic and weather conditions characteristic to the moderately continental climate of a variable character. Their incidence over the years and in the course of a single year differs, is variable and depends on weather conditions. Some years are dry, some are rainy, with mild or harsh winters, and with more or less windy days. Frequencies and duration of foggy periods and periods with low temperatures and ice also differ.

According to significance, duration and frequency of hydrometeorological conditions on the Sava River fairway, the most distinctive and harmful, from a nautical point of view, are:

High and extremely high, and low and extremely low water levels

Low and high water levels adversely affect navigational conditions, and in both cases can cause suspension of navigation. If, however, vessels continue to navigate, there is a risk of huge material damage and endangering of human lives. In addition to loss of visual contact with the shore, high water levels negatively affect navigational conditions due to the increased velocity of water currents that carry a large number of tree trunks and other floating objects, which can damage and put out of function the steering device and propulsion system. Consequently, this means that the vessel is exposed to water torrents with unforeseeable severe consequences.

Negative effects of high water levels are directly reflected in the fact that navigation is sometimes suspended because of insufficient clearance under artificial obstacles in the fairway (Šabac and Belgrade old railway bridges and other). Low water levels can reduce commercial efficiency, have a negative effect on cargo space utilisation, towing power, and convoy size, result in frequent need for convoy disbanding, etc. It is not uncommon that suspension of navigation owing to low water levels often results in loss of cargo and damage to vessels, especially on the Šamac, Rača, Šabac and some other sectors.

Rapids

Rapids occur regularly on riverbeds that have a steep gradient and come about during low water levels. They occur in places where natural or artificial objects are entrenched in the riverbed, or as a result from the sudden narrowing of a riverbed with high riverbanks. Rapids can significantly affect the manoeuvring abilities and navigation of a vessel and, therefore, must be taken into consideration when entering sectors where they are a common occurrence.

Number of days with fog and frequency of foggy periods

Most frequently, fog forms on the Sava River in spring and in autumn. As a rule, fog begins to form at the same time when water levels become good for navigation. Plains along the banks of rivers, ponds and river branches are good places for the formation of fog. On the Upper Sava sector, fog is particularly pronounced around the confluence of Mali and Veliki Strug, on the Middle Sava in the zones of the Šamac sector, Županja, Brod and Rača sector, while the Lower Sava sector is particularly affected by fog around Sremska Mitrovica, Šabac, Ostružnica and the confluence.

Number of days with low temperatures and ice

Of all the rivers in the region, the Sava River is the last one to freeze. The reasons for this are manifold:

- High concentration of saltpetre (KNO3) in the water;
- Chemical composition of mineral substances dissolved in water of the Sava River and its tributaries;

- Severe pollution with wastewater from industrial installations positioned on the riverbanks;
- Pollution of coastal farmland with pesticides and other water-borne substances that end up in the Sava River, etc.;
- Hot water from the nuclear power plant “Krško” and thermal power plant “Nikola Tesla”, Obrenovac.

The Sava River can freeze when several days of low temperatures, -14 °C and below, coincide with very low water levels.

Number of windy days and their incidence

As already stated, a number of windy days and their incidence in the Sava River Basin are of secondary importance. The Košava wind does not have a significant effect on navigation on the Sava River area, with the exception of some sections on the Lower Sava sector, where shorter suspensions of navigation may occur rarely. Occurrence of windstorms originating from the slopes of mountains of Bosnia and Herzegovina is the best signal for suspension of navigation and for vessels to remain leeward until the storm weakens. Consequences of windstorms could be catastrophic for convoys and their cargo, as well as for human lives. These phenomena are short in duration, thus timely and brief suspensions of navigation have no greater impact on the organisation of navigation, fulfilment of obligations and the navigation itself.

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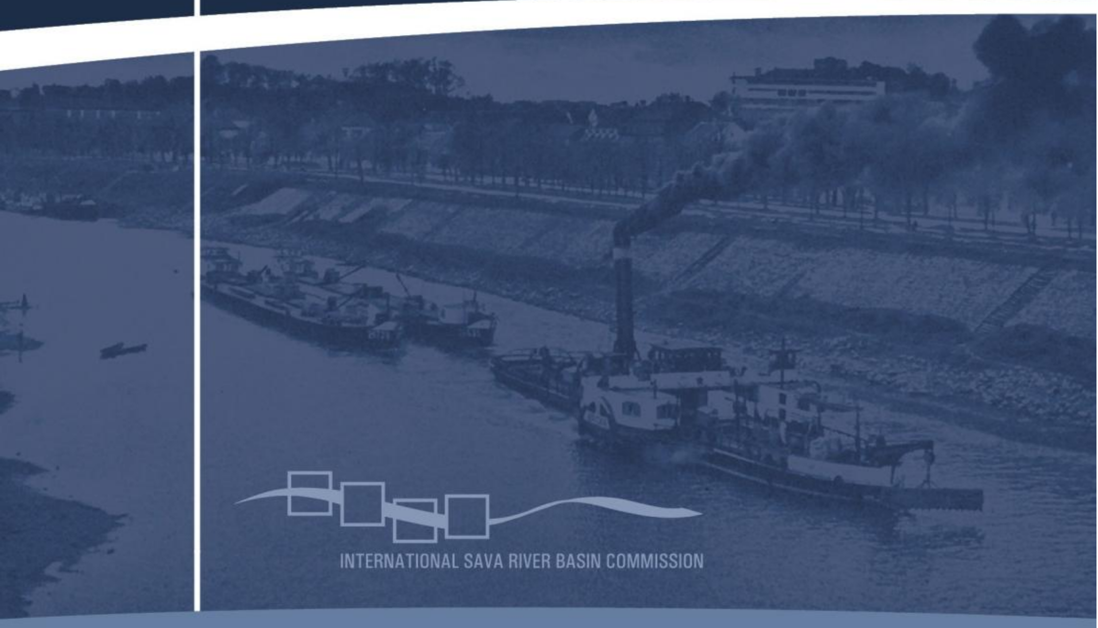
All available and recognised literature used in navigation schools and transport faculties (water-transport departments) was consulted in the development of this Manual. In addition to the Editorial Committee, which provided unquestionable contribution to this publication, the role of the ISRBC Permanent Expert Group for Navigation (PEG NAV), which defined the structure of this Manual, was also of vital importance Also, use was made of all information available on the internet, which have not been published, but are in accordance with modern trends and indicate directions for development of new technologies in this form of transport. In addition to the listed sources, invaluable were the interviews with captains and other navigators whose navigation and life experience on the Sava River were a source of information not available in literature.

Significant contribution to this publication was provided by the competent authorities from Member States to the International Sava River Basin Commission competent for inland waterways, and especially by the Agency for Inland Waterways from Vukovar and the Directorate for Inland Waterways, Belgrade, whose representatives are members of the aforementioned Editorial Committee that prepared this publication.



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