### SMART RIVERS 2019

#### A_WATERWAYS : MANAGEMENT AND GENERAL DESIGN

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Page 1
**Introduction**

The research for this paper has been carried out as part of an international working group set up by PIANC to produce guidance on the application of Early Contractor Involvement in waterborne transport infrastructure projects. Examples of such projects include port developments, access channels, protective breakwaters, container terminals, inland waterway development and maintenance, and locks for docks.

Features of such projects are shared with transportation infrastructure projects more generally, such as highways and bridges, and underground and over-ground railways: projects are high value; execution depends heavily on project-specific methods of construction plant and temporary works; key decisions on ‘linear’ elements have a very large impact; environmental and ecological considerations are significant; projects need to be designed for future use and expectations (e.g. vessel size, container handling equipment) rather than for sale or rental value - future operators, regulators and users are therefore key stakeholders; project constructors and suppliers tend to be fewer and larger than in building and commercial development projects; projects are generally heavily dependent on site conditions and site information.

Lessons can also be learnt from sectors other than transportation infrastructure, but practices may not be directly transferable. For example, petrochemical sector projects have similar physical characteristics but the immediate revenue-earning potential of projects and the limited number of owners and participants in that sector create different commercial and practical dynamics.

**Context**

It is increasingly acknowledged that the consequences of budgetary constraints and the increasingly complex nature of infrastructure works affect both preparatory and procurement processes for large or complex infrastructure projects in general and for waterborne transport infrastructure projects specifically. Early Contractor Involvement in these processes is therefore very valuable in certain cases. Previous efforts such as the Forum on Early Contractor Involvement organized by IADC have started up knowledge exchange and discussions addressing various aspects of Early Contractor Involvement related to maritime infrastructure construction. These efforts did not address frameworks relating to how the relevant parties in an ECI process should act. This lack of guidelines often results in inefficiencies, misaligned focus or distortions in the relationship between the parties involved. Therefore there is a need to establish a set of structured and well accepted guidelines to ECI processes. A new effort is proposed to
fill this need by developing i) a framework derived from existing methods and ii) approaches for informing decision makers managing procurement and early development of waterborne transport infrastructure construction projects.

**What is Early Contractor Involvement?**

The definition of Early Contractor Involvement formulated by the Working Group is:

“any strategy (by whatever name) initiated by infrastructure owners towards contractors, key supply chain members and stakeholders with the purpose of optimizing values in project delivery and objectives through their participation and knowledge-sharing in stages of project planning and design prior to execution contract award.”

**Challenges**

While early work on ECI was directed towards persuading owners and contributors of its potential benefits, there is now sufficient experience to say confidently that ECI strategies can be applied with successful results, but that success is not guaranteed. There are challenges because accepted wisdom and practice point in certain directions, which are not immediately compatible with the adoption of ECI, so fundamental changes are needed:

1. Accepted wisdom and practice says that contractors should be chosen by Owners (and that subcontractors and suppliers should be chosen by contractors) and the contract/subcontract prices should be fixed, on the basis of lowest price, tendered in competition based on objective criteria stated in advance, with all tender activities transparent. This approach is embodied for public bodies in regulations. It also commonly forms part of corporate governance for private organizations. ECI, on the other hand, requires that initial selection of contractors occurs before price-driven tender criteria have been developed, and that the execution phase price is not settled until the end of the ECI phase. The process of reaching a price for the execution phase may even involve the price negotiation with a single contractor without competition. Not only does this go against accepted wisdom and practice, it requires the Owner to be able to assess the reasonableness of prices without the comfort of competition, and to negotiate without the commercial leverage provided by competition.

2. Accepted wisdom and practice is that, prior to award of the execution phase contract, the Owner does not pay contractors anything, and the bidding contractors divulge as little information to the Owner as possible. ECI requires contractors to share information with Owners, and Owners to pay contractors for work done and ideas provided, during the ECI phase.

3. Accepted wisdom and practice favours the off-loading of all design risk down the contractual chain, regardless of who actually carries out the design, in order to satisfy funders and avoid the need to cover the risk by insurance. This again is inimical to ECI.

4. Accepted wisdom and practice favours a strict chain-of-contracts approach, with no engagement between parties who are not in direct contract. This does not fit with ECI.

5. Accepted wisdom and practice favours a ‘control’ approach by project managers. This is inappropriate in the context of the creative activities in the ECI phase

These challenges can be solved and the changes made, but only if the Owner has the capability and will to do what is necessary. Making ECI work depends on capabilities and relationships. Historical downgrading or down-sizing of capability and functions within Owner organizations has increased the challenge.

The PIANC guidance is intended to address these challenges and any other obstacles, and explore how they can be overcome if it is decided that adopting an ECI strategy is appropriate.
When is ECI appropriate?
ECI is not a strategy to be entered into unadvisedly or lightly. The Infrastructure Owner must decide not only whether its organization is willing and able, but also whether the effort is justified by the nature of the project. ECI effectively requires the Infrastructure Owner to enter into a partnership with the constructor and any other members of the ECI team. The point was well made by Lambert & Knemeyer (2004): “Partnerships are costly to implement – they require extra communication, coordination and risk sharing. They are justified only if they stand to yield substantially better results than the firm could achieve without partnering.”

There is, therefore, a threshold question: what features of a project or objectives of the Infrastructure Owner make an ECI strategy appropriate and worthwhile. ‘Complexity’ of the project is perhaps the most significant factor. The point is made by Chapman (2016) that “while ‘complex’ and ‘complicated’ are often treated as synonymous, a complicated project is no longer complex once the challenges of projects of that nature have been adequately solved, and knowledge, understanding, experience and capability have developed.”

Once the challenges of projects of a certain nature have been resolved, there may be insufficient further benefits available to justify adopting an ECI strategy. However, ECI may still be relevant on non-complex projects if the Infrastructure Owner wishes to explore the possibility of applying innovatory methods.

The appropriateness of ECI also depends on the cultural context. For example, ECI will unlikely to work in places that rank low on the Corruption Perceptions Index (CPI). This is not only because a collaborative approach could introduce situations where parties are not at arm’s length, but also because the fear of suspicion leads to risk-averse, bureaucratic behaviour, and inhibits exchanges and negotiations.

The nature of ECI Inputs
In order to develop a strategy to achieve benefits through inputs by contributors, one needs first to understand the potential inputs and the benefits that might be achievable.

There are two key ECI inputs by constructor and supplier contributors:

- The first is knowledge-sharing, problem-solving, creative contributions to design, construction methods and preparatory works.
- The second is the provision of input on costs and cost implications of implementing designs, construction methods and preparatory works.

There are various possible approaches. Early constructor and supplier input to design can just be ‘consultancy’, providing general advice which will be relevant whoever eventually undertakes the work. The more advanced form of ECI involves the constructor and/or suppliers putting forward specific ideas as to how they would do the job themselves and, after developing their designs, providing a committed price for doing the job.

Other potential inputs by contractors and the supply chain include

- input on planning of site investigations, model testing and other information gathering, to provide data which will be relevant to construction as well as to permanent works design
- developing (and obtaining approval for) innovative methods and equipment
- setting up training facilities for locally-recruited operatives
• advising on availability and lead in times for construction plant, permanent works equipment and materials
• advising on means of mitigating environmental and ecological impacts
• providing input to satisfy or negotiate with regulators, third party stake-holders and other interested parties.

The benefits of ECI
The primary benefits of ECI should be that:
• the ideas of the constructors and suppliers, and their designers, are received when
  o they can be taken into account in applications for planning or similar approvals or consents, or for commissioning model testing
  o they minimize abortive design work, and
  o they can be considered, evaluated and implemented without making ‘late changes’
• The tendency to sub-optimisation by each contributor in its own interests may be reduced
• Reliable cost forecasts, based on a developed design and information, are established for the benefit of both owner and contractors, before any price is agreed.

Two approaches to ECI
Two main approaches to ECI have developed:
• ECI with multiple contractor teams, developing designs concurrently during the ECI phase, followed by final selection based on competitive bids
• ECI with a single-contractor team selected on the basis of preliminary submissions, followed by price negotiation for the execution phase at the end of the ECI phase

The multiple contractor, competitive bid approach is favoured particularly by the Dutch, but it has also been used elsewhere. It involves selection of a small number of constructor-led groups (usually three) to develop their designs, with some interaction between Owner and individual bidders, during the ECI phase and then submit bids. It is effectively limited-bid, early-start Design and Build.

The single contractor ECI approach has found favour in the UK. It involves selecting a single constructor-led group to develop a design though the ECI phase for which a price is then negotiated. This enables more interaction between Owner and contributors and integration of all parties’ design contributions. It reduces to a minimum the amount of discarded design effort. However, it removes competition.

There is a third approach, where design responsibility and control are retained by the Client. However, this has not yet been considered in detail by the Working Group.

Selection of contributors
All ECI strategies involve selection of contributors to participate in the ECI phase. The challenge is to ensure not just that the best contributors are selected, but also that the process complies with relevant procurement rules and will be robust in the event of a challenge. This requires careful preparation and conduct of the process, as procurement rules have commonly been formulated on the basis of a simple transactional approach to procurement. There may be a need to press for changes to procurement rules.

While selection must be based to some extent on pricing, the main selection criteria for involvement in an ECI process fall under two main headings: **capabilities** and **attitude**.
The capabilities required can include competence, creativity, experience, human resources, ability to recruit further resources and expertise, financial resources and equipment resources. Capabilities can be measured and verified by reference to objective criteria. Verification of capabilities therefore leads to ‘confidence’ rather than ‘trust’.

**Attitude** is also important but less susceptible to objective assessment. The importance of attitude is because ECI requires collaboration, willingness to make effort and devote resources, willingness to share information and ideas, honesty and a rejection of opportunism. Such characteristics and behaviours require **trustworthiness** and **trustfulness**. Assessment of attitude requires assessment both of the parent organization and of the individuals who will be involved. Assessment will depend on reputation and references, but other methods may be devised.

All that can be assessed with attitude is the starting condition. Behaviours and attitudes will be then be reinforced or undermined by the reciprocated behaviours and attitudes. They will also depend on financial pressures and long term prospects of mutual involvement.

**Integration of ECI into Overall Project Procurement Strategy**

As the last part of the ECI definition states “...in stages of project planning and design prior to execution contract award”, the end of the ECI phase is regarded as when the execution contract is awarded. However, the ultimate effectiveness of the ECI strategy for project value can only be truly assessed at the end of the execution phase, when the project is brought into service and the final accounts are settled. This will depend not only on the strategy during the ECI phase, but also the strategy for arrangements to build on the achievements of the ECI phase after the transition into the execution phase, and to integrate ECI into the overall procurement strategy. This is an area which will be addressed in the Guidelines.

**Way Forward**

Based on these considerations, ECI experiences of the past decade such as the Beatrix Locks, Melbourne Port and Odense Terminal are being evaluated by the workgroup. As a final part of its research, the workgroup will use its findings to provide the sector with guidelines and possible frameworks that encompass ECI best practices, focusing on aspects such as a.o. ECI feasibility, how to define objective and scope, transparency and confidentiality through a code of conduct, financial aspects and guidance on existing cooperation agreements.
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Title:
Contrat de Partenariat pour le remplacement de 29 barrages sur l’Aisne et la Meuse. Mise en œuvre de 4 centrales hydroélectrique

Abstract:
FR -
Voies Navigables de France (VNF) a pour mission d’assurer les différents usages liés au réseau navigable français. L’Aisne et la Meuse en font partie. Afin de remplacer 29 barrages à aiguilles construits au XIXème siècle, VNF a fait le choix de recourir à un partenariat public privé.

En 2013, VNF a ainsi signé un contrat de partenariat avec BAMEO, société crée pour ce projet et dont les actionnaires sont VINCI Concessions, MERIDIAM et SHEMA filiale d’EDF.

La conception, le financement, la construction des ouvrages, visant à remplacer 29 barrages manuels avant 2020 a été assortie de la mission de l’exploitation et maintenance du parc de 31 barrages et ses 4 centrales hydroélectriques pendant 30 ans.

Cet article présentera les intérêts de ce mode de passation de marché en regard du besoin de VNF, les modalités de mise en œuvre ainsi que la mise en application par BAMEO.
Les présentations du Concepteur-Constructeur COREBAM viendront compléter cette présentation du concédant VNF et du maître d’ouvrage BAMEO.

ENG-
Voies navigables de France (VNF) mission is to ensure the various uses related to the French navigable network. The Aisne and Meuse rivers are part of it. To replace 29 needle dams built in the 19th century, VNF has chosen to use a Public-Private Partnership.

In 2013, VNF signed a contract with BAMEO, a special purpose vehicle created for this project and whose shareholders are VINCI Concessions, MERIDIAM and SHEMA, subsidiary of EDF.

The design, financing and construction of the works to replace 29 manual dams by 2020 has been accompanied by the mission of operating and maintaining the 31 dams and its 4 hydroelectric plants for 30 years.

This article will present the interests of this method of contracting in relation to VNF’s need, the terms of implementation and the implementation itself by BAMEO.

The presentations by the designer-builder COREBAM will complete this presentation by the public entity, VNF, and the Master of Works, BAMEO.

SOMMAIRE ET DESCRIPTIF SUCCINCT DE LA PRESENTATION (1500 mots et 3 pages)

1. Périmètre :

Un projet unique impliquant le remplacement de barrages existants sur deux bassins versants différents, l’Aisne et la Meuse.

Au travers de 2 régions et 4 départements, ce sont 31 barrages de navigation qui sont intégrés au périmètre du contrat dont 29 barrages à aiguilles, qui sont remplacés par des bouchures gonflables à l’eau, et 2 barrages à clapets existants déjà rénovés par VNF entre 2001 et 2010.

Au total ce sont donc plus de 250 km de voies navigables (dont plus de 200 sur le seul fleuve Meuse) qui sont concernés par ce projet.

2. Objectifs du projet :

Les objectifs principaux du projet correspondent à la modernisation des méthodes d’exploitation des barrages présents sur ces 2 cours d’eau. Ces objectifs sont :

- Sécuriser les situations à risque liées à la manœuvre des barrages et ainsi améliorer les conditions de travail des personnels d’exploitation (pénibilité, risques d’accidents…) ;
- Fiableiser les niveaux d’eau en modernisant la gestion du plan d’eau et fiabiliser ainsi le niveau de service de l’ensemble des usages (navigation, prélèvements et rejets).

Il s’agit également d’un projet ambitieux en termes délais de construction mais aussi de maintenance et de maintien de niveau de performance sur toute la durée du contrat, justifiant le choix de standardisation (technologie, équipements, dimensions, matériaux…) des ouvrages reconstruits.

Le projet comporte enfin un volet environnemental avec notamment un objectif de rétablissement de la continuité écologique le long des cours d’eau, et en particulier la libre circulation des poissons. Il comporte également une contribution au développement d’énergies renouvelables.
dans la production de la France (trois nouvelles microcentrales hydroélectriques et reprise d’une microcentrale existante).

3. Le mode contractuel :
Le choix du mode contractuel s’est tourné vers le contrat de partenariat. Par ce contrat le titulaire BAMÉO, la société spécifiquement constituée pour ce projet, s’engage à assurer le financement, la conception, la construction, l’exploitation, la maintenance courante et le gros entretien renouvellement (GER) des 31 ouvrages du périmètre du projet.
Ce contrat repose également sur le respect par BAMÉO du programme fonctionnel et performantiel défini par VNF, préalablement à la conclusion du contrat. Ce programme exprime l’ensemble des critères de performances en matière de gestion de la ligne d’eau et de qualité des ouvrages. Il a été une des pièces maîtresses du dossier de consultation.

Ce type de contrat permet d’envisager la réalisation des objectifs du projet tout en garantissant à la Personne Publique :
- le respect des délais et des coûts
- des économies d’échelles
- une meilleure gestion à terme de l’équipement avec des coûts de maintenance intégrés.

Le contrat a été signé le 24 octobre 2013 après 18 mois de dialogue avec les différents candidats. Il s’étalait sur une durée de 30 ans et prévoyait une date limite pour l’achèvement de l’ensemble des travaux en mars 2020, soit 7 ans seulement après la signature. Le montant global du projet s’élève à 312 millions d’euros d’investissement HT dont 256 M€ HT de travaux.

4. Déclinaisons des objectifs de performance :
Les objectifs de performance se déclinent selon les familles suivantes :

a) Les performances liées à la gestion hydraulique :
Ces performances se traduisent tout d’abord par des contraintes d’exploitation qui traduisent le niveau de service des Ouvrages, à savoir :
- L’effacement des ouvrages en période de crue ;
- Le respect du débit minimum biologique en période d’étage ;
- Respect des cotes d’exploitation limites qui permettent de garantir les usages ;
S’ajoutent les performances relatives au «fonctionnement de l’Ouvrage» en période normale qui se traduit par une cote de retenue et une plage de régulation à respecter (au maximum de +/- 10 cm) proposées par BAMÉO.
Un indicateur suit également la gestion douce des ouvrages dont la performance est calculée à partir de la variation moyenne du niveau d’eau au droit de chaque ouvrage ayant pour objectif d’éviter des variations brusques du plan d’eau.
Ces performances sont à respecter pendant toute la durée du contrat, 7j/7 et 24h/24, y compris durant les périodes de maintenance ou de GER.
b) **Les performances environnementales**

Le contrat prévoit des performances à respecter autant en phase de travaux qu’en période d’exploitation, notamment :

- Le rétablissement de la continuité écologique. BAMEO a la responsabilité de la conception - réalisation et du fonctionnement des équipements de montaison et de dévalaison des poissons sur chaque ouvrage ;
- La continuité au passage de la petite et grande faune ;
- La limitation des impacts sur les espèces et les habitats ;
- L’intégration paysagère et architecturale ;
- La non-dégradation de la qualité de l’eau ;
- La réduction des déchets à la source ;
- L’optimisation du bilan carbone.

c) **Les performances relevant de la gestion patrimoniale** :

Le contrat définit avec précision les durées de vie théorique et résiduelles à respecter pour l’ensemble des équipements d’un ouvrage (génie civil, vantellerie, gonflables, …).

Pour garantir cette performance, un suivi de l’état fonctionnel des équipements, avec un niveau de performance à la clé, est réalisé pendant toute la durée du contrat. Il permet notamment d’affiner le plan de maintenance et de GER au cours de la vie de l’ouvrage.

En fin de contrat, un audit complet de l’ensemble des ouvrages est réalisé par BAMEO afin de garantir à la personne publique le respect des durées de vie résiduelles et le cas échéant de réaliser les travaux de remise en conformité qui s’imposent.

5. **Les différents acteurs et leurs responsabilités**

Afin de garantir le respect de ses obligations contractuelles, BAMEO s’appuie sur deux sous-contrats :

- Un contrat de conception - construction passé avec COREBAM, groupement temporaire d’entreprises de Vinci Construction France. Ce groupement a en charge l’ensemble des obligations relatives aux prestations de conception, de construction de l’ensemble des ouvrages et de la déconstruction de l’ensemble des barrages manuels, ainsi que l’ensemble des obligations relatives aux acquisitions foncières, à l’obtention des autorisations administratives, aux opérations et prestations nécessaires à la mise en service des ouvrages, à la levée des réserves.

- Un contrat d’exploitation – maintenance conclu avec SeMAO, société spécialement créée pour la réalisation du projet et dont les actionnaires sont SHEMA et Vinci-Concessions. Selon les termes de ce contrat, SeMAO a en charge les prestations d’exploitation et de
maintenance des ouvrages (y compris des microcentrales). Il est à noter que les prestations liées au GER restent à la charge de BAMEO.

BAMEO a d’autre part conclut avec des prêteurs une série d’accords lui permettant de financer le projet. La responsabilité du maintien de ce financement incombe en premier lieu, et durant toute la durée du contrat à la seule société de projet.

Pour sa part, VNF reste garant du respect de la tenue de la ligne d’eau et du niveau de service correspondant face aux usagers de la voie d’eau. VNF reste gestionnaire de l’ensemble des ouvrages en dehors du périmètre du contrat (écluses, biefs, …).

En tant que personne publique, VNF s’assure du respect de ses engagements contractuels et réalise la surveillance de la conformité de la conception et de la réalisation des ouvrages aux exigences du contrat en termes de performance. A ce titre, VNF s’appuie sur son Entité de Surveillance, entité émanant de VNF et regroupant ses diverses compétences techniques : maîtrise d’œuvre, exploitation, maintenance, etc.

6. Gains obtenus

Suite à la signature du contrat en octobre 2013, les délais principaux relatifs à l’obtention des autorisations administratives, à la conception-construction et aux mises en service ont été respectés. En particulier, on retiendra :

- un coût forfaitaire et non révisable ;
- la réalisation de l’ensemble des travaux en moins de 7 ans y compris la conception. À noter les 18 mois pour l’obtention de l’ensemble des autorisations administratives nécessaires au démarrage des travaux sur les deux bassins versants : arrêtés interpréfectoraux loi sur l’eau et espèces protégées ;

Concernant l’exploitation des ouvrages, BAMEO respecte de manière générale l’ensemble des performances. Les retours d’expérience des premières années, y compris certains incidents, sont néanmoins mis au profit par BAMEO pour optimiser cette gestion par exemple l’ajustement des paramètres des automates de régulation pour mieux tenir compte des conditions propres à chaque site et des interfaces entre les différents ouvrages de l’itinéraire.
1. **Background**

*Nautical and economical*

The dam of Ampsin-Neuville, on the Meuse River, creates a navigable reach of nearly 20 km and a fall of 4,70 m. Two locks allow the crossing. These works were commissioned in 1958.

The minor river bed has a width of about 120 m at this point. A hydroelectric power plant, capable of producing up to 10 MW, was added to the dam in the sixties.

The largest existing lock is designed for class Va ships (136 x 16 m). Due to the increasing size of the ships, the small class II lock (55 x 7.5 m) has been out of service for more than a decade.

This site is included in the Meuse / Rhine-Main-Danube axis and in the extension of the most important waterway in Belgium : the Albert canal.

It is the third most important site in Wallonia for the transport of goods by inland waterway ships.

The development of waterway transport leads to the formation of a bottleneck on this site. The tonnage passing through this site has doubled in twenty years. The lock complex must be converted to ensure the
passage of class VIb convoys or the simultaneous passage of several ships of equivalent overall capacity as already available at other lock sites on this axis.

Sixty percent of the goods transiting through this site are materials from the extractive industry, mainly from upstream quarries.

The project aims to develop sustainable mobility through modal shift and business development by:

- increasing fluidity of river traffic;
- improving the security and reliability of the navigation network;
- increasing safety and users comfort.

**Hydraulic**

The river is subject to floods in winter. The necessary partial occupation of the river for works is acceptable only during the seven months of the low water period.

**Geological**

The structures, inscribed in the thickness of clay-silty and sandy-gravelly alluviums, are based on intensely folded and faulty or even tectonized rocks. The bedrock is made up of alternating soft shale containing hard sandstone shale beds.

**Environmental**

The artificial banks, surmounted, to the south, by a fast lane, channel the river. Habitat areas coexist with a grassland area to the north and a forested slope to the south. A nuclear power plant is present upstream.

2. **Choosing the solution**

Five main configurations of the structures were studied. They were the subject of a multi-criteria analysis. Environmental concerns are paramount.

This analysis was based on a similar level of detail for each solution. They present minor differences in costs. The choice was therefore made on the basis of qualitative criteria alone. The main criteria are related to flood management, safety of navigation, fluidity of traffic, lock management and environmental impacts. These criteria are themselves subdivided, so as to allow an analysis of simpler aspects to be appreciated, such as impacts on fauna and flora and on the population.

The choice was made to build, during a first phase, a class Vb lock (225 x 12.5 m) on the site of the class II lock. The class VIb lock (225 x 25 m) will replace the class Va lock (136 x 16 m) during a second phase, after the commissioning of the class Vb lock. This chronology makes it possible to maintain navigation during the works while limiting the impact of interventions on the environment. The particular population impacts of this configuration are minimal.

The 225 m x 12.5 m lock has sufficient capacity to ensure the flow of ships during the construction of the 225 m x 25 m lock. The functioning of the 225 m x 12.5 m sluice induces longer emptying and filling times. In addition, the capacity of waiting areas is limited during construction. The capacity of the 225 m x 12.5 m lock is likely to saturate if traffic increases significantly. It is therefore necessary to build the 25 m wide lock in the wake of the 12.5 m wide lock.

3. **Project design**

**Locks**

The chamber walls of the two locks are designed without expansion joint. The floors of the locks are primarily intended to protect the base from erosion and the transfer of horizontal forces between the walls. The floor of the Vb lock also plays a key structural role during the construction phase of the class VIb lock.

The future class Vb lock is equipped with single-leaf doors and is filled by sluices in the gates.

The future class VIb lock is equipped with an upstream flap gate and a mitre downstream gate and is filled through the heads. Two aqueducts, upstream of the head, carry the water in a chamber located under the
upstream threshold. The chamber’s geometry has been designed in order to ensure a feed distributed frontally over the width of the lock.

**Buildings**

A new control unit is built on the island between the two locks. It is designed to offer operators a clear view into both locks.

**Banks**

Hydraulic, numerical and model-scale studies as well as a nautical study were conducted to optimize the configuration. The approach channel and the banks must be modified to ensure the manoeuvring of larger ships. This constraint requires modifying the national road on a length of about 1 km, downstream of the site. In this context, the existing road, with two lanes in each direction of traffic, will be replaced by a peri-urban road.

Part of the banks concrete, built in the middle of the twentieth century, will be demolished to restore links between the aquatic environment and the bank. Inundated transition zones, in which aquatic fauna and flora can develop, will be created. These transformations are also designed to increase the habitats of birds. Trails for walkers are also included, at a distance.

**Fish passes**

The project also incorporates the creation of several fish passes. One of them, about 700 m long, is an artificial river. It is particularly intended for salmonids, carp, pike and small species. This unique work includes spawning areas. It consists of riffles, intended for migration, pools, intended for rest, and spawning grounds. The riffles have a minimum depth of 30 cm, slopes of 1.5 % and the average flow velocity is limited to 0.5 m/s. The pools have a depth of more than 1.5 m. The spawning grounds have a depth of 40 to 60 cm and are intended for lithophilic species. Part of the bank of this fish pass is also designed to encourage the nesting of shore swallows.

Another fish pass is specifically designed for eels. It has a slope slightly less than 20 % and is equipped with a rough surface. It is supplied by a low flow of water.

**Footbridge**

The facilities include pathways for pedestrians and cyclists. A CorTen steel footbridge will overhang the site. This footbridge is also intended to support a mobile gantry used to create a dam maintenance cofferdam.

4. **Carbon footprint**

The project design has been optimized to reduce the carbon footprint. Emissions occur mainly during construction of structures and marginally during operation. CO2 is mainly produced by thermal decontamination of land, manufacturing of steel and cement as well as demolitions. The avoided production of CO2 will result from a modal shift, from road to inland waterway transport. The increased gauge capacity resulting from the project will allow avoiding the production, during the locks’ lifetime, of 150,000 tons of CO2.

5. **Planning**

Works, which will last for about five years, began in the summer of 2018. The commissioning of the class Vb lock is scheduled for 2021 and that of the class Vlb lock at the end of the year 2023.

The complexity of the works lies in their organization by ensuring:

- the continuity of navigation, taking into account the expected increase in traffic. For this purpose, a temporary bridge is built to access the central zone of the site, between the dam and the lock in service;
- the flow of the river in all flow conditions.
6. **Financing**

The project is financed by the “Société de Financement Complémentaire des Infrastructures”. It aims at removing a bottleneck on the international navigation network. For this reason, it is the subject of a financial contribution from the European Union within the framework of the budget of the Trans-European Transport Networks.
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Titre:
Les apports sociaux et environnementaux de la mise à grand gabarit du site éclusier d’Ampsin-Neuville sur la Meuse

Article:

1. Contexte

Nautique et économique

Le barrage d’Ampsin-Neuville, sur la Meuse, crée un bief navigable de près de 20 km et une chute de 4,70 m. Deux écluses en permettent le franchissement. Ces ouvrages ont été mis en service en 1958. Le lit mineur du fleuve présente, à cet endroit, une largeur d’environ 120 m. Une centrale hydroélectrique, capable de produire 10 MW, a été adjointe au barrage dans les années soixante.

La plus grande des deux écluses (136 x 16 m) est destinée au passage de bateaux de classe Va. Vu l’accroissement des dimensions des bateaux, la petite écluse, de classe II, n’est plus en service depuis plus d’une décennie.

Ce site est inscrit sur l’axe Meuse/Rhin-Main-Danube et dans la prolongation de la voie navigable la plus importante de Belgique : le canal Albert.

Il est le troisième site le plus important de Wallonie pour le transport de marchandises par voie d’eau.

Le développement du transport fluvial conduit à la formation d’un goulot d’étranglement à cet endroit. Le tonnage transitant sur ce site a doublé en vingt ans. Le complexe éclusier doit être transformé pour assurer le passage de convois de classe VIb ou le passage simultané de plusieurs bateaux d’une capacité globale équivalente tel que le permettent déjà les autres sites éclusiers de cet axe.

Soixante pourcents des marchandises transitant par ce site sont des matériaux issus de l’industrie extractive, principalement issus de carrières exploitées en amont.
Le projet vise à développer une mobilité durable par le biais d’un transfert modal et du développement de l’activité via :
- l’accroissement de la fluidité du trafic fluvial ;
- l’amélioration de la sécurité et la fiabilité du réseau ;
- l’augmentation de la sécurité et le confort des usagers.

Hydraulique
Le fleuve est sujet à des crues en hiver. La nécessaire emprise des travaux dans le fleuve est acceptable uniquement pendant les sept mois de la période d’été.

Géologique
Les ouvrages, inscrits dans l’épaisseur des alluvions argilo-limoneuses et sablo-graveleuses, sont fondés sur des roches intensément plissées et failleées voire tectonisées. Le bedrock est constitué d’une alternance de schistes tendres renfermant des banes durs de schiste gréseux.

Environnemental
Les berges artificielles, surmontées, au sud, d’une voie rapide, canalisent le fleuve. Des zones d’habitat côtoient une zone de prairie au nord et un versant boisé au sud. Une centrale nucléaire est présente à l’amont.

2. Choix de la solution
Cinq configurations principales des ouvrages ont été étudiées. Elles ont fait l’objet d’une analyse multicritères. Les préoccupations environnementales sont prépondérantes.
Cette analyse a été fondée sur un niveau de détail apparenté de chaque solution. Elles présentent des différences de coûts peu significatives. Le choix a donc été opéré sur base des seuls critères qualitatifs. Les critères principaux sont relatifs à la gestion des crues, à la sécurité de la navigation, à la fluidité du trafic, à la gestion des écluses et aux incidences environnementales. Ces critères sont eux-mêmes subdivisés, de manière à permettre une analyse d’aspects plus simples à apprécier, tels que les incidences sur la faune et la flore et sur la population.
Le choix s’est porté sur la construction, durant une première phase, d’un sas de classe Vb (225 x 12,5 m) sur le site de l’écluse de classe II. L’écluse de classe VIb (225 x 25 m) se substituera au sas de classe Va (136 x 16 m) durant une deuxième phase, après la mise en service de l’écluse de classe Vb. Cette chronologie permet d’assurer le maintien de la navigation durant les travaux tout en limitant l’impact des interventions sur l’environnement. Les incidences notamment sur la population de cette configuration sont minimales.
L’écluse de 225 m x 12,5 m présente une capacité suffisante pour assurer le flux de bateaux pendant la construction du sas de 225 m x 25 m. Le mode de sasement contraint de l’écluse de 225 m x 12,5 m induit des durées de vidange et de remplissage plus importantes. En outre, la capacité des zones d’attente est limitée pendant les travaux. La capacité de l’écluse de 225 m x 12,5 m est susceptible de saturer en cas d’augmentation significative du trafic. Il est donc nécessaire de construire le sas de 25 m de large dans la foulée du sas de 12,5 m de large.

3. Projet

Ecluses
Les bajoyers des deux écluses ne comportent pas de joint. Les radiers des sas visent essentiellement à protéger le socle de l’érosion et au transfert des forces horizontales entre les bajoyers. Le radier de l’écluse Vb joue également un rôle structurel prépondérant lors de la phase de construction de l’écluse de classe VIb.
La future écluse de classe Vb est équipée de portes à simple vantail et est alimentée au moyen de vannettes intégrées dans les portes.
La future écluse de classe VIb est équipée d’une porte clapet à l’amont et d’une porte busquée à l’aval et est alimentée par contournement des têtes. Deux aqueducs, à l’amont de la tête, acheminent l’eau dans une chambre située sous le seuil amont. Sa géométrie a été étudiée de manière à assurer une alimentation répartie frontalement sur la largeur du sas.
**Bâtiments**

Un nouveau poste de commande est construit sur l’île entre les deux écluses. Il est conçu pour assurer une visibilité directe des opérateurs dans le fond des deux sas.

**Berges**

Des études hydrauliques, numériques et sur modèle réduit, et une étude nautique ont été menées afin d’optimiser la configuration. Les avant-portes et les berges doivent être modifiés pour assurer la manœuvre des bateaux de grandes dimensions. Cette contrainte nécessite de prêter attention à la modification de la route nationale sur environ 1 km de long, à l’aval du site. Dans ce cadre, la route, présentant deux voies dans chaque sens de circulation, sera remplacée par une route à caractère périurbain.


**Passes à poissons**

Le projet intègre également la création de plusieurs passes à poissons. L’une d’entre-elles, d’environ 700 m de long, est une rivière artificielle. Elle est notamment destinée à la montaison des salmonidés, carpes, brochets mais aussi de quelques espèces. Cet ouvrage singulier intègre des zones de frai. Il est constitué de radiers, destinés à la migration, de moulles, destinées au repos, et de frayères. Les radiers possèdent une profondeur minimale de 30 cm, des pentes de 1,5% et la vitesse d’écoulement moyenne y est limitée à 0,5 m/s. Les moulles possèdent une profondeur de plus de 1,5 m. Les frayères possèdent une profondeur de 40 à 60 cm et sont destinées aux espèces lithophiles. Une partie de la berge de cette passe à poissons est en outre aménagée pour favoriser la nidification des hirondelles des rivages.

Une autre passe à poissons est spécifiquement destinée aux anguilles. Elle présente une pente un peu inférieure à 20 % et est équipée d’une surface rugueuse. Elle est alimentée par un faible débit.

**Passerelle**

Les aménagements intègrent des cheminement destinés aux piétons et cyclistes. Une passerelle en acier autopatinable surplombera l’ensemble des ouvrages. Cette passerelle est également destinée à supporter un portique mobile utilisé pour créer un batardeau de maintenance du barrage.

4. **Empreinte carbone**

La conception a fait l’objet d’une optimisation visant à réduire l’empreinte carbone. Les émissions se produisent essentiellement durant la construction des ouvrages et de manière marginale pendant l’exploitation. Le CO₂ est principalement produit par la décontamination thermique des terres, la fabrication de l’acier et du ciment et les démolitions. La production évitée de CO₂ résulte du transfert du mode de transport, de la route vers la voie d’eau. La mise à grand gabarit permet d’éviter la production, pendant la durée de vie des ouvrages, de 150 000 tonnes de CO₂.

5. **Planification**


La complexité des travaux réside dans leur organisation en assurant :
- la continuité de la navigation, en tenant compte de l’accroissement prévu du trafic. A cet effet un pont provisoire est construit pour accéder au centre du site, entre le barrage et l’écluse en service ;
- l’écoulement du fleuve dans toutes les conditions de débit.

6. **Financement**

Le projet est financé par la « Société de Financement Complémentaire des Infrastructures ». Il est destiné à supprimer un obstacle sur le réseau de navigation international. A ce titre, il fait l’objet d’une contribution financière de l’Union européenne dans le cadre du budget des Réseaux Transeuropéens de Transport.
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Title:
DBFM New Flood Barrier Limmel, why integrated contracts lead to better performance

Abstract:
As its infrastructure is vital to the country’s safety, economy and environment, the Dutch Waterway Authority (Rijkswaterstaat) has known a long tradition in obtaining value for money for its large infrastructure projects. From experience that low prices are recipes for project failures, Rijkswaterstaat has learnt to implement integrated and long-term contracts in the market in order to secure quality over price. After a number of large road and tunnel PPP projects, Rijkswaterstaat has launched the world’s first DBFM (Design Build Finance and Maintain) waterway infrastructure project north of Maastricht. The design, financing, construction and 30 year maintenance of a new flood barrier was the first in a programme of large DBFM lock projects, the Sluizenprogramma.
Rijkswaterstaat approached the market with a competitive dialogue based on multicriteria selection, being an example of early contractors involvement. Due to the required flood safety of the inland land, emphasis in the contract was largely put on reliability and availability of the old and new asset, in accordance with the Machine Guideline. This has resulted in a design that both surprised and delighted the client.
Combining proven technology in an innovative way and using simple physical laws, the flood barrier is able to meet the high requirements in a simple, ingenious way. E.g. the reliability requirements were met by allowing the steel gate to be closed just by opening one valve, leaving the rest of the process to gravity while guaranteeing a controlled closure. Another example was the use of an impervious soil layer as a watertight system performing under high and contradictory groundwater pressures. Consequently few components lead to lower construction costs and more importantly less complicated maintenance.
This article will tell the story of this first “wet” PPP project, the challenges, the successes and the failures. And especially what it takes to achieve a performing collaboration between client and contractor leading to a succesful project.
Introduction
North of the city of Maastricht (NL) lies the flood barrier of Limmel, protecting the downstream Juliana Canal and land against seasonal floodings of the river Meuse. An existing 80-year-old flood barrier was to be replaced by an entirely new one in the first “wet” Private-Public-Participation (PPP)-project.

The former barrier of Limmel functionned both as a lock and as a flood barrier in times of high flows of the river Meuse, accomodating ships class CEMT Va. Although the infrastructure was functionning as an open gate most of the operational time, the narrow passages (16 m large, 3.5 m deep) were experienced as an obstacle to the continously growing tonnage on the canal.

Fig.1 Former flood barrier Limmel (built in 1933, demolished 2017)

The river Meuse in the Netherlands is being upgraded towards class CEMT Vb under the so-called “Maasroute” programme of works. To meet the requirements for this type of vessel, it was necessary to adapt the existing infrastructure. It was decided to demolish the existing flood lock barrier and have it replaced by a single gate in order to allow two ships with maximum length 190 m, 11.4 m width and 3.5 m depth to pass each other at the same time.

The first “wet” PPP
Historically the Netherlands spend and focus on their vital, usally water-related infrastructure. The Dutch Waterway Authority, Rijkswaterstaat, has a long tradition in obtaining value for money for its large infrastructure projects. In collaboration with the private market, this governement organisation has worked out a constitution, called the “Marktvisie” (Market Vision). Rijkswaterstaat has learnt the hard way that focus on lowest prices bids prove to be the recipe for project failures. In answer Rijkswaterstaat has implemented integrated and long-term contracts in the market in order to seek quality over price. Examples of these types of contracts are Designed/Build/Finance/Maintain (DBFM), Best Value Procurement (BVP), Alliances, etc.

Over the past decades many large road infrastructure projects were positionned in the market as DBFM-projects. In 2013 Rijkswaterstaat, launched the first DBFM waterway infrastructure project of “New Flood Barrier Limmel” in a programme of large lock projects, the “Sluizenprogramma”. In order to gain experience and mitigate the risk of putting a waterway project in the market, Rijkswaterstaat deliberately chose a small
project to start with. “Little Limmel” (€ 50 mln) was to be followed by larger projects such as Zeetoegang IJmond (€ 580 mln), 3e Kolk Beatrixsluis (€ 225 mln), et. al.

Market approach
Rijkswaterstaat approached the market with a competitive dialogue, based on multicriteria selection to maximize early contractors involvement. Typically a call to the market is launched with a requirement of pre-qualification (reference projects). After a first selection, usually 5 competitors have to submit a relatively limited quality product. Private partners are to explain their vision on a set of pre-defined project risks. As a standard, Rijkswaterstaat requests a vision on how to avoid “unsatisfied end-users”, “unsatisfied environment” and “unsatisfied operators”, together with one or more specific risks. E.g. as it is a flood gate, Limmel’s 4th risk was “the reliability and availability of the new asset”. After a few formal contacts between client and contractor, a document of 20 pages is then used as a selection criterion allowing 3 remaining parties pass the post. This approach limits the transaction costs in the first selection round.

Next, the dialogue phase intensifies and a set of quality products is required. The 3 remaining private partners are to submit a preliminary design and management plans as a “Qualitative Submittal”. Typically a few weeks later, a detailed price is produced as the “Quantitative Submittal”. While the price only has to conform to a ceiling or target figure, the qualitative product is weighed and rated by a review commission, providing a score that is calculated into a fictive discount on the submitted price. The impact of this deduction depends on the project, but usually results in a full 50 % of fictive reduction on the price. Henceforth it is possible to beat the competition with higher quality without the economical disadvantage of this strategy. The pre-definition of risks allows the client to drive the market towards a desired solution without limiting the private partners in their inventivity.

At the end of 2014 project Limmel was won by a consortium of BESIX Group and co-investor Rebel Group. The works started mid of 2015 and were completed in a first phase in March 2017. After demolition of the existing asset, the project has gone through its first year of the 30-year exploitation phase (since April 2018).

Keep it simple
To Rijkswaterstaat the reliability and availability of the asset are of highest importance. To mitigate the flood hazards, the certainty that the flood gate will close at any time is to be mathematically demonstrated. Furthermore the asset interferes with the economical function of the canal, requiring a maximal availability of the canal.

Based on previous experiences, the consortium selected the system of two 22 m high concrete towers and a 47 m wide steel lifting gate, even though other solutions like miter gates or a rotating gate were allowed. However they scored less on reliability and maintainability.

The design was deliberately robust and modest, based on proven technology and concepts. BESIX and the Architect, Quist-Wintermans, had built two similar structures before (in the Netherlands), therefore creating a “family” of similar looking flood gates in the Netherlands.

Fig. 2 Construction of the new concrete towers inside the existing infrastructure
Key in the concept was the lifting mechanism. In order to comply with the required reliability of 1/3875 per operation, a mechanism inspired by a previous flood gate was conceived. The idea is to be able to close the gate at any time by opening one emergency valve. Gravity does the rest.

The smaller lock of Heumen has an hydraulic cylinder combined with wheels and cables. The larger dimensions of Limmel prevented an exact copy. Connecting two hydraulic cylinders hydraulically and relying on the (relative) incompressibility of oil, copied the Heumen solution into a hydraulic version of the same principle (Fig. 3): the oil of the “slave” cylinder is supported by the oil in the “master” cylinder. The entire system is continuously under pressure, keeping the steel gate door at height. Once the pressure is released from the master cylinder, the slave cylinder experiences the same release, moving oil from one side of the canal to the other via the steel gate. Equal volumes of oil result in equal movements of both cylinders, securing the essential equal descent of both sides of the gate. In normal conditions this is controlled by simple hydraulic pumps, but in case of emergency, the pressure can be released by opening the emergency valve.

![Fig. 3 Hydraulic principle of the lifting mechanism](image)

**Not a greenfield project**

Though Limmel is a rather small project, high risk lifting operations have taken place. The limited workspace due to the presence of the existing lock required an intense preparation. This was first put to the test when a new culvert was installed underneath the canal (Fig. 4). Two glassfibre reinforced polymer (GRP) tubes of 1.6m diameter and 80 m length were assembled into a boat structure and sunk in 3 hours time. Next, the 90 m steel bridge structure was to be transported within the existing lock perimeter, to be turned 90° in a 70x70 area and lifted 9,5m (Fig.5).
Coping with set-backs
In September 2016 the lifting of the steel gate was to take place. During transport over water the steel gate got damaged in a (naval) traffic accident and needed to return to the workshop for repair. Only thanks to the close collaboration between client and contractors, the team succeeded only two months later to finish the job after all while meeting the original milestones.
Unfortunately, fate struck the project for a second time. On 7th July 2017 a component of the hydraulic mechanism failed and set the steel gate in motion. Despite emergency actions, the steel gate landed in a tilted position, heavily damaging the hydraulic mechanism. Fortunately without any victims or third party damage. During the recovery operation, the team suffered a second and more dramatic blow when a co-worker lost his life in the final phase of the operation. The impact of such an event deeply traumatizes family and team members.

This disaster, despite all preventive efforts and measures, could have been the end of the project or at least profoundly have disturbed the relations between all partners. On the contrary, during these heavy tidings the investments in the relationship between client and contractor finally paid off: the team put all effort in investigating, repairing and rebuildin, and did not fall into quarrel. As a result all was repaired by the end of 2017 and the project was once again completed within the foreseen milestones.

![Image of failure of the lifting mechanism](image-url)

**Fig. 7 Failure of the lifting mechanism**

**Lessons learnt**
Limmel proved to be a succesful pilot for the Sluizenprogramma, delivering value to the client. During the project a continuous monitoring of client and stakeholders’ satisfaction, scientifically demonstrated to all partners the benefits of investing in a mature project management and client-contractor relationship. Under ominous tidings it was proven that, if all goes well, any project will succeed, but when things turn bad, only the strong relations resist the storm. Built-up trust and collaboration are key, and will be needed for the next 29 years.
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Keywords:
Flow fluctuation, Navigable tunnel, Cross-section coefficient, Ship model test, Wave damping system

Title:
Analysis of Flow Fluctuation Characteristic and Improvement Measures in Navigable Tunnel

Abstract:
In alpine and gorge areas, rivers usually have large water level drop, many beaches, steep slopes and strong current, which bring great difficulties and challenges to the construction of navigation structures. The navigable tunnel is an effective way to solve the layout problem of navigation structures in alpine and gorge areas, which can make full use of the topographical condition of the field. However, the navigable tunnel is a typical narrow channel in shallow water. When ships navigate in such channels, the sailing resistance will increase and the maneuverability will decrease. There are few studies on this special restricted channel at home and abroad, and few engineering cases are in operation. The major projects reported are confined to Gou-pitan Tunnel in China and Stad Ship Tunnel in Norway. The Gou-pitan Tunnel has just been completed, while Stad Marine Ship Tunnel in Norway is still under planning and construction.

Ship wave is a kind of wave produced by squeezing and frictioning the contact water during the course of navigation. There are obvious differences between ship waves in navigation tunnels and those in open waters. Based on the specific engineering layout, the water-level fluctuation characteristics caused by ship's navigation in navigable tunnels are systematically analyzed by means of ship model test and other technical means. The research results of this article illustrate the inherent law between the maximum water swelling height caused by ship navigation and the key technical parameters such as ship speed, water depth, cross-section coefficient, maneuvering conditions (single ship and multi-ship).

At the end of this paper, the layout scheme of wave damping system in navigation tunnel is put forward by theoretical analysis. Some guiding design suggestions are also given. The research results may provide references for improving the navigation conditions of ships in navigable tunnels and enhancing the safety and comfort of ships in tunnels.

Introduction
Inland waterway transportation is an important part of national comprehensive transportation system and comprehensive utilization of water resources, which has been attached great importance by all countries in the world. However, it is very difficult to arrange and construct navigation structures in alpine and gorge areas. Firstly, the water level drop in alpine and gorge areas is very large, with many beaches, steep slopes and rapid flow. Secondly, there is often not enough space for layout of navigation structures, which restricts the extension of waterway to a certain extent, especially in the mountainous areas in central and Western China.


Research status

The research results of navigation tunnels at home and abroad are relatively few. Nevertheless, there are still some relevant engineering and research achievements for reference, such as the Malpas Tunnel on the Midi Canal, the first navigation tunnel in the world and the Rove Tunnel on the Marseille-Rona Canal, the longest navigation tunnel in the world at present, which was opened in 1927. From 2008 to 2011, NHRI systematically studied the layout scheme of the Goupitan navigation tunnel in Wujiang River by means of large-scale physical model. The construction of navigation tunnel has been completed now. Besides, the Stad Ship Tunnel in Norway is being planned and constructed. The total length of the tunnel is about 1800 meters, the total width is 27m and the height above the water surface is 25m. The construction is expected to be completed in 2022.

Ship wave is a kind of complex non-linear traveling wave phenomenon. Its wave shape is affected by different water depth, topography, ship speed and so on. There are obvious differences between ship waves in restricted channels such as navigable tunnels and those in open waters. The width of the tunnel channel is usually less than 1 times the ship's length, and the cross-section coefficient is small, even smaller than the value 6.0 in navigation standard (The cross-section coefficients refer to the ratio of the cross-section area to the submerged area of a ship). The confinement of the tunnel's side wall is obvious, which leads to the reflection of scattered wave and the encounter with ship hull, thus the complex process of wave superposition occurs.

Test methods and research conditions

This paper is based on the specific project layout. The total length of the tunnel is about 2400 m, the upstream and downstream ships run one-way at staggered time, the net width of the tunnel is 18 m, and the design water depth is 4.5m, as shown in Figure 1.

![Figure 1 The layout of navigable tunnel of the specific project](image)

The towed ship model is used to carry out the experiment in this study, as shown in Figure 2. The test considers the characteristics of water flow fluctuation in navigation tunnels under different speeds, maneuvering conditions, and water depth conditions. The relationship between the maximum water swelling height and the key technical parameters such as ship speed, channel depth, cross-section coefficient and manoeuvring conditions is analyzed. The working conditions refer to Table 1.

![Figure 2 The towed ship model](image)
Table 1  The research conditions

<table>
<thead>
<tr>
<th>Number</th>
<th>Ship Speed (km/h)</th>
<th>Water Depth (m)</th>
<th>Number of Ships</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>chy001～chy007</td>
<td>3.76～7.66</td>
<td>4.50</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>chy101～chy110</td>
<td>3.58～7.95</td>
<td>5.30</td>
<td>1</td>
<td>26 groups of experiments were conducted.</td>
</tr>
<tr>
<td>chy201～chy209</td>
<td>4.78～8.86</td>
<td>6.90</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>chy30</td>
<td>6.0</td>
<td>4.50</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Test results and analysis

Generally, the wave generated by a ship sailing in a restricted channel belongs to the Kelvin wave state, i.e. $F_s < 0.84$. However, due to the limitation of the side walls on both sides of the tunnel, ship waves in the tunnel usually cannot form a complete fan-shaped propagation area. The relationship between the maximum wave height and water depth and speed is shown in Figure 3.

![Figure 3 The relationship between maximum swelling height and water depth and speed](image)

Analysis of the result data shows that:(1) When a ship is sailing in a navigable tunnel, part of the water body can not be discharged in time to form a surface surge in front of the bow, and the water surface after the stern decreases.(2) When the cross-section coefficient is constant, the maximum wave height mainly depends on the speed; when the speed is constant, the maximum wave height depends on the cross-section coefficient. (3) The maximum water surface surge heights formed before the bow of the first ship are still the highest in Multi-ship tests.(4) The disturbance and influence of the ship on the stern current is basically equal to the length of the ship, beyond which the water surface restores calm basically.

Improvement Measures

Ship waves in tunnels are mainly scattered waves (progressive wave) formed by squeezing the water in the front half of the bow. According to engineering experience, in order to eliminate the long wave fluctuation of water flow in narrow and closed waters, the best way is to arrange wave elimination measures perpendicular to the direction of long wave propagation. However, in the navigable tunnel, the direction of long wave propagation caused by ship waves is basically the same as that of ship's navigation, which makes the design of wave elimination measures extremely difficult. The unreasonable arrangement of wave elimination measures will hinder the navigation of ships or greatly increase the size of tunnels. In addition, the navigation of ships in any position in tunnels will disturb the surrounding water body to form new wave sources.

Aiming at the special structure type of navigation tunnel, this paper puts forward the wave elimination system in the waters below the sidewalks on both sides of the navigation tunnel where ships can not navigate. In order to facilitate the construction of the project, the recommended layout is shown in figure 4 and figure 5.
Figure 4 The recommended layout of wave damping system

Figure 5 A detailed arrangement of wave-absorbing plates

Assuming that the ship is located in the middle of the channel, and introducing the tunnel width B, the ship width b, the Kelvin angle δ (The Angle between Peak Line and Ship's Traveling Line) and the wave propagation angle θ. The influence range length L of the ship wave along the tunnel direction can be deduced as shown in Formula (1):

\[ L = \frac{B - b}{2} \left( \frac{1}{\tan \theta} + \frac{1}{\tan \delta} \right) \]  

In order to achieve good wave-absorbing effect, at least a set of wave-absorbing system should be arranged in each wave-affected area. This measure can make full use of the space beneath the sidewalks on both sides of the navigation tunnel without additional space occupied, and can realize energy dissipation by grading and decentralization. The test results show that the effect of this measure is remarkable, which can be used as a reference for other similar navigation tunnel projects.

Conclusion

Based on the specific engineering arrangement, the water level fluctuation characteristics caused by the ship's navigation in the navigation tunnel are analyzed by the towed ship model test. The results show that the ship wave height is directly related to the cross-section coefficient and speed in the navigation tunnel. In order to reduce the fluctuation of water surface caused by ship navigation in the tunnel, A space-saving layout of the wave damping system was proposed, which can provide a reference for similar navigation tunnel construction.

Funding

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Optimisation des investissements dans les infrastructures de navigation grâce à une chaine complète de modélisation.

Article court

Contexte

Aux niveaux français et européen, les pouvoirs publics mènent diverses politiques en faveur du développement du transport de fret par voie d’eau. Des intérêts et objectifs divers sous-tendent ces politiques et les projets qui les mettent en œuvre : augmentations prévues de trafic, évolution de la cale et augmentation du gabarit, projets d’aménagements des voies d’eau non directement liés au trafic, ou encore questions de sécurité. Les aménagements liés aux voies navigables sont généralement coûteux, et leur financement est souvent difficile, dans un contexte où les contraintes non budgétaires sont également nombreuses (emprise, environnement, partage des usages,…). De ce fait, il est impératif de définir précisément les aménagements à réaliser afin de répondre aux besoins. Cela passe d’abord par une bonne connaissance des conditions de trafic, depuis l’échelle du réseau jusqu’à l’échelle d’un obstacle ponctuel à la navigation. Cela passe ensuite par une conception des solutions techniques et organisationnelles parfaitement adaptées aux besoins et aux spécificités du réseau, si nécessaire en s’écartant des prescriptions des documents de référence et des usages. Les outils récents de modélisation appuient cette démarche et permettent désormais de mieux cibler les investissements, affiner les programmes des opérations et proposer le cas échéant des alternatives pour éviter, limiter ou mieux calibrer les travaux de grande envergure et en définir les conditions d’usage.

Intérêt général de la simulation numérique

De façon générale, la simulation numérique appliquée au domaine des voies navigables répond aux mêmes enjeux que dans d’autres domaines des infrastructures :

• Favoriser le diagnostic de l’état actuel, et ainsi préciser et objectiver les besoins ;
Tester des éventails de solutions et leurs conditions de validité ;
Justifier des écarts par rapport aux prescriptions et pratiques habituelles, et définir les conditions de sécurité et de fluidité du trafic associées.

L’article propose une description de deux outils récents qui permettent de rencontrer ce triple objectif :
- L’analyse des flux de navigation permet de modéliser de façon simplifiée l’ensemble d’un réseau de voies navigables, mailé ou non, y compris les écluses, zones d’attentes, garages d’écluse, zones d’alternat, zones de limitation de vitesse... ;
- Les études de trajectographie se concentrent ensuite sur un secteur défini. Ces études permettent d’étudier la sécurité du passage d’un bateau/convoyé donné selon divers scénarios de conditions environnementales et d’aménagement.

Analyse des flux de navigation : une vue globale du système

L’analyse des flux de navigation permet d’évaluer la fluidité du trafic et identifier les goulots d’étranglement selon divers scénarios d’évolution de la cale, de l’infrastructure et de gestion de la voie d’eau. Le modèle permet donc de préciser les zones à traiter à l’échelle du réseau sur lesquelles une étude plus approfondie peut ensuite être menée. Dans le cas des canaux, il permet également d’évaluer les consommations d’eau (liées à la navigation) selon ces mêmes scénarios.

Le logiciel ITS (Inland Traffic Simulation) est un logiciel développé par la société DN&T qui permet de tester les conditions d’écoulement au regard des capacités des voies navigables. L’outil propose une simulation de type discret - asynchrone. Une simulation à événements discrets modélise le fonctionnement d’un système comme une séquence discrète d’événements dans le temps. Chaque événement se produit à un instant donné dans le temps et marque un changement d’état dans le système. Entre des événements consécutifs, aucun changement dans le système n’est supposé se produire. Ainsi la simulation peut sauter directement dans le temps d’un événement à l’autre. L’avantage de ce type de simulation est qu’il permet de réaliser des analyses rapides des systèmes de grande taille et complexité : l’outil est applicable sur des réseaux simples (une entrée, une sortie) mais également maillés (plusieurs entrées, plusieurs sorties, interconnections).

La simulation se base sur une modélisation de l’infrastructure du réseau et de la flotte qui le fréquente. Citons par exemple :
- Description des biefs avec leurs données géométriques (longueur, largeur, profondeur), vitesse limite, les périodes d’inactivité (de nature déterministe, journalière, aléatoire). Un bief représente un tronçon linéaire de voie navigable mais également des points singuliers, comme des passages rétrécis, en alternat, dans une courbe ou sous un pont ;
- Description des écluses avec les données géométriques (longueur, largeur, profondeur, hauteur de chute), durée de remplissage, vidange, période d’inactivité (de nature déterministe, journalière, aléatoire) ;
- Description de la flotte avec les données géométriques (longueur, largeur, tirant d’eau), niveau de priorité pour l’accès aux écluses, durée de manœuvre dans les écluses, vitesses de navigation, composition de la flotte par type de bateau ;
- Règles de navigation (notamment alternat, trématage), appliquées à chaque type de bateau ;
- ...

Entre autres résultats, l’analyse des flux de navigation, et en particulier le logiciel ITS permet de :
- Analyser la fluidité du trafic ;
- Définir les modalités d’optimisation de l’utilisation de l’infrastructure existante ;
- Calculer le temps d’attente classifié par type d’attente ;
- Calculer la durée de parcours ;
- Calculer la consommation d’eau liée à la navigation ;
- Déterminer la longueur des garages d’écluse ;
- Taux d’occupation des écluses.
L’analyse des flux de navigation est donc un outil indispensable au diagnostic et au processus décisionnel lors de l’étude de modification de la voie d’eau ou de son exploitation.

**Trajectographie : une vue locale**

Les études de trajectographie ont deux finalités principales :

- Aide au diagnostic pour définir les conditions de navigabilité et de sécurité sur un secteur. Il peut s’agir par exemple de préciser dans quelles conditions environnementales (courant, vent) et de chargement, un bateau d’un gabarit donné peut naviguer en sécurité sur un tronçon de cours d’eau identifié ;
- Aide à l’aménagement, pour préciser techniquement la conception d’un aménagement ponctuel (bassin de virement, quai…) ou linéaire (rescindement, modification de méandre, redéfinition du chenal de navigation…) ;

Par ailleurs, les études de trajectographie permettent de définir les manœuvres à réaliser pour manœuvrer en toute sécurité (pour un bassin de virement par exemple).

Ces études sont réalisées couramment depuis plus de 10 ans, avec une évolution constante dans les outils et les méthodologies utilisés. Les évolutions récentes concernent le moteur de calcul mais également les modalités de simulation :

- La prise en compte des milieux confinés (faible largeur, faible profondeur), que constituent les chenaux de navigation intérieure ;
- La prise en compte détaillée de champs de courant issus de modélisations hydrauliques ;
- La prise en compte d’un nombre croissant de degrés de liberté, pour rendre compte plus finement des mouvements réels des bateaux, et les stratégies des calibration de ces modèles complexes ;
- La croissance des possibilités logicielles et matérielles pour la gestion d’un environnement 3D en temps réel, et les fonctionnalités associées.

Les études de trajectographie sont progressivement devenues un maillon essentiel d’une étude complète d’aménagement de voies navigables, pour les projets neufs ou les modifications. Elles permettent de pallier au manque de normes ou références (par exemple, pour les bassins de virement non circulaires), ou aux contraintes imposées par les documents de référence à portées générales (rayon de courbure des méandres par exemple), dans le cadre d’aménagements pour lesquels les contraintes se multiplient (budget, environnement, emprises, usages).

**Retour d’expérience et enseignements**

De nombreux exemples permettent d’illustrer les propos ci-dessus. Quelques-uns sont détaillés ci-après, tirés d’études menées par ISL et/ou DN&T, parfois en partenariat avec d’autres sociétés d’ingénierie ou laboratoires.

- Stationnement dans le bras de Meudon sur la Seine : étude des conditions de sécurité de la navigation liée à la présence de péniches résidentielles en zone soumise à interdiction de stationner ;
- Etude de trajectographie sur la Seine à Paris : définition de l’emprise maximale des nouveaux établissements flottants qui seront positionnés à l’avenir à proximité de la Mairie de Paris, permettant de garantir la sécurité de navigation sur le secteur ;
- Bassin de virement d’Arques (en collaboration avec le Flanders Hydraulic Research) : l’objectif et de tester configurations de bassins de virement alternatives à la forme circulaire, pour tenir compte de contraintes fortes (voie de chemin de fer, sols pollués, propriétés privées)
- Etude du tracé de la mise à grand gabarit de la liaison Bray/Nogent-sur-Seine: les études de trajectographie ont permis de définir les adaptations du tracé par rapport au tracé initial défini sur plan afin de garantir des conditions optimales de navigation, y compris en termes de sécurité.

L’article complet détaillera les principaux enseignements de ces différentes études et veillera à élargir le propos pour suggérer une méthodologie complète de gestion des projets d’analyse des conditions de navigation.
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Mots clés:  
simulateur, fluvial, formation, zone à risque, sécurité, innovation, réduction des coûts et des risques

Title:  
Simulateur de navigation sur le Rhône et la Saône

Article:

Entre les années 2000 et 2006, à la demande du Comité des Armateurs Fluviaux (CAF), le Cerema Direction Technique Eau, Mer et Fleuves (ex CETMEF), a réalisé un prototype de simulateur de navigation fluviale dont une version est installée au Centre de Formation d’Apprentis à la Navigation Intérieure (CFANI) et utilisée pour la formation initiale des apprentis pilotes.

De l’avis des utilisateurs professionnels, ce prototype, s’il permet une première approche de la conduite d’un bateau, nécessitait des développements complémentaires d’adaptation et d’amélioration pour que les navigants retrouvent fidèlement les sensations et le comportement de bateaux-types dans les diverses situations de conduite (vent, courant, etc.).

L’augmentation du trafic sur l’axe fluvial Rhône/Saône, qu’il soit de marchandises ou de passagers, nécessite des conducteurs bien formés, responsables, respectueux du fleuve et des autres usagers. De plus, la navigation sur le Rhône est un exercice difficile notamment en raison de l’importance du débit, des vents, des courants et de la présence de nombreuses zones délicates à passer. Il en est de même sur la Saône dans la traversée de Lyon et sur certains secteurs à méandres plus en amont.


Les contours techniques de ce nouveau simulateur ont été validés par le groupe d’experts, après la réalisation d’audits sur les simulateurs de navigation fluviale existants en France, en Allemagne, et en Belgique notamment.

Objectif du projet

L’objectif du projet consistait à intégrer de nouveaux développements dans le premier prototype de simulateur de navigation afin d’en faire un véritable simulateur de formation pour la navigation sur le bassin Rhône-Saône, en tenant compte des spécificités du bassin en la matière : forts vents, bateaux particuliers, trafic dense.
Le point fort du nouveau simulateur est le modèle de manœuvrabilité de bateau sur lequel il s’appuie, qui inclut des modèles courantologiques et d’hydrodynamique navale évolués et calibrés grâce aux observations des navigants.

Les premiers développements ont débuté en 2010, et l’inauguration du simulateur a eu lieu à en avril 2016. Le simulateur de navigation installé au Port de Lyon s’adresse à tout type de conducteurs, en formation ou confirmé, afin qu’ils puissent expérimenter différentes situations critiques et adopter un comportement raisonné gage d’une navigation plus sûre et économe.

Présentation du simulateur de formation

Le simulateur de navigation ne contient qu’un seul poste navigant principal représentant à l’identique la cabine de pilotage du bateau simulé autour de laquelle des écrans, représentant différents points de vue en 3 dimensions, permettent de simuler la navigation à 240° à travers les sites choisis et d’immerger le navigant dans un contexte lui donnant l’illusion de la réalité, avec un défilement du paysage entièrement numérisé : ponts, berges, balisage, écluse.

La cabine de pilotage

L’originalité du poste navigant principal réside dans le fait que la timonerie de la cabine est interchangeable, au moyen de tiroirs encastrables, en fonction du type de bateau utilisé au cours de la formation.

Le poste instructeur

Le poste instructeur, à partir duquel les exercices sont préparés, paramétrés, lancés et contrôlés, est situé dans une troisième pièce. Il qui permet de paramétrer, centraliser, synchroniser et superviser l’ensemble des simulations en cours (aussi bien sur les postes secondaires que sur le poste principal).
Le simulateur comprend également cinq postes secondaires, situés dans une autre pièce que la cabine de pilotage, qui permettent, malgré un équipement plus léger, à d’autres apprenants de participer à l’exercice.

Les bateaux modélisés

La navigation sur le bassin Rhône-Saône est particulière. Elle ne ressemble pas à la navigation rencontrée sur d’autres bassins. Les bateaux circulant sur le Rhône sont adaptés : ils disposent notamment d’une motorisation plus puissante. Pour accroître le réalisme de la simulation, il a été nécessaire de développer plusieurs types de bateaux, chacun étant plus ou moins chargés.

Les bateaux modélisés sont actuellement au nombre de 5 :

• deux automoteurs (128m et 135 m) ;
• un pousseur avec une barge ;
• un pousseur avec deux barges ;
• et un paquebot à passagers.  
Chacun de ces bateaux peut être affiché de façon chargée et léger ; ce qui implique un niveau de flottaison différent.

Les sites de simulations sur le Rhône

La volonté de créer un simulateur de navigation spécifique au fleuve Rhône, qui présente des caractéristiques particulières en raison des conditions hydrométéorologiques induisant des courants forts et des vents parfois violents, a conduit à sélectionner neuf sites référencés comme délicat pour la navigation. Ces sites sont :

• La traversée de Vienne, sur 2,2 km ;
• L’entrée nord de Tournon, sur 3,5 km ;
• Le site de La Voulte, sur 2,7 km ;
• Le canal de Donzère, sur 4 km ;
• Le site de Montfaucon sur 5,8 km ;
La traversée d’Avignon, sur 3,3 km ;
La traversée de Tarascon, sur 2 km ;
La traversée d’Arles, sur 3,8 km
Le site de Terrin, sur 6,5 km

Pour chacun des neuf sites, le simulateur de navigation, et donc la courantologie, a été élaboré pour trois états de débit du Rhône :

- étiage ;
- semi-permanent ;
- Plus Hautes Eaux Navigables (PHEN).

L’extension du simulateur à la Saône

En 2013, Voies Navigables de France (VNF) a exprimé sa volonté de faire partie du partenariat et d’intégrer le comité de pilotage du développement du simulateur. VNF a souhaité développer la modélisation de sections critiques identifiées sur la rivière Saône, en amont de Lyon, susceptibles d’être intégré dans le simulateur pour enrichir le simulateur et de contribuer ainsi à une amélioration de la sécurité de navigation sur le réseau à grand gabarit du bassin Rhône-Saône.

5 sites sur la Saône sont installés.

- Zone d’alternat de Lyon PK 0 à 7 ;
- Passage de l’île Barebe PK 9 à 11 ;
- Traversée de Chalon-sur-Saône PK 139 à 146 ;
- Passage de l’ancien barrage de Verdun sur le Doubs PK 166 à 168 ;
- Méandres de Charnay-les-Chalon à Trugny (bief Ecuelle Seurre) PK 175 à 188.

De nouveau bateaux, propres à la Saône, pourront également être intégrés au simulateur selon les besoins.

Conclusion

Le simulateur de formation permet de placer le pilote dans des situations rares ou particulières, qu’il ne pourrait peut-être pas rencontrer sur un site réel pendant sa durée de formation (pannes, conditions climatiques ou hydrologiques extrêmes...), en se dotant des capacités de multiplier à la demande le nombre et les caractéristiques des situations pédagogiques expérimentées.

Il est un atout pour améliorer la sécurité de la navigation fluviale dans la mesure où il permet aux bateliers de s’entraîner sur des situations météorologiques, de débits ou aléas mécaniques.

Pour les conducteurs débutants, il permet :
- Une mise en situation du passage sur les tronçons réputés délicats
- Un gain de temps dans l’apprentissage des bons réflexes à la conduite

Pour les conducteurs expérimentés, il permet :
- Une montée en compétences sur la conduite dans des situations difficiles et la conduite rationnelle

Pour l’Entreprise :
- Une économie de temps par rapport à une conduite en « double » de plusieurs mois
- Une amélioration des performances de la sécurité et baisse de l’accidentologie
- Des économies d’énergie grâce à l’apprentissage de la conduite rationnelle
- Des gains de productivité par la diminution des incidents et une usure moins rapide du matériel
- Une amélioration de l’image de professionnalisme de votre société
- Une meilleure qualité de service rendue à vos clients
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Keywords:  
waterway design, fuel consumption, social cost

Title:  
The influence of a waterway cross section size on a fuel consumption of an inland vessel – a sensitivity analysis

Extended Abstract/Short Paper:
Inland vessels are designed to optimize (minimize) the fuel consumption, given a mix of waterways they navigate through and the loading conditions prevailing in their lifetime. The waterways are typically designed to minimize the construction (CAPEX) costs and later their maintenance (OPEX) costs. This usually results in as small as possible cross sections of the waterways. The minimal cross section sizes are dictated by the safety of navigation of the design vessels (CEMT class of the waterway). It is not common that the authorities (typically owners and investors in the waterway construction) are interested in the minimization of the fuel consumption by the design vessel for the waterway. Considering social and environmental costs a global approach could be investigated: employing the possibility to increase the waterway cross section size that the total construction and maintenance costs plus the design vessels fleet fuel costs (and therefore CO2 emissions) are minimized.

Optimization of the propulsion of Class Va container ship for CEMT V class waterway
For this analysis we have created a resistance-propulsion model of representative vessel – a Class Va container ship, in full load condition. This kind of ship we often use in our ship handling simulations for optimization of inland waterways. The power of the main engines was taken from statistical analysis of existing Class Va vessels (from RWS and MARIN). We have assumed that this ship would sail over a CEMT V class waterway; we also assumed economical speed of this vessel on the waterway (we used guidelines from RWS Richtlijnen Vaarwegen 2017 and ROK1.4 – about design of hydraulic structures). Then we designed optimal (series) propeller for this vessel, with maximum ful effectiveness at this speed. We also accounted for the engine map features (engine map shows Specific Fuel Consumption SFOC as a function of engine revolutions and engine power, cf. Figure 1).
We used 3 different methods to calculate the ship resistance increase in channel; also, we looked into the change of propulsion coefficients (like wake factor) in shallow water. Each of methods resulted in different optimal propeller, and in different resistance-propulsion model. These models are subsequently used in the sensitivity analysis.
The optimization variables are propeler pitch and revolution; the speed of vessel is constant (economical speed) and the SFOC engine map is used to select point {revolutions, power} that gives minimal SFOC. This part of propulsion optimization shows how the resistance of the inland vessel depends on the parameters of the waterwa (and how the results depend on the resistance model being applied).
Sensitivity analysis of the fuel consumption FC on the waterway cross-section parameters
It is OBVIOUS that the increase of channel cross section area reduces the resistance of the sailing vessel, thu – at the same speed – reduces the Fuel Consumption. The NOT OBVIOUS is the relation between the rate of the cross-section area increase and the rate of the Fuel Consumption decrease; this relation is analyzed in this work.
The reference point is the given channel cross section parameters (area, and the channel width and depth), the cross section area increases, producing the rate of change in relation to the original cross-section (note that the change of cross-section area may be obtained by varying channel width, or depth or both, so these are also sensitivity parameters).
The change of the channel cross-section parameters results in change of the vessel resistance and propulsion factors, and then – at fixed ship’s speed – it changes the operation point of the vessel’s main engine (revolutions, power, Specific Fuel Consumption SFOC, cf. Figure 1), thus changes the total Fuel Consumption on a specified sailing route.

![SFOC map](image)

Figure 1 - Example of the SFOC presented as an engine performance map {revolutions, power}

We show how to develop (numerically) the Fuel Consumption rate changes as function of the cross section parameters (area, width, depth, slopes), i.e., we show the sensitivity parameters dFC/dArea, dFC/dWidth, dFC/dDepth, dFC/dSlope; the latter three are given for fixed cross-section area change.

The sensitivity indices are calculated and presented for two base waterway types – CEMT V and CEMT VI, and the loaded Class Va vessel. For each waterway type the cross section parameters are systematically varied (new, increased area, then – for this area, change of the width, or change of the depth, or change of the slope – varying both the width and depth). For the “new” cross section the resistance and propulsion are calculated, and the power and revolutions of the main engine are calculated given the ship speed, and finally, the SFOC. Then the sensitivity indices are calculated, and the sensitivity maps are obtained.

This analysis looks also into change of the vessel draught – we use 90% design load draught and 75% design load draught; one may see that each different draught creates a “new design vessel”, so we calculate also resistances and propulsion coefficients for these “vessels” (we do not modify the propulsion). This produces another 2 series of sensitivity coefficients, which allow to have insight into the effect of the ship partly loaded condition on the fuel consumption and on the effect of the waterway cross section parameters’ changes.

Optimization of the propulsion of Class Va container ship mx of waterways (CEMT V and CEMT VI)
After obtaining an insight of the changes of fuel consumption due to the change of the waterway parameters we analyze the optimization of the Class Va container ship propulsion when it is known on which waterways it is to sail. Since CEMT VI waterway has larger cross section then the propulsion optimized for CEMT V becomes sub-optimal. Therefore, if the owner of the fleet knows what is the share of CEMT V/CEMT VI in the routes of the design vessel, then it is possible to optimize the propulsion for such a composite waterway (it is typically done in case of sea-going vessels, under the name of long-term propulsive prognosis).
To investigate how the optimal propulsion parameters vary we use PARETO-type optimization, assuming the whole route is divided into CEMT V and CEMT VI segments (25%-75%, 50%-50%, 75%-25%), with standard profiles (per RWS Richtlijnen Vaarwegen 2017). We assume, as previously, that the main engine of given power is to provide economical ship speed (defined from economical analysis) at nominal revolutions, and the propulsive efficiency should be maximized (minimum fuel consumption). The varied parameter is the propeller pitch (we assume standard propeller series and maximum propeller diameter).

Then we show how the propeller parameter and the fuel consumption vary with the change of the waterway class mix along the route. These variations we compare with the fuel consumption for case of single type route (CEMT V or CEMT VI, exclusively), to show what effect such a long-term prognosis may have on the fuel consumption during a fleet lifetime operations. The important aspect is that the overall performance of the vessel (fuel consumption) may be optimized when the characteristics of the composite waterways the ship is to operate are known at the vessel design stage. Similarly, the economical performance of the existing vessel on a new route (a new composite waterway) may be analysed by accounting for the sub-optimal performance of the propulsion in each of the waterway segment.

We omit here variation in ship draught (loading state) or deck cargo load (wind resistance), but this may be well accounted for in real-life optimal fleet design.

**Sensitivity of fuel consumption on the wind conditions (Class Va loaded container ship)**

We have also developed a fuel consumption / CO2 discharge module and implemented it on a real-time ship maneuvering simulator (SHIP-NAVIGATOR, cf. Figure 2).

![Figure 2 - Example of the fuel consumption module applied to analysis of maneuvers along prescribed track](image)

Using the propulsion optimization results, and the model of resistance increase in channel, a model of ClassVa loaded container vessel is created in the simulator. Then this model sails in a CEMT V virtual channel; the ship is controlled by an autopilot in so called Fast-Time simulation mode. During these simulations we assume the ship speed profile to be followed. In each run we use different wind speed and wind direction (we apply time-varying gusting wind). The autopilot has to use rudder angle and drift angle of the ship to keep the ship on the desired track; the longitudinal rudder and hull forces then add to the ship resistance and to the wind resistance, modifying the engine operational point {rpm, power, SFCC}. This ultimately produces Fuel Consumption on the ship route. These variations of the Fuel Consumption – given waterway class, route, design vessel and ship speed profile on the route - are functions of the wind speed and wind direction.

This illustrates that the concept of long-term operational performance (well used in sea-going ship design optimization) could be as well applied for joint optimization of the inland waterway and fleet of ships sailing over it.
Modelling the traffic capacity of the narrow canal Roeselare-Lys, Flanders (Belgium)

INTRODUCTION

In Flanders (Belgium), the future Seine-Scheldt connection will be made via the Lys River. The canal between the city of Roeselare and the Lys River offers a direct access to this Seine-Scheldt connection (see Figure 1). To benefit from the expected economic development due to the Seine-Scheldt connection the canal must be upgraded and made accessible for ships with a higher draught.

![Figure 1: Location of the canal Roeselare-Lys (black rectangle) in relation to the Flemish waterways network](image_url)
Currently the canal is calibrated to allow access up to CEMT class IV ships with a draught up to 2.8 m, but in practice CEMT class Va ships with a length up to 110 m and a beam up to 11.5 m are allowed to sail on the canal. Past the so-called Bruane bridge (this is the port area of Roeselare), allowed ship dimensions are smaller, namely 86 m length and 9.6 m beam. The preferred alternative for upgrading aims for accessibility for ships up to CEMT class Va with a draught up to 3.2 m. Beyond the Bruane bridge the canal will be deepened as far as the stability of the existing quay walls enables (with of course a maximum of 3.2 m). The upgrading alternative is investigated further for the Flemish waterway authorities, De Vlaamse Waterweg nv, by verifying the structural stability of the existing canal infrastructure in relation to the planned deepening.

Besides the stability verification, the study for the canal upgrade also contains a nautical study. After all, in order to limit the spatial impact of the upgrading of the canal, deepening and enlargement will be kept as much as possible between the existing banks. This limited width requires a more detailed study of the navigation aspects. Therefore the study includes a detailed nautical design, and nautical simulations executed by Flanders Hydraulics Research. In addition, a traffic capacity model is set up to study the impacts of certain manoeuvring cases in the narrow canal on the travel time, such as meeting of (large) ships, evasion of moored vessels, or ships turning in one of the three turning basins. This paper discusses this traffic capacity modelling.

**IMDC Waterways**

For this study ‘IMDC Waterways’ (Integrated Model for Design and Capacity analysis of Waterways) is used. In the past, IMDC already developed IMDC Locks, a discrete-event model processing time series of arrival times that enabled the simulation of navigation lock complexes (Bayart et al., 2011). IMDC Waterways originated from this due to the need to take the mutual influence of lock complexes into account, as well as to investigate other bottlenecks on the navigation route, such as bridges, sharp bends or tidal windows (Bayart et al., 2013).

Within IMDC Waterways, a fairway is defined by nodes connected by links. The links determine the transit time between two consecutive nodes, while in the nodes the possible ship encounters are evaluated. Ships can be moored temporarily at intermediate destinations, which leads to a local narrowing of the fairway. This is an especially useful implementation for the canal Roeselare-Lys due to the many quay walls along it. The transit time depends on its type (‘waterway’ or ‘lock’) and the presence of other (sailing or moored) vessels. A ‘lock’ branch uses the previously developed IMDC Locks to model transit time, while a ‘waterway’ branch models the interactions between vessels (alternating navigation, overtaking, crossing).

The model of the 15 km-long canal Roeselare-Lys consists of 40 nodes connected by 39 links, 6 of them being bends. Twelve bridges cross the canal, and three turning basins (Roeselare, Izegem/Kachtem, and Ingelmuinster) are situated in the canal. Also the lock of Ooigem is incorporated in the model, since it has a modulating effect on the traffic entering the canal. It is the only entry and exit point from and to the Lys River.

**TRAFFIC GENERATION**

After setting up the model the input traffic is prepared. This traffic is developed starting from the existing ‘traffic image’, obtained from historical lock registration data at Ooigem (period 2015-2017). From these data it became apparent that a limited number of ships contribute to a large amount of passages on the canal, as can be seen in Figure 2. The left panel shows that about 80% of the lockages is performed for the same 30% of ships (on an average annual total of 4000 lockages). Similar information is shown in the right panel, where the number of lockages of the most frequent ship, second most frequent ship etc. is shown relative to the total amount for that class (AVV class is shown because the lock registration follows this classification). A noteworthy examples is class C2L, where one ship represents more than 95% of passages in that class. In other words, the respective ship is travelling to and from the canal on a full time basis. The above is relevant since not taking this into account with the stochastic traffic generator might lead to two vessels of the same class entering the canal too soon one after the other, while in reality this would be the same vessel, which would not reflect reality. Hence for these cases sufficiently large class-specific inter-arrival times had to be imposed.
Each generated ship must receive a destination (quay wall) as well. Since the historical data of Ooigem lock did not contain such information, a questionnaire was launched among the 51 companies disposing of a concession for a quay wall. An important conclusion from the questionnaire (response rate was 26%) was that up to Bruane bridge, mostly CEMT class IV and Va ships are sailing. Past the bridge, CEMT classes I up to IV occur. This split of course makes sense given the canal dimensions, but this result gives confidence to the assumption that small vessels seldom visit a quay wall situated before Bruane bridge. Also the results of the questionnaire enabled to attribute a destination frequency for 61% of the fleet entering the canal. The destination frequency of the remaining 39% of the ships was estimated making use of the results of the economic study (Technum-IMDC, 2014), the fleet distribution registered at Ooigem lock, and some assumptions regarding the amount of ships berthing at a certain location.

The future traffic was estimated starting from the existing traffic image, by adapting the fleet distribution as defined in the social cost-benefit analysis (Technum-IMDC, 2014). In this analysis, the total transported tonnage increases (projected year 2040), but at the same time introduces a shift towards larger vessels, combined with a larger loading capacity due to the draught increase. This results in a slight decrease of the total amount of ships. Planned developments, such as container terminals and unloading facilities, will generate traffic as well, which is estimated based on the projected yearly tonnage and the assumption that only the largest ships (CEMT class IV and Va) will travel to these new facilities.

**NAUTICAL SIMULATIONS**

In the framework of the project, real-time simulations were performed by Flanders Hydraulics Research. In a first set of simulations (Elloot et al., 2018a) the identified main bottle necks of the canal were simulated, which led to adaptation of the nautical design. In the second set of simulations (Elloot et al., 2018b) this adapted design was verified.

Besides delivering input to the design, results of the nautical simulations were also used as input for the capacity model, mainly in relation to the turning basins. Nautical simulations were performed in each turning basin, with a CEMT class Va ship entering the basin, turning, and sailing in opposite direction, and this for both directions, and with loaded and empty ships. Figure 3 shows an example of the result of such a simulation.
A thorough analysis of the different manoeuvring times was not performed, but it became clear that 10 minutes for a CEMT class Va ship was a representative value for the manoeuvre to be considered in the capacity model. This value relates to the area not being accessible for other ships, which is longer than the actual turning manoeuvre itself. To take smaller ship sizes into account, this value was reduced to 8 min and 5 min for ships of CEMT class IV and class I-III respectively.

RESULTS

Before running the model, some further assumptions were made regarding the ship behaviour. It was assumed that all ships sail up to their destination first, unload their cargo, and then sail further to the nearest turning basin to sail back to the lock at Ooigem. Hence no backwards navigation is considered in the model which, according to skippers, in reality sometimes occurs, especially when the distance is small (< 1 km).

With the traffic generator, a full year of traffic is generated, and imposed to the lock of Ooigem as input. This results a total amount of 3416 ships entering the canal during that year. The model simulates the journey of each ship, taking into account the different interactions (meeting other ships, waiting at a turning basin, berthing and unloading etc.).

Table 1 shows some results, i.e. the percentage of CEMT class Va ships meeting with other large ships (Va or IV). The number of expected meetings between two large ships is an important parameter to analyse the performance level of the canal, as frequent meetings may affect travel time. Since the traffic was stochastically generated, the values in the table can be seen as probabilities for a CEMT class Va ship entering the canal (in the future situation). The results show that a class Va ship has more than 50% chance of not meeting another Va ship during its journey, and about 57% of not meeting a class IV ship. The Va ship has a chance of 31.5% of encountering one other ship, and 21% of meeting two other large ships.

<table>
<thead>
<tr>
<th>No. of meetings [-]</th>
<th>Meeting with Va</th>
<th>Meeting with IV</th>
<th>Meeting with Va or IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amoun [-]</td>
<td>Amoun [%]</td>
<td>Amoun [-]</td>
</tr>
<tr>
<td>0</td>
<td>497</td>
<td>54.0</td>
<td>527</td>
</tr>
<tr>
<td>1</td>
<td>316</td>
<td>34.3</td>
<td>288</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>9.8</td>
<td>73</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>1.4</td>
<td>26</td>
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<tr>
<td>4</td>
<td>4</td>
<td>0.4</td>
<td>6</td>
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<td>5</td>
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<td>6</td>
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<tr>
<td>7</td>
<td>0</td>
<td>0.0</td>
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</tr>
</tbody>
</table>

Another important type of result is the probability that a ship has to wait due to another large ship performing a turning manoeuvre in one of the turning basins. After all, ships turning in these basins temporarily obstruct
the fairway, possibly causing additional delays for other passing ships. Table 2 shows this for CEMT class Va ships. It can be concluded that most times (more than 95%), the CEMT class Va ship is expected not to be impeded by turning ships.

Table 2: Number of times a CEMT class Va ship has to wait due to another ship turning in a turning basin

| No. of times waiting due to turning [-] | Turning of Va | | | Turning of IV | | | | Turning of Va or IV | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 880 | 95.7 | 886 | 96.3 | 850 | 92.4 |
| 1 | 39 | 4.2 | 34 | 3.7 | 65 | 7.1 |
| 2 | 1 | 0.1 | 0 | 0.0 | 5 | 0.5 |

Similar analyses (not shown here) could be made for the probability of encountering stationary vessels moored along the quay walls, which can cause delays too. Of course, the above results only give the probability of encountering certain traffic situations. In a next step, the impact of this on travel time will be calculated.

CONCLUSION

The future Seine-Scheldt connection will enable further economic development along the canal Roeselare-Lys. To benefit from this economic development the canal must be upgraded and made accessible for ships with a higher draught. However to limit the spatial impact, the upgrading must remain within the current boundaries as much as possible, making the design rather narrow for CEMT class Va ships. In a study performed for the Flemish waterway authorities, it is investigated whether the design results in acceptable navigability by means of nautical simulations. Also, because of the rather narrow design, the impact of certain traffic situations, such as large ships meeting each other, ships impeding other ships because of turning manoeuvres, or the presence of large ships being moored along the numerous quay walls, must be assessed. For this, a capacity model was set up, able to simulate ship journeys along the canal for the projected situation. The first results show that a CEMT class Va ship has a relatively high probability of meeting another large ship on its journey. The impact on travel time of one meeting is expected to be rather limited. The probability of impediment by another (large) ship turning in one of the turning basins, is expected to be limited (7%). In a next step, the impact on travel time will be calculated, so that the ‘efficiency’ of the upgrade in terms of travel time can be estimated.

REFERENCES


A comprehensive characterization of the nautical accessibility and traffic flow of the ECMT class Va inland waterway network of Nord-Pas-de-Calais, France
Introduction

The Nord-Pas-de-Calais ECMT Class V network will play a major role in linking the Canal Seine Nord Europe to the ports of Dunkirk, the inland navigation network of Flanders and Wallonia (Belgium) and its connected ports in the Scheldt-Rhine delta such as Ghent, Antwerp and Rotterdam. In the anticipation of the opening of the Canal Seine Nord Europe, the Flemish and Wallonian waterway managers are upgrading their networks to ECMT class Va and, in some cases, class Vb. The existing Nord-Pas-de-Calais Class V network (also known as the “Canal à Grand Gabarit”) is old and does not fully meet the modern geometric standards for canal design and construction. In order to prepare the network for the expected increase in traffic due to the opening of the Seine-Scheldt connection, Voies Navigables de France (VNF) has commissioned a comprehensive analysis of the Grand Gabarit waterway network based on nautical studies.

Moreover, the expected increase in traffic may strongly impact the fluidity of the network. In order to better understand and tackle potential bottlenecks, VNF has also commissioned a traffic flow model to study the traffic flow on the ECMT class V waterway network of the Nord-Pas-de-Calais.

The Seine-Scheldt project and the network

The ECMT class V network of Nord-Pas-de-Calais consists of three distinct branches: Dunkerque - Bauvin, Bauvin - Halluin, and Bauvin - Mortagne-du-Nord. The first canal assures the connection with the Port of Dunkirk. The second canal largely follows the canalized Deûle and Lys Rivers and links the system with the Port of Ghent and more northerly ports in Belgium and the Netherlands through the main axis of Seine-Scheldt liaison of Belgium (the Lys River). The third canal connects the system with the Scheldt River, linking again with the northerly ports, but also the Central Walloon Canal and the Meuse basin. This section will host the junction with the new Canal Seine Nord Europe.

While the Belgian canals and rivers are being upgraded using modern design guidelines and the Canal Seine Nord Europe is being designed accordingly, the Canal à Grand Gabarit, the backbone of the Nord-Pas-de-Calais network, dating largely from the 1950s and 60s, does not fully comply with these guidelines. Although the canal and lock complexes are dimensioned to allow push barge conveyos up to 143 m x 11.4 m, it is not clear whether the locks and canal can accommodate the anticipated growth in traffic due to the construction of the new connection and the upgrading of the connected rivers and canals. It is also not clear what the impact of the increase in traffic on travel and waiting times will be. The anticipated increase in travel and waiting time is generated at locks and at critical narrow canal sections which only allow alternating traffic.

Trajectory analysis

IMDC, together with Flanders Hydraulic Research and the Maritime Technology Division of the University of Ghent, has developed an approach of combined desktop analysis and real time navigation simulations to characterise the performance of the network for different ship types. The combination of both tools allows to reduce the cost of the nautical analysis of waterway. The desktop study uses existing design guidelines to check section geometry and to define accessibility for different ship combinations at ease and safety levels. The nautical characteristics and accessibility of sections liable to be upgraded are checked with real-time nautical simulations. In return, the nautical simulations also enable the verification of the validity of the nautical design principles and help improve the design guidelines and desktop approach.

Finally the results are used to define accessibility conditions for the network (either two-way or alternate traffic stretches for specific ship classes) and to identify bottlenecks requiring infrastructural measures. At this point, a feedback to the concurrent traffic flow study allows the evaluation of the benefits of potential measures and to effectively decide on their implementation.
Trajectory analysis: desktop study to select cases for real time nautical simulations

As mentioned above, the first step of the trajectory analysis consisted in a desktop study, in which geometrical rules were tested on the current canal sections. Rules have been defined to classify waterway sections for ease and safety navigation levels. This allowed the identification of stretches allowing ship encounters (of same or different classes) for a given navigation level (ease, safety) on the one hand, and the identification of stretches allowing alternating traffic only on the other hand.

Based on real time nautical simulations, encounters falling below the ease level (but above safety) have been divided into categories with fair and limited chance to be upgraded to a higher accessibility class without structural measures. The nautical simulation either led to: a confirmation of the accessibility class, the possibility of a (conditional) upgrade, or the deduction of navigation conditions. In a few cases the rules applied in the desktop study were challenged. This led to a review of the strategy for interaction between the desktop study and the nautical simulations.

Additionally, a selection of nautical simulations across the entire range of possible geometrical conditions (canal width, bend radius), allowed to univocally determine allowable encounters. This finally led to a reduction of number of simulation required to determine the accessibility level of the entire network.

Traffic flow model

Figure 2: network, locks (blue dots), reduced accessibility sections (red), from online model and result viewer
Until recently, only models for individual lock complexes or unbranched networks existed. Models for branched network were not available as the used model software did not allow for the combination of branches. The traffic model for the Grand Gabarit network is constructed using IMDC Waterways, a software that allows a detailed definition of branched waterway networks.

The model allows the definition of links and nodes, respectively allowing the definition of the geometry of the waterway and the evaluation of ship encounters. Traffic can be inserted on each individual node, under the form of time series of ship journeys defined by the ship characteristics (length, width, draught, etc.) as well as the journey’s origin and destination. As an additional character of the ship journey, ships are either removed from the system after reaching their destination, or may be moored (temporarily) at intermediate destinations, potentially leading to a partial narrowing of the waterway geometry.

Ship encounters can be either defined by classical access rules such as those defined by regulations or by geometric rules. In the Nord-Pas-de-Calais case, the accessibility of the nautical desktop study has been used as input to the traffic model. The traffic model will be further adapted as more results from the real-time simulations become available.

Ship speed can either be imposed (regulations) and/or calculated based on the characteristics of the ship and the canal section geometry (Schijf’s approach). Here as well, the model will be refined using the results of the real time simulations, not only to correct speed of individual ships, but also to adapt speed in case of encounters and in bends.

Traffic is generated with an improved generator allowing the definition of different statistical distributions to define inter arrival times. In this study, an Erlang distribution (k=5) is used.

Powerful pre and post processing modules allow the creation of statistics illustrated in tables and graphs to analyse the capacity of the network, identify bottlenecks and define traffic saturation.

**Traffic flow simulations**

The model is capable of reproducing the traffic fluxes based on available Origin-Destination lists and lock registries. Traffic analysis shows clear differences in fleet distribution between the different branches. For future projections not only the traffic intensity but also the fleet structure is changed.

Hourly distributions have been analysed at different locks. A sensitivity analysis was performed to select parameters which led to hourly distribution of arrivals times at the locks matching the observations, as this strongly influences waiting times.

Simulated travel and waiting times correspond well with experience of the waterway managers. Waiting times practically only occur at the lock complexes, and are most important on the branches with the larger ship sizes (Dunkerque-Bauvin, and Bauvin-Halluin), and lowest on the double lock complexes on the Bauvin-Mortagne branch (Douai, Courchelettes, Gouulzin).

Secondary results are the lock chamber occupancy, water consumption, distribution of the number of waiting ships at locks, etc.

![Figure 3: Increase of travel time (hours) between Dunkerque and Valenciennes due to increase of traffic](image-url)
The actual network has been tested for increased traffic (cargo multiplied by 2 and 3, redistributed over a fleet structure taking into account the overall increase in ship size). This leads to a significant increase of the waiting times at the Flandres, Fontinettes and Cuinchy locks (Bauvin - Dunkerque branch), and at Don and Grand Carré (Bauvin – Halluin branch), which then welcomes a larger proportion of class V ships coming from the new Canal Seine Nord Europe.

Simulations for increased traffic have been executed with a 24h/24h lock service. A sensitivity analysis on night navigation allowed to parametrise and formulate a hypothesis on the distribution of the number of ships sailing during the night. The results allowed to highlight the interest of night navigation to accommodate future traffic.

The simulations show that chances of ships encounters in narrow canal sections are fairly limited. Such encounters on the canal do not lead to significant increases of travel time. Capacity curves show that the so called comfort capacity of the lock complexes (less than 10% of ships wait for one lock cycle or more at locks) is already close to being reached today at several locks of the Bauvin - Dunkerque and Bauvin-Halluin branches (Cuinchy, Fontinettes, Flandres, resp. Don, Grand Carré, Quesnoy).

Feedback from the trajectory analysis to the traffic flow model

Feedback from the nautical simulations to the traffic flow model is the next step in the development of the models.

The traffic flow is now being modelled using the possible ship encounters resulting from the desk top study. The nautical accessibility from the nautical simulations can be used to refine this.

Now velocity is being imposed by the speed limits from the police regulations (maximum speed) and Schijf’s velocity (lower speed defined by wet cross section and ship characteristics), but this can be refined by taking into account speed reduction during encounters as simulated during the nautical simulations.

Further investigations could include: the study of the effect of adapting speed limits (while staying below speeds potentially causing damage to the banks), the study the effect of imposed speed on the traffic flow (traffic regulation study), the study of the effect of giving priority to larger ships at locks, etc.
Figure 4: example of simulation result sheet (in French), combining visuals of the sailed trajectory and an appreciation of the accessibility level using a colour scale: from top to bottom: the “protocole”, this is an overview of simulated situations (ship types, direction, load); “simulations” section giving an example of a simulated swept path, and an overview of comments on the difficulty as appreciated by the pilots and the nautical expert; the “analysis of the results” indicating the exceedance of thresholds defined for Under Keel Clearance, distance to depth contours, reserves for engine, rudder, distance between ships, with a colour scale; and finally the “conclusion”, an evaluation of the navigability of the section by the nautical expert.
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Mots clés:
Service d’information fluviale, Big Data, Machine Learning, AIS, ETA, Marée

Titre:
Calcul de l’Estimation du Temps d’Arrivée (ETA)

Introduction
Les Services d’Information Fluviale (SIF), et la digitalisation de manière plus générale, répondent à un double enjeu : faciliter les procédures existantes et créer de nouveaux outils. Le Cerema développe actuellement trois outils innovants dans le cadre du projet SIF Seine, porté par VNF et HAROPA. Construits pour être interopérables avec tous les SIF, ces modules ont pour objectif d’améliorer l’efficacité économique et environnementale du transport fluvial.

L’un de ces modules permet d’obtenir des estimations de temps d’arrivée (ETA) des navigants à destination. La connaissance de l’ETA permet notamment d’améliorer l’accueil du bateau dans les ports ainsi que son intégration dans la chaîne logistique internationale.

Limites des méthodes de calcul utilisées actuellement

Le Calcul d’itinéraire fluvial (CIFL) de VNF, le logiciel SINAVI du Cerema ou e-RIS sur le Rhin supérieur par exemple proposent des ETA. Ces estimations sont obtenues avec des approches analytiques type simulation ou méthode probabiliste.

La simulation numérique vise à reproduire le voyage réel, la précision de ces méthodes réside dans la connaissance de toutes les caractéristiques qui influencent le temps de voyage. Pour bien préciser le modèle de simulation, il est très important d’identifier des paramètres spécifiques au moyen d’observations et d’expérimentations. Dans le cas des méthodes probabilistes, la voie navigable est considérée comme un réseau de files d’attente ou une chaîne de Markov. Une analyse doit être effectuée pour traiter les tendances d’arrivée et de service et ainsi permettre de poser l’équation de calcul probabiliste de l’heure d’arrivée [1].

Une des limites principales de ces méthodes de calcul, est qu’elles sont obligées de faire des hypothèses simplificatrices. La vitesse est souvent supposée fixe, quelle que soit la profondeur d’eau ou la vitesse des courants. Les différents bateaux ont des caractéristiques homogènes. Ces méthodes de calcul ne tiennent pas souvent compte de la puissance du moteur, des régimes de navigation ou des dimensions des bateaux [2].
L’apport de l’Intelligence Artificielle


L’intelligence artificielle donne des résultats intéressants pour les ETA dans le maritime. Salleh, Riahi et Yang proposent une prédiction avec un taux d’erreur de 4,2% et 6,6% [5]. Parolas obtient une erreur absolue moyenne de moins de 5 heures pour des bateaux situés à plus de 100 heures du port de Rotterdam [3]. Carlos et Scheidweiler arrivent à prédire pour les prochaines 24 heures, l’ETA des navires au port de Hambourg avec une précision de l’ordre de l’heure [4].

Méthodologie

Dans notre cas, l’Intelligence Artificielle permet d’introduire dans la prévision le phénomène des marées, paramètre de toute importance pour la navigation sur l’estuaire de la Seine, mais difficile à intégrer avec les approches analytiques ou probabilistes. Outre ce paramètre, les débits les caractéristiques techniques des bateaux et les événements ayant impacté la navigation tels que les chômages d’écluses sont inclus.

Pour la phase d’apprentissage, des historiques de trajet et de temps de parcours sur plusieurs mois, en fonction de la marée, de la date et des avis à la batellerie sont nécessaires. Les données sont agrégées dans une base de données « trajets », avec pour chaque trajet le maximum de variables susceptibles d’influencer le temps de parcours du bateau. Cette base de donnée est séparée en deux : un jeu de données pour l’apprentissage et jeu de test.

Dans les faits, le module est construit de manière itérative. Pour chaque version, une variable (courant, caractéristique des ouvrages, caractéristiques des bateaux, trafic, etc.) est ajoutée, apprise et testée, afin de mesurer son impact sur le calcul de l’ETA en comparant les prévisions du module avec les données issues du jeu de test. Si l’impact est négligeable, la variable n’est pas retenue, sinon elle est validée. Le module s’affine ainsi au fur et à mesure de son développement.

Constitution de la base de données AIS

Un an de données AIS (Automatic Identification System), sous format d’archive de trames NMEA, a été transmis au Cerema. L’AIS est un système d’échange de données entre navires rendu obligatoire par l’Organisation Maritime Internationale (OMI) [7] et utilisé aussi pour les bateaux fluviaux. Les données AIS archivées permettent d’extraire des statistiques de temps de voyage pour une population de navires [8]. Les données transmises représentent 53Go de données au format texte compressées en bz2. Une fois décompressées, les données représenteront environ 500Go. Une base de donnée a été constituée et filtrée :

- Un seul signal AIS par bateau et par minute est gardé,
- L’extraction des données est limitée à l’axe Seine,
- 14 bateaux sélectionnés avec VNF et HAROPA ont été conservés.

Définition du modèle du fleuve

L’itinéraire Le Havre-Paris a été découpé en 44 tronçons, définis en fonction des infrastructures telles que les quais et les écluses. La fiabilité des signaux AIS en fonction des zones géographiques a été aussi un paramètre pris en compte lors de la définition de ces tronçons.
Définition de la base « trajets »

La base AIS nettoyée est croisée avec la base tronçons afin de construire la base « trajets ». Un algorithme définit les trajets et filtre les données inutilisables, lorsque par exemple un bateau est à l’arrêt. Seules les données AIS correspondant à l’entrée et à la sortie du tronçon sont conservées. Ces trajets sont validés à partir d’un historique réel des trajets obtenus grâce à la base VELI de VNF.

Apprentissage automatique

L’apprentissage des temps de parcours en fonction des différents paramètres est fait à l’échelle du tronçon. Différentes méthodes d’apprentissage automatique (réseaux neuronaux, réseaux bayésiens, séparateurs à vaste marge …) sont comparées afin de déterminer la méthode la plus adaptée à notre cas d’étude. Un travail de recherche est en cours pour sélectionner les meilleurs algorithmes.

Résultats

Le module est en cours de développement. Sur la base de l’approche développée, le temps de voyage sur l’axe Seine peut être estimé en tenant compte des contraintes dues à l’environnement de navigation. Dans un premier temps, seuls les messages AIS et certaines données telles que la longueur du bateau, sa largeur ou le port en lourd sont intégrés en données d’entrée.

L’algorithme de prévision et les différents coefficients pourront être ensuite améliorés. La base trajet sera consolidée en rajoutant des paramètres tels que les coefficients de marée, les débits, les coefficients de chargement des bateaux ou les restrictions de navigation. Ces données sont issues de différentes bases telles que les bases VELI ou Aghyre de VNF.

Bibliographie


Title:
Optimization of ship locks waiting times and operations

Introduction

River Information Services are information services designed to enhance safety and efficiency of inland waterway transport (IWT) by optimizing traffic, transport processes and overall digitalization. Within the Framework of Seine RIS project, lead by VNF and Haropa, Cerema is developing three innovative modules aiming to improve environmental and economic efficiency of inland transport as well as its integration into the inter-modal logistic chains.

One of this module aims to optimize ship’s passage of locks by specifying an arrival time at the lock to the ship. By knowing at what time the lock will be available for his passage, the ship’s captain can adapt his speed to avoid unnecessary fuel overconsumption. For inland waterway managers, this tool allow them to plan efficiently lock operations and reduce water and energy consumption.

The idea of improving lock scheduling in order to reduce waterway congestion has been gaining popularity in recent years. Indeed, lock often acts as bottleneck for transportation over water and operating them in a more efficient manner can contribute to increase waterway transport attractiveness. For instance, Caris et al. [1] pointed out that lock scheduling has a strong impact on the waiting times and advocates for a more efficient operating of locks in the future.

Lock scheduling has been investigated by several papers in the academic literature. Passchyn et al. [2] developed two mathematical programming models for the scheduling of series of consecutive locks. They concluded that integrated scheduling of consecutive locks can reduce flow time significantly. Ting and Schonfeld [3] investigated the idea of reducing ship speed in order to avoid idle time and concluded that significant economic benefit could be expected for a single lock. In a later paper [4] they studied three different heuristic algorithms to optimize ship lock operations. Smith et al. [5] investigated the impact of alternative decision rules and infrastructural improvements to relieve traffic congestion in a section of the Upper Mississippi River navigation system. They found that that some improvement in performance (especially in
peak periods) can be achieved by scheduling lock activity with priority given to vessels with shortest average processing and lock set-up times. The scheduling of a lock chamber to maximize the space utilization has also been considered in several papers [6,7,8].

Most of these studies either consider a whole network of locks or develop a scheduling algorithm for lock planning on the scale of a whole day. To implement such methods, it is either required to have a centralized lock management system for the whole network or know in advance which ships will be sailing on the network. In the case of Seine river, at the moment, each lock is operated independently (no supervised coordination) and enforcing lock planning one day or more ahead of time would incur deep changes in current sailing practices. The proposed solution in this article allows to bypass those constraints as it acts as an aid decision tool for the lockmaster and only consider real time traffic information. Therefore, this solution could be more easily implemented on French waterway network.

**Kessel overview**

The global objective of Kessel software is to reduce waiting times at a lock and the number of lockage. To fulfill this objective, Kessel retrieves real time information about traffic and lock state, estimates expected waiting times and number of lockage for the current situation and suggest a new scenario to the lockmaster with an estimated arrival time at the lock for each vessel allowing to reduce lockage and waiting times.

In order to run a traffic simulation, Kessel uses 4 modules to get the necessary input data from VNF Webservices or databases (Veli, Itinavi, SGTF). These modules have the following roles:

- Retrieving real time traffic information through AIS;
- Getting specific information on the ships detected by the previous module such as the ship width and breadth;
- Retrieving the destination of each detected ship;
- Obtaining information about lock state.

Once these information have been retrieved, a traffic simulation is executed by calling another Kessel module, SinaviRunner. The results from the traffic simulation allow to estimate the waiting time at the lock and the number of lockage necessary for all the detected ships to pass the lock.

Finally, KesselOptimizer uses optimization techniques to execute SinaviRunner with alternative input conditions for the ship speed in order to reduce lock waiting time and/or the number of lockage.

**SinaviRunner and KesselOptimizer**

SinaviRunner uses Sinavi model to run traffic simulation. Sinavi has been developed, updated and used by Cerema for more than 20 years. It allows to:

- Completely model a waterway network with its different infrastructures (lock, quay,...) and their operating rules;
- Take into account the characteristics of the vessel fleet in terms of ship dimensions and fleet size;
- Specify the navigation rules on the modelled network such as speed limit or alternating one way traffic;

Sinavi model is based on graph theory and queueing theory. It has been successfully used for studies such as impact on traffic in case of a new development on the waterway or a change in navigation rules.

KesselOptimizer uses optimization algorithms to vary the speed of the ships and find a solution reduce lock waiting time and/or the number of lockage. Several global optimization techniques implemented in Scipy and NLopt python packages are tested and compared. The optimization process can be either constrained by the respect of the ship ETA when this information is available or a maximum travel duration

**Kessel testing and validation**

Tancarville lock has been selected as a case study for testing and validation of Kessel. The main motivation for this choice is because this lock is operated by Le Havre Harbor and the lock master has regulatory authority
over it, which is not the case for the other locks located on Seine river, where the first-come first-served rule is enforced.

Ship AIS data as well as lockage logs have been collected. These data allow to reconstruct ship traffic over a defined timeframe and calculate parameters such as ship travel time, lock waiting times and the number of lockage occurring during this timeframe. Timeframes where congestion was observed at Tancarville lock have been selected for the purpose of serving as reference situations.

In a first step, SinaviRunner is executed for the selected timeframes. The simulated results obtained for waiting times, number of lockage and ship travel duration are compared to the values calculated from the collected data to evaluate the accuracy of SinaviRunner.

In a second step, KesselOptimizer is run for the selected timeframes and the optimized results are compared with the reference situation to estimate the efficiency of the optimization process. Several parameters are tested for the optimization such as minimizing the waiting times or the number lockage or a combination of both parameters. The influence of the optimized parameter selection on the traffic behavior is also investigated and discussed. These investigations can give some insight for the choice of the appropriate parameters.

Conclusions and perspectives

Kessel software combines a traffic model (SinaviRunner) and an optimization model (KesselOptimizer). Based on AIS data from ships near the lock, the traffic model calculates waiting times at the lock and the number of lock operations. An optimization algorithm is then used to vary the speed of each ship (i.e. time of arrival at the lock) in order to minimize waiting times and the number of lock operation. This process is iterated on demand by the lockmaster.

Kessel is used on a real case study for the lock of Tancarville. The model results are compared to past situations reconstructed from the lock logs and AIS data to evaluate the efficiency of this approach. Guidance regarding the choice of parameters to consider is also provided.

In the future, Kessel could be further improved by including additional parameter into the optimization process such as fuel consumption, air emissions and take tide levels into account. The feedbacks from an experimentation of Kessel on a lock could also help improving this model.

References


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Keywords:
passing ship effects, dynamic mooring analysis, harbor design

Passing ship effects on inland vessels moored in a side harbor next to a fairway
Introduction
The owner of a small inland harbor intends to re-develop the adjacent industrial area. This includes an optimization of the present harbor for accommodating various classes of inland ships. The side harbor is located along one of the major Dutch transport corridors with an annual traffic intensity of over 65,000 passages of inland and seagoing ships.
Conform prevailing Dutch legislation (Binnenvaartpolitiereglement BPR [1]) passing ships must adapt their sailing speed in such a way that they do not interfere with ships moored along the waterway or in adjacent harbors. Reducing the sailing speed is unwanted regarding nautical safety (less maneuverability, possibility of ramming (overrunning) by the following ship or dangerous overtaking maneuvers) and the tight tidal window for the larger (deep draught) ships. Therefore, it is required by the authorities, that the harbor development may not cause additional hinder for passing ships.
To assess the (nautical) feasibility of the planned harbor optimization, amongst others the effect of passing ships on ships moored in the harbor had to be evaluated. Realistic and sufficiently conservative passing ship scenarios were chosen to be evaluated. The effect of these scenarios and other structural and operational factors (bottom depth, number of ships moored next to each other, number and strength of mooring lines and the use of the innovative high performance mooring device ShoreTension® [2]) on the motions and resulting mooring loads have been investigated with a series of sophisticated mathematical models.
The investigations and conclusions carried out for the required nautical simulation study are described in the present paper.

Methodology
Sailing ships cause a dynamic pressure field moving with them and resulting in forces acting on ships moored along the waterway or inside harbors. These hydrodynamic interaction forces cause motions of the moored ships. If the motions become too high, this may lead to operational downtime or even mooring safety issues (breaking of the mooring equipment). The magnitude of the forces depend amongst others on the waterway and harbor geometry, water depth, size and draught of the passing and moored ship and the passing speed and distance between sailing and moored ships.
Typically, forces caused by passing ships are associated with the primary or double body flow around the passing ship: When two sailing ships pass each other or a sailing ship is passing close to a moored ship or a quay or a bank, the fluid between the two bodies flows.
This flow induces changes in the water pressure and ultimately causes forces on both bodies. The evaluation of the effect of such forces is important in determining the safety of ship maneuvering along narrow channels or rivers, in locks and in many harbors where ships are moored close to navigation channels and often speed limits have to be imposed to ensure safe mooring [2]
Since the moored inland ships are to be situated in a basin adjacent to the river, then also forces due to free-surface effects (ship wave propagation and reflections in the basin) had to be included in the modeling. These effects can be significant, especially in a small shallow basin as can be seen in below figure. Several reflections are missing and peak loads can be significantly lower when using a double body flow model only.

![Passing ship loads (surge) on the moored ship using Model 1 or Model 1+2](image1)

![Passing ship loads (sway) on the moored ship using Model 1 or Model 1+2](image2)

Figure 1: Passing ship loads in surge (left) and sway (right) using Model 1 only or Model 1+2

There are numbers of methods for the calculation of the hydrodynamic interaction forces and the resulting moored ship motions and mooring system loads.
For this study, three mathematical models were coupled (see also Figure 2):

1. Model 1, a time domain double body flow model: Passing ship and fairway are modelled with a panel schematization. Time series of potentials and velocities of ship induced waves are computed for a number of reference points in the computational domain. The model uses for the free surface the boundary condition dQ/dn=0 and is not suitable to model diffraction effects. Therefore, Model 1 was coupled to a diffraction model (Model 2) by transforming the time series of potentials and velocities to the frequency-domain with a Fourier transformation to be used as input for Model 2.

2. Model 2, a 3D frequency domain diffraction model: Moored ship(s) and harbor are modeled with a panel schematization. The computed potentials and velocities from Model 1 are applied on the panels and the frequency dependent free surface elevations in the harbor and the resulting forces and moments on the moored ship are computed. These are transformed to the time-domain with an inverse Fourier transformation as input for Model 3.

3. Model 3, a 3D time domain model for the analysis of the behavior of moored ships: Moored ship(s) with its hydrostatic and aero- and hydrodynamic properties (depending on the ship’s dimension, the proximity of the bottom and the quay wall and the hydrodynamic interaction between two moored ships) and the non-linear mooring system (lines and fenders) are modelled. The passing ship load time series from Model 2 is used as the dominant force to drive this model. As a result, the moored ship motions and related mooring system loads are derived.

With this “model train” the preferred harbor layout was assessed regarding the effect of different passing ship scenarios on the moored ship motions and resulting mooring loads. For this evaluation the type and size of the passing ship, the passing speed and the passing distance was varied. Also the sensitivity of the results to other structural and operational factors like harbor basin depth, number of ships moored next to each other, number and strength of mooring lines and the use of the innovative high performance mooring device ShoreTension® was evaluated.

**Boundary conditions**

**Waterway bathymetry**

The waterway has a fairway width of 210 m for inland ships with a minimum guaranteed water depth of about 5 m. Within this fairway, a 100 m wide deeper fairway for seagoing ships is situated with a minimum water depth of about 10 m. The deeper fairway section is located in a distance of about 60 m to the harbor entrance.

**Harbor geometry**

The present harbor has a rectangular shape, being about 50 m wide, 170 m deep and a limited water depth, and is not suitable for facilitating modern inland ships. For the development of the site, it is essential to optimize the harbor, having a new 250 m long quay wall and more maneuvering space inside the harbor, see Figure 3. Dolphins are planned in front of the old eastern quay so it can be used as a waiting place and if necessary refurbished in a later stage. The first investigated basin depth was resulting in a minimum water depth of 5 m. A second basin depth has been investigated resulting in a minimum water depth of 6.5 m.
Environmental conditions
Loads caused by passing ships increase with reduced under keel clearance. To be on a conservative side, a low water level (99% exceedance value) was simulated assuring a minimum under keel clearance of 10% for the (deep draft) passing ships.
Current velocities at the simulated water levels as well as wind induced waves are negligible small at the project site and were not taken into account. Also the effect of wind was not considered at this stage as the expected shelter of the quay wall and potential buildings or cargo stacks on the new terminal area will be significant at the simulated low water levels for the investigated fully loaded moored ships.

Passing ship scenarios
Realistic and conservative passing ship scenarios were determined. Inland and seagoing ships were simulated representing the worst case scenarios considering ship size, draft, passing speed and distance (defined as the distance between the entrance of the basin to the axis of the passing ship measured amidships).
The passing inland ship is a CEMT class VIc pushed convoy with 6 barges in long formation with a Length over all (L) x Beam (B) x Draught (T) = 270 x 22.8 x 4.0 m. It was simulated with a passing distance of 50 m, a passing speed of 15 km/h (8 kn; speed through the water) and a drift angle typical for the simulated conditions. The passing seagoing ship is a 25.000 DWT Handysize tanker with L x B x T = 175 x 25.0 x 8.5 m. It was simulated with a passing distance of 60 m and 105 m, a passing speed of 15 km/h and 18.5 km/h (8 kn and 10 kn; speed through the water) and a typical drift angle.

Berth
In total three different scenarios were considered to establish the berth at which the impact of the passing ships will be largest. The scenarios are shown in below figure

Moored ships
Class Va inland ships in loaded condition were considered as moored ships (L x B x T = 110 x 11.4 x 3.5 m). These ships were simulated as single ships and also as a side by side mooring configuration (2 class Va ships next to each other).

Mooring system
A preliminary design of the mooring system was carried out, using guidelines from PIANC [3] and Rijkswaterstaat [4]. At the western quay wall bollards (Safe Working Load of SWL = 300 kN; suitable until CEMT class VIa [4]) and energy absorbing cylindrical fenders are planned at two different height and in regular spacings. At the eastern side of the basin four dolphins are planned. Each dolphin is equipped with arm bollards at different heights and wooden fender plates.
Polypropylene type mooring ropes were used, which are relatively elastic (12.5% elongation at 100% Minimum Breaking Load MBL). Two different line strengths were investigated, the minimum required mooring line strength according to ROSR guidelines ([5] also referred to in [4]; Minimum Breaking Load of MBL = 200 kN) and mooring lines with a MBL of 400 kN as in the inland shipping, usually stronger ropes or even stiff wires are used according to [6].

Two different mooring line arrangements were investigated, a conventional as well as an optimized mooring line arrangement (adding an additional spring line, colored cyan as shown in Figure 5). Either by the winch or by the mooring procedure, all lines have a certain level of pretension. Nevertheless it will vary due to tidal water level fluctuations. For this study it is assumed that the lines from a winch have a pretension of about 10% MBL, other lines have less pretension.

![Figure 5: Investigated mooring line arrangements at the western quay](image)

Finally, also the effect of using an innovative high performance mooring device (ShoreTension®) has been investigated. The ShoreTension® is a portable hydraulic cylinder, installed on demand to support the ship’s own mooring system e.g. during severe storm conditions (high wind speeds) or at berths which have problems with (long) waves or passing ship related problems. It consists of a hydraulic cylinder (connected to a bollard) with a long piston, which is connected to a very stiff and strong Dyneema® mooring line running via a second bollard to the ship’s fairlead and to the bitt on-board, see also [2] and [7] and Figure 6. When the tension in the Dyneema® line is high then the piston moves out keeping a high constant tension in the line coping with the peak loads without exceeding the lines breaking load. This process significantly dampens the ship’s motions and absorbs the energy of the moving ship. When the peak loads are over and the tension in the line is small (or the line is slack) the piston moves inward, pulling the ship towards the berth with a small force.

![Figure 6: ShoreTension® cylinder (left) and snatch block to bring the Dyneema® line to the ship (right) [2]](image)

For this study a single ShoreTension® unit was added at the bow of the ship. For some cases a second unit was added at the stern of the ship conform below arrangement. The constant tension during outward motion of the piston was set to 20t, which is equal to the breaking strength of the ship’s regular mooring lines (therefore assuring that the ship’s bollards are not overloaded). This value can be reduced in case smaller ships with less strong mooring equipment want to use the ShoreTension® system.

![Figure 7: ShoreTension® arrangement at stern (left) and bow (right)](image)

**Evaluation criteria**

Load and motion criteria were defined to judge whether the moored ship motions and mooring system loads are acceptable. Load criteria are related to the safe working load of the mooring equipment (lines, bollards and fenders) to determine limiting conditions for safe mooring of the ships.
Motion criteria are related to the motion response of the moored ship to determine limiting conditions for the cargo handling. They depend on the type of cargo and the cargo handling equipment. In case moored ships move more than the defined criteria, (un-)loading operations become less efficient or have to be temporarily stopped. The definitions of the ship motions are presented in Figure 8.

![Figure 8: Sign convention of the ship’s motions](image)

### Simulation program and data processing

To evaluate the effect of passing ships on the safe working and the safe mooring of inland ships in the side harbor, the design ships were investigated in a dynamic moorings analysis using Model 3 (SHIP-Moorings [8]) with the from Model 1+2 derived passing ship load time series. The simulation program of the Dynamic Mooring Analysis (DMA) covered sufficient cases to draw conclusions about the nautical feasibility of the planned harbor optimization.

The outcomes of the simulations are time series of all relevant parameters, such as the six motion modes of the ship (surge, sway, heave, roll, pitch and yaw) and elongations and forces of all mooring lines, forces in the bollards and deflections and forces of the fenders. These time series (see Figure 2 for an example) were analyzed to derive output values for the defined load and motion criteria. In this case only the maximum values occurring during each simulation were analyzed.

### Results

#### General observations

When the ship passes the harbor, water flows out of the basin causing loads on the moored ship. Due to the orientation of the moored ship (moored bow-in and under a large angle to the fairway axis) this results in large negative surge forces pulling the moored ship astern (causing high loads in mooring line number 3, see below figure). When the water flows back into the basin, the ship gets pushed ahead resulting in even larger positive surge forces. Surge forces are therefore in this study the dominant factor.

The inland ship’s typical mooring line arrangement (two spring lines at the ship’s bow and a breast/stern line at the ship’s stern) causes that lines no. 1 and 2 are counteracting ahead motions and no. 3 is counteracting astern motions.

The above described mechanism can be seen in below figure, showing passing ship loads (surge) and resulting ship surge motion and line loads.

![Figure 9: Passing ship loads and resulting moored ship motions and line loads for the below shown mooring line arrangement of the single ship (bow-in mooring)](image)
**Scenario A: berth location within the harbor**

From the passing ship load computations (output of Model 2) it was concluded that the north-western berth (located closest to the fairway) is most critical for moored ships. Surge forces are considerably higher compared to the other two berths, see also Figure 10. At the south-western berth, peak surge forces are about 30-35% and at the eastern berth 20-30% smaller compared to the north-western berth.

![Figure 10: Passing ship loads (surge) on the single moored ship at different berth locations (bow-in mooring)](image)

**Scenario B: bottom depth in the basin**

From the passing ship load computations (output of Model 2) it was concluded that deepening the basin by 1.5 m from 5.0 m to 6.5 m (increase of minimum water depth by 30%; increase of water depth/draft ratio from 1.4 to 1.9) results in a reduction of the peak surge forces of 13% at the most critical north-western berth, see also Figure 11.

From the dynamic mooring simulations (output of Model 3) it can be seen that the reduced passing ship loads also result in lower maximum mooring line loads (between 6-12%).

<table>
<thead>
<tr>
<th>Maximum mooring line load [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line no.</td>
</tr>
<tr>
<td>5.0 m water depth</td>
</tr>
<tr>
<td>6.5 m water depth</td>
</tr>
</tbody>
</table>

![Figure 11: Passing ship loads (surge) on the single moored ship for different water depths (bow-in mooring)](image)

**Scenario C: passing ship type, speed and distance**

The loads caused by the passing seagoing ship are larger compared to the loads caused by the inland ship even though the inland ship is passing 10 m closer to the basin. This is mainly caused by the larger beam (25 m vs. 22.8 m) and especially the draught (8.5 m vs. 4 m) and related smaller under keel clearance of the seagoing ship.

A reduction in passing speed or increase of passing distance causes as expected lower loads, see also Figure 12. Increasing the passing distance by 75% caused a reduction in the peak surge forces of 40%. Reducing the passing speed by 20% caused a reduction in the peak surge forces of 50%. Note: when using a double body flow model, a reduction of about 35% can be expected, as here the relation between passing speed and resulting load is quadratic.
Scenario D: mooring system variations

The effect of variations in the mooring system (optimized line arrangement, stronger lines and using ShoreTension® technology) was established by analyzing the ship motions and resulting mooring system loads (output of Model 3).

Figure 13 shows the maximum line loads and surge motions for the different investigated mooring system parameters. It can be seen that all investigated variations result in significant improvements regarding the ship’s surge motion and resulting maximum line loads. Using the stronger lines or the optimized mooring line arrangement results in 30-40% lower maximum mooring line loads. Using the ShoreTension® system results in a significant reduction of the ship motions and peak loads. Applying a single ShoreTension® results in 45% (line 1 and 2) and 80% (line 3 – which is working in the same direction as the ShoreTension®) reduction of the maximum mooring line loads. Applying two units reduces the loads in all lines by 80-90%.

![Figure 13: Passing ship loads (surge) on the single moored ship for different mooring systems (bow-in mooring)](image)

<table>
<thead>
<tr>
<th>Maximum mooring line load [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line no.</td>
</tr>
<tr>
<td>Conventional</td>
</tr>
<tr>
<td>Stronger lines</td>
</tr>
<tr>
<td>Optimized</td>
</tr>
<tr>
<td>ShoreTension</td>
</tr>
<tr>
<td>2x ShoreTension</td>
</tr>
</tbody>
</table>

Scenario E: single moored ship vs. side-by-side moored ships

From the passing ship load computations (output of Model 2) it was concluded that peak surge are higher for each of the two ships moored in a side-by-side configuration compared to the single moored ship, see also Figure 14. The inner ship in the side-by-side configuration experiences higher surge forces (+15-20% compared to the single moored ship) than the outer ship (+10-15% compared to the single moored ship).

![Figure 14: Passing ship loads (surge) on the single moored ship and side-by-side moored ships (bow-in mooring)](image)

1 Loads in ShoreTension® line(s) not listed. In the investigated scenarios, loads stay at or below the setting of the unit (20t).
From the dynamic mooring simulations (output of Model 3) it was concluded that the maximum loads for the side-by-side configuration are significantly higher compared to the single moored ship. In a side-by-side configuration both ships are moored relatively stiff to each other. Therefore, they move in first instance (as passing ship loads are similar) almost parallel without large relative motions between the ships. Ultimately, the lines of the ship moored to the quay have to counteract the loads on both ships. This means that this mooring lines are much higher (more than double) loaded compared to the lines of the single moored ship. In below table the maximum load in lines no. 1 and 3 are presented for different scenarios.

<table>
<thead>
<tr>
<th>Case</th>
<th>single ship</th>
<th>side-by-side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>line 1</td>
<td>line 3</td>
</tr>
<tr>
<td>175 m tanker passing at 60 m distance with 10 knots</td>
<td>235 kN</td>
<td>155 kN</td>
</tr>
<tr>
<td>5 m water depth in the basin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>175 m tanker passing at 60 m distance with 8 knots</td>
<td>105 kN</td>
<td>75 kN</td>
</tr>
<tr>
<td>5 m water depth in the basin</td>
<td>(-55%)</td>
<td>(-50%)</td>
</tr>
<tr>
<td>175 m tanker passing at 60 m distance with 10 knots</td>
<td>220 kN</td>
<td>145 kN</td>
</tr>
<tr>
<td>6.5 m water depth in the basin</td>
<td>(-10%)</td>
<td>(-5%)</td>
</tr>
</tbody>
</table>

Conclusions
From the results it can be concluded that:

- Ships can be moored safely in the new harbor even under the worst case passing ship conditions, but only under certain conditions (e.g. no side-by-side mooring).
- Taking into account free surface effects is very important when simulating passing ship effects in side harbors next to fairways. When using only a double body flow model, several reflections are missing in the passing ship load time signal and also peak loads are significantly lower.
- The berth closest to the fairway is the most affected by the passing ships.
- Surge forces are dominant as the axis of the moored ships’ is almost perpendicular to the passing ships’ track. The presence of the quay wall strengthens this effect.
- The loads caused by the passing seagoing ship are larger compared to the loads caused by the inland ship. This is mainly caused by the larger beam and draught and related smaller under keel clearance of the seagoing ship.
- The following measures caused as expected lower passing ship loads: decreasing the passing speed, increasing the passing distance and deepening the harbor basin.
- The impact of different mooring system parameters (line strength, pretension, line arrangement) on the moored ship motions and resulting loads in the mooring system can be significant. As in reality the variability in line strengths is large and it is difficult to monitor actual line strength and pretension, this is an important factor of uncertainty.
- Applying the ShoreTension® device(s) results in a significant reduction of the moored ship motions and related mooring system loads. It also prevents the attached line from becoming slack (or overloaded), which is particularly important in tidal areas with fluctuating water levels resulting in a constant change of pretension.

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Keywords:  
Prototype observation; navigable flow condition; hydraulics; ship trial  

Title:  
Prototype observation of navigable Safety of Inland River ships under complex flow conditions  

Abstract:  
The operation of navigation structures in inland waterway in China was greatly affected by the flood discharge of the dam, and the navigable flow condition of the downstream approach channel was an important factor for the navigation safety of ships. In this paper, prototype observation of hydraulics and ships were carried out in accordance with the navigable conditions of the downstream approach channel of Xiangjiaba ship lift in the Jinsha River of China. The characteristics of water surface fluctuation, velocity distribution, ship navigation and berthing conditions under flood discharge conditions were fully investigated. Through comprehensive analysis, the navigable safety of the ship were evaluated and some matters needing attention were suggested. It not only provided the basis for the navigable operation management of Xiangjiaba ship lift, but also provided a reference for other similar engineering navigable safety argumentation.

1 Introduction  
Recently, large verticle ship lifts have been built in the west of China. From 2016 to 2018, nearly ten large ship lifts for ship size 500 t or above were put into operation one after another. The hoisting height of these ship lifts were all above 60 m. Navigation safety for ships to pass through ship lifts became an important issue. However, most of ship lifts in China were built in the mountainous river of the west, and were affected by the water fluctuation caused by power generation and flood discharge\(^1\). Because of the narrow valley of the river, the downstream water level was changing quickly and drastically when the flow out of the reservoir varies. Not only the docking of shiplift but also the ship security was affected\(^2\). The flow conditions for navigation in the connection area between the approach channel and the main river was relatively bad\(^3\). It was concerned whether the navigation conditions met the requirements of the design code. The ship safety should be ensured when it got cross the connection area. Usually, two aspects should be considered to evaluate the navigation conditions and ship safety. First, the velocities in the concerned area including longitudinal velocity, cross velocity and return velocity were investigated for judgement with the code. Second, the real representative ships were employed for navigation trial. The ship navigation behavior could be observed for safety judgement\(^4\). In this paper, the safety of ship navigation of Xiangjiaba ship lift...
was studied. Flow pattern, velocities, water fluctuation in the connection area were measured. Also the ship navigation characteristics were investigated through field measurements. These prototype observed data were very useful for navigation safety evaluation.

2 Overview of the project

Xiangjiaba hydropower project is located in Jinshajiang River upstream of the Changjiang River. The project contains dam, hydropower station, discharging structure, shiplift and so on. Fig.1 shows the layout of the project. The waterway is class IV of China and 1000 t ship is considered to pass the dam through the shiplift. The effective dimension of the chamber of shiplift is 116.0 m×12.0 m×3.0 m (length×width×depth). The minimum navigation flow is 1200 m³/s and the maximum navigation flow is 12000 m³/s. The normal flow from eight hydroturbines is 6400 m³/s. The downstream approach channel is separated from the hydrodynamic water out of the reservoir by the long guide wall. Twelve mooring dolphins are set in the approach channel. The connection area between the approach channel and the main river is suffering the strong interaction of dynamic water and static water. Some bad flow patterns such as oblique flow, return flow and waves may take place. According to China’s design code, the width of the connection area is equal to the distance between the end of guide wall and the side of the river and the length is equal to twice the length of representative ship. The red frame in Fig.1 is the connection area (200 m × 78 m) and it is the main study objective in this paper. The design code requires that the longitudinal velocity, lateral velocity and return velocity should be less than 2.0 m/s, 0.3 m/s and 0.4 m/s respectively. Fig.2 shows the photos of the project and test ship.

![Fig.1 Layout of Xiajiangba shiplift and downstream approach channel](image1)

![Fig.2 Photos of the project and test ship](image2)

3 Flow conditions for navigation

The hydrodynamic characteristics in the connection area under different flow and operation mode were observed. The minimum navigation flow 1200 m³/s without flood discharge, units flow 6400 m³/s without flood discharge, flow above 6400 m³/s with flood discharge were considered. One typical ship of 1000 t was selected for navigation characteristics test. The ship size was 58 m×10.8 m×2.4 m (length×width×draught).

3.1 Flow pattern in the connection area

When the project ran without flood discharge, even the flow up to 6400 m³/s, the water surface of the downstream was very calm. Fig.3(a) showed the flow pattern in the connection area. Just small range return flow appeared near the left bank. So the flow pattern was good without flood discharge. However, when the gate opened to discharge flood based on the units flow, even the discharging flow less than 1000 m³/s, strong
water fluctuation happened in the downstream. Fig. 3(b) showed the flow pattern. The sharp fluctuation was moving from the middle of the river to the left shore. It could be predicted that the wave would have a great effect on the ship rolling and drifting. So flood discharge was an important factor for the safety of navigation.

![Different flow patterns in the connection area](image)

Fig. 3 Different flow patterns in the connection area

3.2 Velocity in the connection area

Different methods were used to measure the velocity in the connection area under different conditions. ADV current meter was employed when the flow was relatively small without flood discharge. The measuring device was fixed in a boat and GPS was used for location of measuring points. It was important to keep the boat stability in the measuring process. So the velocity could be got directly while some errors existed in the result. When the project discharged flood flows the hydrodynamic condition became worsened immediately. It was difficult to maintain the boat stability in the connection area. So a new method was adopted to measure velocity under the condition. A floating ball with an embedded GPS that tracks flows well was put in the concerned area. The ball would move with the current. The position of the ball was obtained at all times. As such, the velocity could be calculated according to distance and time. Although the measuring points could not be fixed in the connection area, it was an effective method for current velocity measuring under the terrible condition. Fig. 4(a) showed the velocity distribution in the connection area at the flow of 4500 m³/s without flood discharge. It could be found the longitudinal velocity and lateral velocity were all small. While the return flow velocity was relatively big. The maximum value was about 0.7 m/s and exceeded the requirement of the code. But the area exceeding the standard was mainly concentrated near the shore. The green lines in Fig. 4(a) was the tracking lines of representative ship across the area for several times between the main river and the approach channel. The ship navigation track zone did not pass through the exceeding standard area of return flow. Fig. 4(b) showed the velocity distribution in the connection area at the total flow of 7000 m³/s including 1000 m³/s flood discharge. The velocities increased with the increasing flow. The longitudinal velocity was still less than 2.0 m/s, but the cross velocity and return velocity of small part range exceeded the standard. The maximum cross velocity and return velocity were 0.68 m/s and 0.82 m/s respectively. The exceeding area was also in the return flow zone. Although the velocity could not meet the requirement of the code, the ship might still go through the connection area safely as a result of its advanced driving performance. So the ship trial was needed to investigate the ship behavior across the concerned area.

![Velocities in the connection area under different conditions](image)

Fig. 4 Velocities in the connection area under different conditions

3.3 Wave in the connection area
From above pictures of flow pattern under different conditions, it could be found the water level fluctuation was affected significantly by flood discharging. The wave was also an important factor for navigation safety. Therefore, water fluctuation characteristics in the connection were investigated as well. A wave sensor was set at the end of the guide wall to observe the fluctuation of the water surface under the above two operation conditions. Fig.5(a) showed the water fluctuation in the connection area at the flow of 4500 m$^3$/s without flood discharge. The maximum wave height was about 10 cm. Fig.4(b) showed the water fluctuation in the connection area at the total flow of 7000 m$^3$/s including 1000 m$^3$/s flood discharging. The maximum wave height measured in the connection area was up to 100 cm, which was ten times of that without flood discharge. So the water fluctuation induced by flood discharge was very terrible although just 1000 m$^3$/s in the total flow of 7500 m$^3$/s. According to the experience of Three Gorges Project, the maximum wave height should be controlled within 50 cm. So attention should be paid to the stability of ships under large fluctuations when they go through the connection area.

![Graph](image1)

(a) 4500 m$^3$/s without flood discharge  
(b) 7000 m$^3$/s including 1000 m$^3$/s flood discharge

**Fig.5** Water fluctuation in the connection area under different conditions

4 Characteristics of ship navigation and mooring force

The behavior of the test ship going through the connection area was investigated under different conditions. According to the observed results of hydrodynamic parameters, the ship rolling under the water fluctuation induced by flood discharge should be concerned. Meanwhile, in order to ensure the ship berthing safety, the mooring force of the test ship at the dolphins in the downstream approach channel was measured.

4.1 Ship navigation characteristics

Fig.6 showed the ship rolling angle in the navigation process from downstream main river to the approach channel under different conditions. Fig.6(a) was the ship rolling under 4500 m$^3$/s without flood discharge. The rolling angle was very small and the maximum value is less than 0.5°. The ship was very steady in the whole process without flood discharge. Fig.6(b) was the ship rolling under the total flow of 7000 m$^3$/s including 1000 m$^3$/s flood discharge. The rolling of the ship under the condition of flood discharge was obviously larger than that of the non-flood discharge. Especially when the ship entered the approach channel from the mainstream through the connection area, the rolling fluctuated greatly. And after entering the diversion channel, it was still affected by the wave and the rolling fluctuation of the ship was still large. The maximum rolling angle was about 3° and took place in the connection area. So it was certificated the connection section was critical for the safety of the navigation ship.

![Graph](image2)

(a) 4500 m$^3$/s without flood discharge  
(b) 7000 m$^3$/s including 1000 m$^3$/s flood discharge

**Fig.6** Ship rolling in the navigation process under different conditions

The rolling of representative ships under other working conditions was also observed. The statistics of observed working conditions and tilting extremes were shown in Table 1. Three ships were all the size of
1000t, which were only different in the power of the main engine. It could be found that the rolling of the ship became larger and obvious as long as there was flood discharge. From the point of view of different flood discharge, the maximum rolling angle remained unchanged with the increase of flood discharge, which was basically kept at about 3°~4°.

### Table 1 Extreme value statistics of ship rolling under different conditions

<table>
<thead>
<tr>
<th>Ship</th>
<th>Total flow (m³/s)</th>
<th>Flood discharging (m³/s)</th>
<th>Navigation direction</th>
<th>Maximum rolling angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chuanlin No.6</td>
<td>7000</td>
<td>1000</td>
<td>upward</td>
<td>2.674</td>
</tr>
<tr>
<td>(unloaded)</td>
<td></td>
<td></td>
<td>downward</td>
<td>2.789</td>
</tr>
<tr>
<td></td>
<td>7500</td>
<td>1500</td>
<td>upward</td>
<td>3.169</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>downward</td>
<td>2.877</td>
</tr>
<tr>
<td>Xinglong No.2</td>
<td>7000</td>
<td>1000</td>
<td>upward</td>
<td>3.319</td>
</tr>
<tr>
<td>(loaded)</td>
<td></td>
<td></td>
<td>downward</td>
<td>3.384</td>
</tr>
<tr>
<td></td>
<td>7500</td>
<td>1500</td>
<td>upward</td>
<td>2.956</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>downward</td>
<td>4.110</td>
</tr>
<tr>
<td>Jiangning No.2</td>
<td>7500</td>
<td>1500</td>
<td>upward</td>
<td>2.273</td>
</tr>
<tr>
<td>(unloaded)</td>
<td></td>
<td></td>
<td>downward</td>
<td>2.976</td>
</tr>
<tr>
<td></td>
<td>8000</td>
<td>2000</td>
<td>upward</td>
<td>3.536</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>downward</td>
<td>3.452</td>
</tr>
<tr>
<td></td>
<td>8500</td>
<td>2500</td>
<td>upward</td>
<td>2.567</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>downward</td>
<td>1.786</td>
</tr>
</tbody>
</table>

### 4.2 Mooring force characteristics

Under the condition of flood discharge, the downstream approach channel fluctuated greatly. When the ship was moored by the pier downstream waiting to pass through the ship lift, the ship was rolling and heaving under the action of waves. Two cables at the bow and stern of the 1000 t ship were tied to two piers, and the tension curves of the cables under the condition of total 7000 m³/s discharge including 1000 m³/s flood discharge was shown in Fig.7. It could be seen the tension of the bow cable was relatively large. The maximum tension was about 110 kN, but the mooring force in the design code of China is 35 kN for 1000 t ship. The mooring force of the ship far exceeded the specified value of the code. Table 2 showed the comparison of mooring forces between no flood discharge and flood discharge. Clearly, flood discharge made the mooring force larger especially in the approach channels of upstream and downstream.

![Fig.7 Mooring force of 1000t ship at the downstream dolphin](image)

### Table 2 Ship mooring forces under different conditions

<table>
<thead>
<tr>
<th>Ship position</th>
<th>Maximum mooring force (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No flood discharge (4500 m³/s)</td>
</tr>
<tr>
<td>Upstream approach channel</td>
<td>1.30</td>
</tr>
<tr>
<td>Lift chamber</td>
<td>6.54</td>
</tr>
<tr>
<td>Auxiliary lock</td>
<td>6.32</td>
</tr>
<tr>
<td>Downstream approach channel</td>
<td>1.10</td>
</tr>
</tbody>
</table>

### 5 Safety analysis

Prototype observation showed that there was a large return and transverse flow velocity in the connection area, and the water surface fluctuated strongly during flood discharge, and some regional flow velocity and wave height exceeded the requirements of the code. Because the ship performance was...
improved, the ship navigation safety could not be judged directly just according to the hydrodynamic parameters. Referring to the relevant data, the limit rolling angle of the test ship was 10.4°. From the safety point of view, it was considered that the ship rolling angle should be less than 10°. Considering the comfort of the staff on board, the rolling angle should be controlled below 4°. From ship test, the maximum rolling angles of the ship were 3°~4° under different conditions of flood discharge (1000 m³/s, 1500 m³/s, 2000 m³/s and 2500 m³/s), and the rolling angle of the representative ship was acceptable. In addition, the ship mooring force was more than the code under the condition of flood discharge, but the safety factor of 4~8 times was taken into account in the design of the cable and pier. So the safety of ship berthing was not affected. However, attention should be paid to the physical and mental health of the staff on board. Therefore, under the tested flood discharge conditions, the navigation of the ship was safe according to the hydrodynamic parameters, ship navigation characteristics and ship berthing conditions. However, when the flood discharge increased step by step, the stability of the ship still needs to be tested.

6 Conclusions

The navigation flow conditions in the downstream of hydropower project of mountain river is bringing great challenges to the safety of ship navigation especially under the condition of flood discharge. It is of great significance to demonstrate the safety of navigation ships by hydrodynamic prototype observation and ship trial. The observation results in this paper provide the basis for the navigation safety management of Xiangjiaba Shiplift, which can also be used for reference in other similar projects.

Acknowledgements

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Keywords:  
Squat, midship sinkage, dynamic trim, inland vessels, inland waterways, validation, model test results

Title  
Validation of squat formulas for inland vessels

Abstract  
Several empirical squat formulas are available in literature. This paper validates four of them with the results of model tests that are conducted at MARIN, to conclude on the best squat method for inland vessels.

Introduction  
The CoVadem initiative aims at providing near real-time and expected water depth information of inland waterways in Europe, based on continuous water depth measurements by a large number of inland ships during normal operation. Currently, more than 80 ships are participating the CoVadem network and are equipped with the necessary instrumentation. Measured underkeel clearance, the ship draught and position data are transferred to a CoVadem cloud service. Actual water depth is calculated by summing the underkeel clearance with the ship draught at the start of the voyage and the squat (the combined dynamic midship sinkage and trim effects) both at the location of the depth transducer. In average operational conditions for inland ships, midships sinkage is expected to be approximately 10 cm and dynamic trim some centimetres over the ship length. In extreme conditions with relatively high ship speed through water and small underkeel clearance in a narrow waterway, midship sinkage can probably increase to approximately 40 cm with 10 cm trim over the ship length. For an accurate water depth calculation, the best squat formula available for inland ships is to be used.

This paper compares four squat formulas with model tests conducted at MARIN. Some squat formulas only provide a mean or maximum squat and no dynamic trim. However, most inland ships participating in CoVadem measure the underkeel clearance close to the bow, making the dynamic trim important. Therefore, only squat formulas are selected that also yield a value for the dynamic trim. Also, the formula should be valid for restricted waterways. The selected methods are Barrass (2006), Ankudinov (Briggs 2009), Tuck/Stocks (Stocks 2002) and Römisch (1989).

Selected squat formulas
Barrass (2006) is a straightforward prediction method that fulfils these requirements. It is not meant to be the most accurate method, but should give a quick estimate of the order of magnitude of the maximum squat in the early design phase of a waterway. Barrass has analysed 600 results measured on ships and ship models.

The squat $Z$ at bow and bow down trim are defined as:

$$Z_{bow} = \frac{C_{B}S^{0.81}V_k^{2.08}}{20} \ [m], \ trim = K_{i}Z_{bow} \ [m]$$

With

$C_{B}$ = block coefficient of the ship

$V_k$ = ship speed through water [knots], and

$S$ = blockage factor of the ship in the waterway $= BT/(W_{mm}H)$

$B$ = ship breadth moulded [m]

$T$ = draught midships [m]

$H$ = water depth [m]

$K_i$ = trim coefficient

$W_{eff}$ = width of influence $= 7.04B/(C_{B}^{0.85})$

The Ankudinov method is a semi empirical method in which the coefficients have been deduced using hydrodynamic methods and systematic model tests (Briggs 2009). It has been modified several times since 1996 and in 2009 a validation was published against model tests and full scale data.

$$Z_{mid} = \left(1 + K_p^5P_{Hu}P_{F \rho}P_{h/T}P_{Ch1}\right), \ trim = 1.7P_{Hu}P_{F \rho}P_{h/T}K_{tr}P_{Ch2}$$

With

$K_p^5$ = propeller parameter

$P_{Hu}$ = ship hull parameter

$P_{F \rho}$ = ship forward speed parameter

$P_{h/T}$ = water depth effect parameter

$P_{Ch1}$ = restricted waterway parameter

$P_{Ch2}$ = vessel trim parameter

$K_{tr}$ = trim coefficient

$P_{Ch2}$ = channel effect trim correction parameter

Tuck (1966) published a squat equation based on slender-body potential theory, for shallow water of infinite width. This equation is the basis for many other squat formulas. Hoof (1974) simplified Tuck’s method. Huuska (1976) extended Hoof’s work to include waterways of restricted width by adding a correction factor (Ks) for waterway width that Guliev (1971) had developed (PIANC 2014). Probably, Huuska’s and Guliev’s work are based on model test results. Stocks (2002) presented a version with trim component.

$$Z_{bow} = 1.46 \frac{V}{L_{pp}^2} \frac{F_{nh}^2}{\sqrt{1-F_{nh}^2}} K_S + 0.5 L_{pp} \sin \left(\frac{V}{L_{pp}}\right) \frac{F_{nh}^2}{\sqrt{1-F_{nh}^2}} K_S$$

With

$V$ = ship volumetric displacement [m$^3$]

$L_{pp}$ = ship length between perpendiculars [m]

$F_{nh}$ = Froude number based on the undisturbed water depth $= V/(gh)^{1/2}$, with $V$ [m/s], $h$ = water depth [m], $g$ = acceleration of gravity [m/s$^2$]

$K_S$ = value for restricted waterway
Römisch (1989) is one of the formulas in PIANC (2014) and is based on model experiments including different fairway configurations.

\[ Z_{bow} = C_V C_F K_{\Delta T} T, \quad Z_{stern} = C_V K_{\Delta T} T \]

With

- \( C_V \) = correction factor for ship speed which depends on the factor speed/critical speed
- \( C_F \) = correction factor for ship shape, \((10C_B/L_{pp})^2\)
- \( K_{\Delta T} \) = correction factor for squat at ship critical speed

**Discussion of squat formulas**

According to Barrass, the squat formula above, should be used for open water conditions. For narrower rivers, he gives other formulas that lead to higher squat. The width of influence (waterway width affected by the ship) calculated with the formula presented in this paper is already very small. Therefore, a further restriction was not considered necessary.

The model tests to validate Ankudinov were performed with self-propelled models of Panamax and Post-Panamax containerships in a range of waterway configurations. The full scale measurements were performed in the Panama Canal with containerships, bulk carriers and tankers; large seagoing ships in very narrow waterways. According to Briggs 2009-2 Ankudinov over predicted the bow squat (with a factor between 1.25 and 2.2, while the prediction of the stern squat is more accurate (factor 0.95 to 1.4). The best correspondence was found for the full scale comparisons.

Ankudinov, Barrass and Stocks all represented the restricted waterway effects by a speed independent factor. Römisch relies on a hydrodynamic approach for restricted waterways as he uses the critical speed \( V_{cr} \) of Schijf’s theory (1949, 1953) which is based on the continuity and Bernoulli equations. This formula is recommended by Pompeé (2015) for the squat calculation of inland ships and it is the only formula mentioned in PIANC (2019).

Römisch’s trim calculation depends on the block coefficient, the ship length and the breadth of the ship. For ships with dimensions of 110 m x 11.45 m and \( C_B \) between 0.82 and 0.94 that are mainly used in our study, the dynamic trim according to Römisch would always be stern down, and only wider or shorter ships would trim bow down. Barrass’s equation gives bow down trim for inland ships, as the \( C_B \) for these ships is above 0.7. Also Ankudinov and Stocks result in bow down trim for the ships used in our study.

All squat formulas have limitations. Pompeé 2015 summarized the limitations of many formulas. Only Römisch is suited for the large block coefficients of inland ships. All equations require \( h/T \) to be small (below 2.25). For Ankudinov it should be below 1.3, which only very rarely occurs in the case of inland ships.

**Squat formula comparison with MARIN model tests**

Results of propulsion model test by MARIN of three inland ships with a length of 110 meter and breadth of 11.4 meter have been used for the comparison: a twin-screw tanker, cargo ship and a triple-screw passenger ship. The tank width has been used as input for the waterway width in the empirical formulas. If not directly available, the sinkage from all sources is translated to midship sinkage by using the corresponding trim calculation.

With respect to CoVadem, a good squat formula, that contributes to the calculation of the CoVadem water depth information, is one that slightly underestimates the squat.

The figures and table show that based on the available model test results Römisch gives the best fit to calculate the midship sinkage. Ankudinov gave an overestimation of midship sinkage for all situations.
For the range of ships tested, Römisch always calculates a stern down trim, while the other formulas always calculate a bow down trim. The model tests sometimes give a bow down trim and sometimes a stern down trim. For this set of model tests, it was observed that the direction of trim is draught dependent. Below a certain draught, the ships tend to trim stern down. All ships have the same length and width, so it is impossible create a dimensionless variable that indicates the trim direction.
Conclusions and recommendations

The midship sinkage calculated by Römisch is found to have the best correspondence with the results from model tests carried out by MARIN. Generally, inland ships will trim with the bow down, contrary to the Römisch formula. However, the model tests indicated that inland ships with shallow draught often trim with the stern down. Unfortunately, none of the selected squat formulas correctly predicted the direction of trim for all model test results.

The midship sinkage of Römisch has been selected for implementation in the CoVadem production environment. The recommendation is to perform dynamic trim measurements on an inland ship to gather data that can be used to create a more accurate dynamic trim prediction model for inland ships.

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Building a strategic scheme for management and investments on the Walloon waterways network

Introduction

The Walloon waterways network covers 450 km of canalized rivers and canals, 82 locks, 6 ship lifts, 45 river weirs and 6 large reservoirs (Figure 1). More than 200 km of this network are currently accessible to vessels of ECMT class Va and larger. These waterways contribute to the North Sea - Mediterranean and to the Rhine - Alpine corridors of the Trans-European Network of Transport. The yearly traffic reaches 40 million tons, or 1700 million tons.km.

Recently, the Walloon Government has fixed ambitious objectives for its waterways in a Mobility Vision for 2030. This vision seeks for an improved mobility in Wallonia in terms of fluidity, safety and sustainability, for both persons and goods. Notably, the carbon emissions should be reduced by 40 %. Wallonia wants to be recognised as an efficient and sustainable region for transport and logistics. Regarding waterways, this will imply a significant modal shift for freight transport, with a share growing from 14 % in 2017 to 18 % by 2030.
New policies and instruments to support this Mobility Vision are to be detailed in a Regional Mobility Scheme. As a complement, a Strategic Scheme of Management and Investments will develop actions regarding the infrastructures: maintenance, upgrade and operation. It will overtop existing investment plans by providing a general overview and by considering more in detail the service level offered by the infrastructure. As a summary, the main purpose of the Strategic Scheme is to insure that the planned works will enable to offer the service level required for the wanted traffic growth, and to identify possible additional required actions.

**Methodology**

The Walloon waterways administration recently initiated the elaboration of this Strategic Scheme of Management and Investments 2020-2050. Four main steps are identified in this process (Figure 2): (1) Definition of objectives; (2) Diagnosis of existing infrastructure; (3) Identification of required actions; and (4) Prioritization and planning of actions. The process is supported by the definition of performance indicators. All the process also involves continuous and in-depth consultation with all stakeholders: waterways managers, port authorities, and users.

**Figure 2: Strategic Scheme: Elaboration process**

Different themes have to be considered by the Strategic Scheme, to reflect the multipurpose character of the inland waterway. The first theme focuses on fluvial transport. Getting inspiration from the “Guidelines towards achieving a Good Navigation Status” prepared for the European Commission, hard and soft criteria have to be considered. Hard criteria concern the waterway dimensions (lock chambers, fairways, admissible draft and air clearance, etc.); and their theoretical and practical capacity (travel time, locking time, opening time, actual availability of the infrastructure, etc.). Soft criteria concern the service to traffic and ancillary services (RIS, traffic management, mooring facilities, etc.). Additional themes linked to transport will cover port infrastructures and services, including development perspectives. Second set of themes will address other functions of the waterway: water management (water resources for navigation, flood management, water supply); environment (sediments, ecological continuity, habitats, etc.); mobility (soft mobility on service roads); tourism (pleasure navigation, bathing areas, etc.); and hydropower.

Multiple performance indicators may be defined in each theme, to reflect its complexity. For each performance indicator, a target value will then be fixed. The different objectives have to be compliant with the global traffic growth objective fixed by the government, but also with the European rules for Trans-European Networks, and the European Agreement on main-inland waterways. They should additionally account for existing and reasonable technical constraints. A long-term perspective should be considered at this stage, including notably the impact of climate change, but also emerging technologies in transport. Then, the initial value of each indicator has to be assessed, and possible actions to improve its status can be listed. These actions can be building new infrastructures, planning maintenance or improvement works, but also modifying procedures or rules to smoothen the traffic. Resources required for each action will be estimated in terms of budget, human resources, time, etc. Lastly, the different actions will be prioritised to elaborate a
long-term planning. Periodic evaluations and updates will be operated during the execution of the action plan.

Specific care is devoted to the definition of the performance indicators, as they support all the process. Usual indicators focus on results, like e.g. the total tonnage of freight moved on the waterways. Such information is valuable but only indicates the network performance a posteriori. Indicators devoted to the means should therefore be preferred, like e.g. the effective capacity of the locks or the number of available mooring/loading quays. This will help to ensure a priori that the infrastructure offers the proper level of service.

Ideally, the indicators of the Strategic Scheme should be summarized in a compact dashboard. This implies that indicators related to similar sub-themes will be aggregated in more general indicators, using appropriate weighting. For geographically distributed information, the data related to each network section will e.g. be weighted by the actual traffic observed on the section. Threshold values will also be associated to the indicators. In some case, the threshold could reflect the minimum local value instead of the weighted average.

For practical use, the indicators should also be based as much as possible on existing data. Notably, traffic predictions are required to check that the future infrastructure will offer the adequate level of service and capacity. In the present development, it was chosen to estimate the future traffic from the current traffic and a global growth rate based on the government objectives rather than from economical trend analyses. The later may indeed face difficulties to account for disruptive actions and their consequences.

**Preliminary developments**

At the time of submitting this communication, the elaboration process is still under way, but some preliminary comments can be formulated.

As far as the physical capacity of the network is concerned, most of the future objectives are already fixed by the existing investments plans. Several lock and fairway upgrades are already plan to enable traffic of larger vessels. Some future upgrades will be questioned within the scheme. Most of them would require works probably technically or economically not feasible. For the later, feasibility studies could be suggested as preliminary action.

First analyses also highlighted a lack of data for some themes or sub-themes. First actions will therefore focus on the collection of currently non-centralised data. This would concern for example the effective availability of the locks, the equipment of mooring places, the energetic performance of equipments, etc.

Actions will also focus on the improvement of maintenance processes, to improve the network reliability. This would increase its attractiveness for new freight. It is also a pre-requisite for implementing remote control of the locks and weirs, as foreseen in a near future.
Romanian Inland Waterways Transportation System – Engineering and Maintenance

1. Generalities. Romanian Inland Waterways Transportation (IWT) System

The main components of the IWT System in Romania are located in the southern part of the country (figure 1) and are represented by (1) Danube River (2588 km navigable length, 1075 km in Romania) with its maritime connection Sulina Canal linking Danube Delta with the Black Sea (class VII) and the (2) Danube - Black Sea Canal (65km) (class VIc) with the smaller branch Poarta Alba - Midia Navodari Canal (31km) (class Va). Additionally the more than 100 years old (3) Bega Canal (44km up to the Serbian border-confluence DTD Canal) (class II) is still not fully rehabilitated for navigation and (4) Prut River is partly navigable upstream Giurgiulesti (border with R.Moldova) (class II) for restricted high water levels periods. The missing link, (5) Bucharest - Danube Canal a waterway with a designed shipping capacity of more than 24 million tonnes/year, a 19th century romanian key project is not yet completed.

Further on some current ongoing projects concerning maintenance and navigation conditions improvement for the main IWT components will be briefly presented.
2. Improvement of navigation conditions on the Romanian - Bulgarian joint sector of the Danube

Danube on the Romanian – Bulgarian joint sector is still a river very close to its natural condition with low waters / high waters variations of about 6.00 - 7.00 m without dams and locks (except Iron Gates 1 and 2 located far upstream) where permanent annual navigation conditions are difficult to achieve in the critical points (depths of minimum 2.50m for low water levels season). Following the principle than free flowing rivers are less and less navigable, those minimal depths of 2.50m are more and more difficult to be achieved.

According the "Convention on the Navigation on the Danube", the navigation conditions on the Danube sector between km 845.5 and km 375 are the responsibility of the two riparian countries, Romania and Bulgaria. On the basis of the Romanian-Bulgarian bilateral agreement, the two states defined their responsibility sectors, on the Danube joint sector, as follows: between km 845.5 and km 610, the responsibility for maintaining the waterway belongs to the Romanian part and between km 610 and km 375, to the Bulgarian part.

Danube fairway maintenance works is carried out by the two Romanian and Bulgarian administrations, AFDJ Galati and IAPPD Ruse. In order to ensure minimal navigation conditions recommended by the Danube Commission, maintenance works are currently being carried out through topobathimetrical survey, signaling and dredging activities. Due to the characteristics and dynamics of the bed morphology, the maintenance of minimum navigation conditions through dredging works are effective over a short period of time. In this respect, it is very important to study the geomorphological and hydrological conditions, which influence this Danube sector, in order to elaborate complex technical solutions, which will help to improve the navigation conditions and also have a minimal impact on the environment. The design of the various structures include calculations, load assessments and stability conditions (groins, embankment structures, bottom sills, chevrons). Navigation conditions for convoys (with tug-boat/pusher) both downstream-upstream shall be analysed over the river sectors where the current flow velocities increase in the navigable channel area. This major project for the development of Danube river infrastructure has as its main objective the improvement of the navigation conditions in order to increase traffic safety and number of days in which minimal conditions of navigation and the development of traffic on the Rhine - Danube corridor are secured.

The project was launched with a Feasibility Study, Environmental Impact Assessment, and an Appropriate Assessment for Natura 2000 sites. The Feasibility Study, along with complementary studies (EIA and Appropriate Assessment) were finalized and delivered in 2011. According the recommendations of the Danube Commission, for the proposed sector, the recommended fairway width is 180 m and the minimum
depth at ENR of 25 dm and the radius of 1000 m. For sectors where the minimum depths are not secured, a width reduction up to 150 m was allowed. A radius reduction from 1000m up to 750m was permitted when the geomorphologically conditions were not favorable. Some of the technical solutions developed in this study have become inapplicable due to the important morphological changes occurring in different sectors of the river, actually an updated version of the study is ongoing.

In the current situation in periods with low water levels, corresponding to a Danube flow of less than 3000 mc/s, no minimal navigation conditions are ensured throughout the year, generating critical points for navigation. Average number of days with secured navigation conditions is 280 days/year and the objective of this project is to increase this value up to 340 days/year, matching with a traffic gain of 20%.

On the Iron Gate II-Silistea sector, 12 critical points have been identified Garla Mare (Km 839-Km 837), Salcia (km 824-820), Bogdan-Secian (km 786-782), Dobrina (Km 762-756), Bechet (Km 678-673), Corabia (Km 632-626), Belene (Km 577-560), Vardim (Km 542-539), Iantra (Km 537-534), Batin (Km 530-520), Kosui (km 428-423), Popina (Km 408-401).

3. Maximal navigation speeds for Danube Black Sea Canal and Poarta Alba Midia Navodari Canal

Danube-Black Sea Canal (CDMN) and Poarta Alba Midia Navodari Canal (CPAMN) are the two waterways linking Danube with the Black Sea on a shorter way that the natural course via Sulina Canal. CDMN has a length of 64.4 km and is operating since 1984 and CPAMN has a length of 27.7 km and is operating since1987. For the two artificial navigation channels CDMN and CPAMN, aspects related to the maintenance of the infrastructure as well as the recent analysis of the maximum acceptable navigation speeds balanced with the current regulations will be presented.

The current period is characterized by an increase in the cargo traffic of ships transiting the main two romanian waterways CDMN and CPAMN but also by the navigation companies concern to increase the navigation speeds. The need to determine the maximum admissible speeds of channel navigation is closely related to the parameters of the waves produced (H, L, T, v) in the shore area where interaction with banks protections and sites geotechnical conditions occurs. The intention is to define admissible cruising speeds of vessels on the waterway, depending on the ship type, canal cross section and navigation conditions. On one side, unnecessary speed limitations should be avoided, but on the other side the stability of the canals banks has to be guaranteed and the safety of navigation conditions maintained.

The design parameters required to design the armour layers to resist normal hydraulic actions are maximum wave height / flow velocity , maximum rapid drawdown / excess pore water pressure and maximum drawdown velocity. All those parameters can be determined either by direct measurements, calculations (BAW code of practice) or numerical analysis-Computational Fluid Dynamics (CFD Fluent). We choose to use the numerical analysis CFD Fluent to determine those parameters and to verify the obtained parameters values, in-situ topographic high accuracy measurements have been performed.

From the CFD numerical analysis, the relevant values (significant waves, drawdown, speed / time drawdown, return current speed, instantaneous position at any time of the water surface have been obtained via numerical modeling. The hydraulic parameters computed earlier influence the critical depth at which a rock fill sliding of the bank protection can occur but also the pressure of pore water whose pulsating variation together with the geotechnical characteristics of the soil (permeability, internal friction angle, cohesion, volumetric weight) determines the technical design solution for the shore bank protection.

The study indicated areas for which the increase in drawdown causes instability for situations where the weight per square meter of rocks armour becomes inferior to the theoretical required weight, allowing floating and extraction from the armour of a number of blocks. Considering the empirical components of the calculation formulas and the imperfections of existing banks protections, it is proposed that a drawdown value larger than 30-40 cm should be considered as potentially dangerous for the resilience / stability and operational safety of bank protections for the two inland waterways. CFD software calculations concluded the next decisions. Fully loaded convoys should be are allowed to navigate up to 9km/h on the channel axis
and should reduce the speed to below 8km/h when crossing other convoys or ships; Empty convoys may navigate up to 12km/h in the channel axis; The sea going 5000 tons Cargo fully loaded are allowed to navigate up to 8 km/h on the channel axis and should reduce the speed to below 7km/h when crossing other convoys or ships; The passenger ships may navigate in the channel alignment at speeds of up to 14 km/h and should reduce the speed to below 8 km/h when crossing other convoys or ships. Those proposals have to be related with the safety navigation requirements of the Romanian Naval Authority. Also it has been suggested to place in critical banks protections stability areas a monitoring gsm/gps interconnected buoys network capable of presenting and recording, in real time, the state of agitation (waves) in the area of the shores, correlated with the passage of different convoys at different speeds.

4. Banks protection on Sulina Channel

Sulina Canal is 73 km long navigable waterway, has a depth of 24ft/7.32m and has to secure ship up to 25.000DWT traffic between the Black Sea and the Danube with romanian maritime ports of Tulcea, Galati and Braila plus the EU Corridor 7 Rhine-Main-Danube. Sulina Channel divides the Danube Delta in two almost equal parts and represents the main communication link for the local population in the region. Danube Delta constitute also a unique territory World Heritage Site / UNESCO Biosphere Reserve / wetlands / rivers / lakes / meadows / sand dunes / forests. For Sulina Channel there will be presented some aspects of the final design stage of banks protections and Sulina bar depth issues. Sulina Channel reconcile the requirements of different anthropogenic functions: Fairway for waterborne transportation / Flood storage and attenuation / Discharge of wastewater / Fishing and hunting / Irrigation / Drinking water / Recreation and natural functions: Evolution through morphological processes / Maintenance of hydrological balance / Maintenance of physical and biological processes / Provision of habitat / Continuity of sediment processes. The design philosophy was connected with environmental impact assessment, physical analysis, actual hydraulic verifications and morphological modelling. Design technical solutions considered to achieve overall safe navigation and environmental benefits of Sulina Channel within the next years. Also navigation generated loads on banks protections and maximal allowed speed (drawdown, return flow, stern/bow wave, slope stability) have been considered. The main issues solved in the feasibility study have been:

- **Tulcea arm diversion into St Gheorghe and Sulina to improve discharge and sediment transportation** (2D Numerical Flow Model) and further works to reduce Sulina inflow with groins/mole and simulation for different floods: 1%, 2%, 5%, 10%, 20%;
- **Entrance Channel sedimentation through Sulina Bar** (performing dredging on a regular basis at Sulina Bar to guarantee the minimum depth as defined by the International Danube Convention;
- **Banks Protections and new mooring structures**;

Maintaining the fragile balance between influx of water and sediments by Sulina Channel to the Danube Delta and also preserving the Danube Delta biodiversity and acceptance of floods allowing the accumulation of alluvial deposits between the dikes and the bank protections will lead to a land restoration and dikes sheltering. Maintaining the fairway for navigation on Sulina Channel was the final scope of work.
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EDF, exploitant 4.0 du multi-usage de l’eau


UN PRODUCTEUR HYDRO-ELECTRIQUE DE REFERENCE

EDF assure l’exploitation et la maintenance de 8 centrales hydroélectriques sur le Rhin. Les centrales hydroélectriques du Rhin, dites « au fil de l’eau », exploitent en continu le débit du fleuve dérivé par des barrages servant également à maintenir un débit minimum dans le cours naturel et assurer la sécurité des biens et des personnes en cas de crue.

Avec une puissance installée de 1400 MW, ce sont chaque année près de 8 TWh qui sont produits, soit 20% de la puissance hydraulique française, permettant d’éviter l’émission de plus de 3,5 millions de tonnes de CO2 par an dans l’atmosphère.

Produce de l’électricité en toute sûreté et sécurité est une priorité constante pour EDF. Pour atteindre un niveau de performance toujours plus haut, EDF a mis en place un CCSH (Centre de Conduite et de Surveillance Hydraulique).

LA FIABILITE D’UN CENTRE DE SUPERVISION ET DE SURVEILLANCE

Véritable tour de contrôle destinée à superviser le fleuve et les aménagements hydroélectriques du Rhin en continu, le CCSH contrôle et commande à distance la chaîne des centrales et des barrages (hors barrage agricole) du Rhin pour en optimiser la production en fonction de la demande énergétique.

Pour les besoins de la navigation, le CCSH contrôle les niveaux d’eau dans les ports, le tirant d’eau et le tirant d’air sous les ponts.

Grâce à la collecte de prévisions hydrologiques et de mesures, le CCSH contribue également à la gestion des crues, en coordination avec les autorités françaises et allemandes.

Les aménagements et digues font également l’objet d’une surveillance rigoureuse et de contrôles permanents de la part des équipes d’exploitation : inspections visuelles ou par outils d’auscultation, relevés des niveaux piézométriques (compressibilité des liquides), relevés de fonds par bateau spécialement équipé afin de surveiller la sédimentation.
**DES e-Outils de Surveillance au Service d’Une Haute Performance**

Le CCSH intègre également une activité de surveillance des aménagements hydrauliques dans le but de détecter des précurseurs et de mettre en œuvre avec une grande réactivité des actions permettant d’éviter des incidents de fonctionnements.


**UNE GESTION PATRIMONIALE EXEMPLAIRE**

EDF, concessionnaire historique des aménagements hydroélectriques sur le Rhin exploite et entretient les ouvrages avec un haut niveau d’exigence patrimoniale.

Les écluses, quant à elles, font l’objet depuis 2012 d’un programme de rénovation d’envergure de près de 100 millions d’euros.
- Modernisation du contrôle commande, visant à en fiabiliser le fonctionnement
- Rénovation de l’ensemble des postes de commande des écluses
- Installation de systèmes vidéo sur chaque écluse afin de mieux en surveiller les éclusages et le fonctionnement des écluses
- Rénovation des équipements lourds : portes, mécanismes de manœuvre, …

Ce programme a pour objectif de garantir un haut niveau de disponibilité des installations et d’en sécuriser le fonctionnement.

**UN OPÉRATEUR DE LA VOIE D’EAU TOURNE VERS L’AVENIR**

EDF assure la navigation libre et gratuite sur le Rhin et veille à la sécurité au bord du fleuve. Pour compenser la pente naturelle du Rhin, 132 mètres entre Bâle et Lauterbourg, chaque centrale hydroélectrique est couplée à une écluse qui permet aux navigants de franchir la chute utilisée pour produire de l’hydroélectricité.

Equipées de deux sas, les écluses permettent le passage des bateaux 24h/24, 7j/7. 49 éclusiers assurent la navigation en continu, 365 jours par an. Agents assermentés, ils font respecter au quotidien le RPNR (Règlement de Police de la Navigation sur le Rhin) en allemand, langue officielle sur le Rhin.

L’enjeu économique de la navigation est important puisque le Rhin relie Rotterdam, premier port maritime européen aux ports fluviaux de Strasbourg, de Mulhouse-Ottmarsheim et de Bâle. L’enjeu écologique aussi : 1 péniche peut transporter 2200 tonnes de marchandises et éviter la circulation de 110 poids-lourds.

L’enjeu touristique est également de plus en plus prégnant avec le développement de la croisière fluviale à bord de paquebots née sur le bassin Rhin-Main-Danube. Aujourd’hui encore, ce bassin est moteur sur ce produit à l’échelle européenne et la flotte continue de croître. Les compagnies développent de manière considérable leur activité dont le Rhin supérieur constitue un des maillons du bassin. Avec des unités de 135 mètres et une offre de croisières à thème de plus en plus large, c’est un secteur en pleine expansion.

Tourné vers l’avenir, EDF, opérateur majeur de la voie d’eau a modernisé ses écluses grand gabarit permettant l’éclusage de ces unités de grande taille dans des conditions de haute fiabilité et performance.

Il a développé, en partenariat avec VNF un outil au service des navigants, permettant la mise à disposition connectée d’une information fluviale efficace et moderne.

Il contribue ainsi à l’essor de la navigation sur le Rhin et à l’amélioration de la gestion du trafic en lien avec les acteurs clé de la navigation.

**L’INNOVATION AU SERVICE DU TERRITOIRE : DEVELOPPEMENT ECONOMIQUE**

L’hydro-électricité, première des énergies renouvelables, participe à l’aménagement du territoire. Elle a été et demeure un facteur essentiel de développement pour certains territoires grâce aux retombées économiques
locales liées à la production d’électricité, mais aussi aux autres usages qu’elle permet comme l’alimentation en eau potable, l’irrigation, le tourisme, la navigation...
Le développement économique et solidaire du territoire renouvelle la mission de service public dans laquelle EDF est engagée en France et particulièrement en Alsace depuis déjà longtemps.

➢ L’INNOVATION AU SERVICE DU TERRITOIRE : DEVELOPPEMENT ENVIRONNEMENTAL

En tant qu’acteur du multi-usage de l’eau, EDF met au cœur de ses projets la préservation de l’environnement et de la biodiversité ainsi que la continuité piscicole sur le Rhin et la restauration des écosystèmes du Rhin.
« Sur la vallée du Rhin, tous les seuils ou barrages dans le lit du Rhin sont équipés d’ouvrages destinés à faciliter la circulation piscicole et les trois usines à l’aval exploitées par EDF sont également équipées de passe à poissons, permettant la migration vers les affluents principaux du Rhin Supérieur.
Ainsi, la passe à poissons de Strasbourg, inaugurée en 2016, est un aménagement remarquable par ses dimensions adaptées au débit du Rhin, mais également par son caractère novateur, puisqu’elle a été réalisée sous la forme d’une rivière reconstituée. Quant à ses caractéristiques techniques, elles correspondent aux meilleurs standards actuels.
Avec la mise en service de cet équipement, EDF contribue à faire de l’île du Rohrschollen un site naturel exceptionnel et exemplaire.
Tout comme sa grande sœur de Strasbourg, la passe à poissons de Gerstheim intègre une rivière reconstituée, appelée aussi passe naturelle, de quatre cents mètres de long, qui contourne la centrale hydroélectrique et ses équipements. Cette conception particulière de la zone de cheminement des poissons donne son caractère remarquable et novateur à la passe de Gerstheim. Rapides, courbes, rochers et graviers se succèdent, comme en milieu naturel, de manière à diversifier les écoulements de l’eau et à favoriser la biodiversité aquatique. Des fosses permettent aux poissons de se reposer et des blocs de pierre leurs servent d’abris pour se réfugier. Les migrateurs y trouvent des conditions de transit favorables et les espèces locales, des conditions de vie propices.
La passe à poissons de Gerstheim sera officiellement inaugurée le 6 juin 2019 permettant de rétablir la libre circulation des poissons jusqu’à l’Elz Dreisam, affluent allemand du Rhin, lieu de reproduction de poissons migrateurs.
Enfin, la concession de Kembs, est un projet exemplaire de mesures environnementales pour la restauration des éco-systèmes du Rhin.
5 mesures phares ont été mises en place en partenariat avec les acteurs régionaux :
- Augmentation significative dans le Vieux Rhin du débit minimum, dit «débit réservé»
- Rétablissement des apports naturels de gravier dans le Vieux Rhin
- Réalisation de 4 ouvrages pour améliorer la circulation des espèces animales
- Renaturation des milieux humides sur l’île du Rhin
- Construction, au pied du barrage, d’une nouvelle centrale hydroélectrique d’une puissance de 8,4 MW

Depuis 90 ans, par ses ouvrages hydroélectriques, ses écluses et son activité industrielle dans le secteur de l’énergie, EDF accompagne le territoire dans son développement économique, environnemental et sociétal. Il est aujourd’hui reconnu comme un exploitant hydroélectrique et concessionnaire de référence, centré autour du multi-usage de l’eau et résolument tournée vers l’avenir au service du territoire.
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Title:  
Guidelines for inland waterways in rivers  

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

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

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

For navigating, longitudinal current and a longitudinal current gradient are common features. The expectation is therefore that a limited additional fairway width is sufficient to compensate for the effects of current. This is supported by results from the literature. Several studies show that the variability in path width due to the combined effect of the human factor, instability of the ship and the effect of a longitudinal current fall largely within the manoeuvring margins [Ref. 3 and 4]. Based on observation of operational practice and results of manoeuvring simulations a lane of 1.3B (with B the ships beam) is used as base condition. BAW [Ref. 3] has processed experiments of the US Army Corps of Engineers with pushed convoys on the Mississippi and supplemented it with its own experiments with motor vessels to get an impression of the extra path width as a result of the longitudinal current. The tests involved a wide variation in ships with regard to length and width, a large variation in sailing speeds and flow rates, both up and down. A contribution from the current was visible, although there was little difference between upstream and downstream. The latter indicates that horizontal instational effects of the current are the most likely cause for the contribution to the basic path width of a vessel. Together with the assumption that $h=1.4T$ the following regression formula for the extra path width has been derived from the data:

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

with:

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

For most inland vessels with a sailing speed of 13 km/h through the water and a current velocity of 0.5 m/s, the extra path width ($\Delta b$) is about 0.3B. Upstream slightly larger than 0.3B, downstream slightly smaller. This is in line with the 1.3B basic path width above. With increasing flow velocity, the additional path width increases.

Based on the previous discussion it is recommended to take into account an additional surcharge on width of the lane of 0.1B for current velocities from 0.5 m/s to 1 m/s and a surcharge of 0.2B for current velocities higher than 1 m/s. Below 0.5 m/s no surcharge is required. The surcharge must be applied per lane and must be available at the draft of the loaded ship.

**Crosswind surcharge**

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

**Intensity surcharge**

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

The following formula can be used to derive the required additional fairway width:

$$\Delta b = c_l*(l-v-2050)^2+c_i*(in-30,000)$$

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

The coefficients \( c_i \) and \( c_i \) are:
• \( c_i = 3.6 \times 10^{-5} \);
• \( c_i = 0.00053 \).

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

**Width surcharge in bends**

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

![Figure 1](image1.png)

**Figure 1** Definition sketch for the extra path width (\( \Delta b \)) in a bend.

![Figure 2](image2.png)

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

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

Figure 2 illustrates the value for the factor \( C = \frac{1}{2}C_r^2 \) as it follows from Fisher’s formulas for a loaded CEMT Class Va vessel with a sailing speed of 13 km/h relative to the water. \( C = 0.25 \) is recommended by RVW2017 for current velocities less than 0.5 m/s. The factor is shown as a function of the water depth/draft ratio and the current velocity (positive for sailing downstream and negative for upstream). The calculated value is just above the recommended value. The factor decreases with decreasing \( h/T \) ratio. The factor increases sharply as the current increases.
The empirical model can only be used if there is no interaction between the bends in a river. If there is interaction, such as in short consecutive opposite turns, additional research is necessary. Also for smaller bend radii (R<4L), additional research using maneuvering simulation models is required.

**Line of sight (LOS) in bends**

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

[Ref. 3] Driving Dynamics of Inland Vessels, Bundesanstalt für Wasserbau (BAW), Karlsruhe, Germany, 2016.
Manoeuvring Models, Preliminary overwiev of project limits, Risk Assessment, Accurate collision frequencies determination, Reduction in Projects Costs and Time

Automated Methodology to Assess Navigable Areas of Long Rivers for different vessels and hydraulic-meteo conditions, including Nautical risk assessment for Accident frequency evaluation (grounding or collision)

Long rivers and navigable areas subject to new traffic and developments usually require assessment by detailed methodologies considering mathematical manoeuvring models, either autopilot fast-time models or real-time manoeuvring simulations.

- Real-Time Manoeuvring simulations provide very precise and reliable results incorporating human factor, allowing to determine the probability of sailing out of the navigable areas limits, with specific local conditions and more accurate results than those obtained by generic conservative formulation, but have a main disadvantage: the high timing and cost of assessing long stretches over tens or hundreds of kilometers.
- Fast-Time Autopilot models allow a preliminary assessment of the whole navigable area, independent of the length, in a reduced timeframe and cost. Moreover, allows to accurately determine the probability of grounding or collision of the vessel adrift for local conditions by performing thousands of manoeuvres, linking the results to the frequency of the environmental factors (water level, currents, wind, waves, ...), at different sections of the river.

Industrial and port areas in rivers usually have several terminals located along the shoreline, terminal after terminal, with vessels moving upstream and downstream continuously at a certain speed. Therefore, maritime and fluvial authorities have been paying special attention to nautical risks derived from events such as high traffic density or new nautical activities, which could lead to hazardous situations involving potential undesired consequences. In those cases, risk assessment is important to determine whether risk levels are acceptable, or mitigation measures are required.
This paper is focused on a methodology developed by SiporT21 for both, the automatization of manoeuvre simulations by means of autopilot fast-time manoeuvring models (SHIPMA in this case) and the nautical risk assessment of navigable areas. Particularly, the frequency of hazardous situations (grounding/collision) during navigation based on autopilot fast-time manoeuvring models and Real-Time Manoeuvring simulations.

This methodology allows to perform, in a short period of time and with a limited cost, hundreds or thousands of manoeuvres, varying vessel types and sizes according to local traffic distribution, hydraulic and meteo conditions, manoeuvring strategies (vessel speed, ...). The analysis of results, highly automated as well, provides very useful information in a very short time, based on hundreds of manoeuvres, to elaborate a proper insight of the whole system considering all variables (navigable area, vessels and hydraulic-meteo conditions), and even nautical risk assessments and a quantitative and detailed evaluation of the grounding/collision frequencies.

If the automatization process is performed for the assessments of navigable areas, the main results that can be extracted to be used in decision making and future assessments are:
- Required vs existing navigable areas (guaranteed fairway width and actual fairway width)
- Critical areas and conditions, to be later assessed in detail using more accurate tools (Real-Time Manoeuvring Simulation)
- Differences between vessels (type, size, loading condition, ...)
- Critical hydraulic-meteo factors (water levels, current, wind, waves, ...)
- Preliminary operational limits for access/Departure manoeuvres by linking the results with the frequency of the hydraulic and meteo conditions

The following image shows an example in which required navigable width, based on fast-time autopilot manoeuvres, is compared with available width, all together for different vessels and different drafts, and for the whole transit along the river.

![Image of a fast assessment of multiple scenarios](image_url)

In the figure it is easy to find critical areas in which available width is not enough for specific ship-environment scenarios, differences in vessel type and size. Bars (required width) exceeding the blue dotted line (guaranteed fairway width) indicate difficult areas to be analyzed, meanwhile red dotted line indicate fairway width at a guaranteed depth of 10.36 m. If several of these graphs are compared, operational limits and differences due to environmental conditions can also be determined.
If the automated process is used for assessing navigable risks, it has to be considered first that all Hazards Identified can be grouped in two main hazardous situations, which require different tools:

- Powered grounding or collision: It is an incident caused by human, technical or watch-keeping errors, in which the vessel sails with collision or grounding course and no evasion manoeuvres are performed.
- Drifting grounding or collision: It is an incident caused by vessel related failures such as total loss of steering and propulsion units, for instance, in which the vessel drifts with grounding or collision course.

The methodology is based on the usage of specific ship manoeuvring tools and simulation, therefore allowing to use specific numerical models for different types of vessels and loading conditions. The advantages of the methodology and tools developed by Siport21 consist on the determination of:

- Accurate grounding or collision frequencies for powered and drifting collision
- Based on accurate vessel numerical models with coefficients based on vessel type and loading condition
- Risk associated to a new terminal or new traffic can be determined
- Risk associated to overall increase of traffic can be determined
- Most adequate location of new terminals based on nautical risk assessments
- Accurate collision speed and course to be used in consequence analysis
- Critical environmental conditions for nautical risks, as well as critical areas and response times
- Assessment of mitigation measures as usage of tugs

![Figure 2. Emergency scenarios. Left is blackout at different sections to check interferences Right is vessel drifting after line break under different wind conditions](image)

The disadvantage of the methodology is its cost, mainly when powering collision/grounding frequencies are determined accurately, based on Real-Time Manoeuvring simulation, and not on empirical and generic values. Nevertheless, after a cost benefit-analysis this methodology proves worthy, as projects eventually considered non-feasible when applying a (conservative) deterministic approach can be demonstrated feasible if based on accurate probabilistic results. The larger the size and relevance of the project, the more interesting and useful.

Therefore, this methodology, that can be used both for the assessment of Navigable areas of different vessels under different scenarios and to evaluate and quantify grounding and collision frequencies is considered as the best tool. It allows to:

- Assess long navigable areas to gain a preliminary insight on the project limits, and it is recommended to be considered at the first stage of projects in rivers and long fairways.
- Determine quantitative collision/grounding frequencies either of vessel at navigation or against terminals on the river banks, giving insight and inputs for the quantitative consequence analysis, useful as well in detailed phases of the project.
1. Introduction

The transition towards natural river banks in the Netherlands has resulted in irregularities in shorelines and underwater banks. These irregularities and especially submerged banks affect water flow near the bank, placing unexpected and substantial manoeuvring loads on passing vessels. Ships therefore require additional lateral space in the fairway to correct for these effects.

The forces induced by an irregular bank on a typical 110-metre inland vessel are investigated by means of full-scale CFD\(^1\) calculations. The vessel is fitted with a single propeller and two spade rudders. Based on the results, a time-domain simulation model is developed, and the effect of the irregular bank on the ship motions is investigated through a large number of simulations. The irregular bank is modelled on the situation near Gennep on the Meuse river in the Netherlands, where unexpected behaviour of passing ships has been reported.

\(^1\) Computational Fluid Dynamics
Figure 2: Geometry of the fairway, including the underwater irregular bank.

The vessel considered is a typical 110-metre inland ship, with a beam of 11.40 m and a draught at rest of 3.50 m. The water depth in the fairway is 5.20 m. The ship sails upstream at 3.5 m/s through the water, with and without current.

This investigation follows a study conducted in 2017, where MARIN and Rijkswaterstaat investigated the feasibility of a numerical approach by comparing model tests with CFD calculations.

Figure 3: Photos of a model run and one of the obstacles used in these experiments, conducted by Deltares.

Results of that study showed that the hydrodynamic forces are well captured by the CFD results. Surge and sway forces showed similar trends and order of magnitudes. Computed yaw moments evidenced a shift in time with respect to the model test results. (Exer 2015, Oud 2017)

2. Modelling

The time-domain simulations of the situation shown in Figure 1 have been computed with the following inputs:

1. A manoeuvring model of the hull forces.
2. A mathematical model describing the forces induced by the irregular bank on the vessel.
3. An autopilot to control the ship's response.

Manoeuvring model

Designing a mathematical manoeuvring model is a major aspect of conducting manoeuvring time-domain simulations. Not only does the model include the forces induced by the hull sailing in the water, but it also contains the propeller and rudder effects, as well as the interaction between hull, rudder and propeller.

The hull forces are first predicted with an in-house simulation software based on slender-body theory. A second assessment of the hull forces is done by means of CFD calculations in shallow water with the MARIN package ReFRESCO (Oud 2018). In these calculations, the ship is in a captive set-up and sails at forward speed in different combinations of drift angle and yaw rate.
The results are used to define a mathematical model describing the hull forces as a function of the longitudinal and transverse ship velocities, and the ship yaw rate.

The rudder forces are calculated based on the airfoil theory. They also include various interactions with the propeller and the hull.

**Irregular bank**

The vessel is sailing in a confined fairway. Therefore, external forces are also applied to the ship. They are distinguished into two categories: bank forces induced by sailing along a regular bank, and forces induced by sailing along the irregularity.

The mathematical description of the forces induced by the bank and the obstacle are derived from CFD simulations. In these simulations, the ship is sailing along the fairway in a captive set-up, at a constant distance from the starboard bank. Three distances between the starboard bank and the starboard side of the vessel are investigated: 2.25B, 2.50B, and 2.75B, B being the ship beam. The analytical formulation includes both the suction effect of the bank and the obstacle-induced forces.

![Figure 4: Front section of the fairway with the ship sailing along the bank (3 distance from the shore).](image)

**Autopilot**

During the time-domain simulations, the ship is controlled by an autopilot. The latter aims to mimic the behaviour of (1) an actual onboard autopilot, and (2) the helmsman. Three modes are described to cover a large range of reactions. In configuration A (optimistic), the autopilot reacts instantaneously to any unexpected ship behaviour. In configuration B (intermediate), a delay is introduced to the autopilot reaction. In configuration C (pessimistic), no steering is applied and the rudder angle remains constant. In configurations A, B and C, the ship is sailing upstream.

**3. Sailed trajectory**

The free-sailing time-domain simulations have been conducted with the modelling described above (Bedos, 2019). Figure 3 displays the ship trajectory (at midship) of a single simulation. The black full line represents the bank at the keel level. The yellow hatched area is half-a-ship-width wide: an intersection with the ship track means the vessel collides with the bank. The right figure is a zoomed view, including ship position along the trajectory and rudder angles.

![Figure 5: Bird’s-eye view of the ship sailing in the fairway. Right:zoomed view of the ship sailing nearby the obstacle.](image)
The ship is first sucked towards the bump, before being pushed away when it reaches the hollow. Eventually, the vessel returns to its original straight course.

A systematic variation of the initial transversal position of the ship is shown in Figure 4. Each line represents the trajectory of the vessel (midship, centreline) for a single simulation. Results of the three autopilot configurations are displayed (from top to bottom: no delay, delay, no reaction).

![Figure 6: Bird’s-eye views of a ship sailing along the obstacle, with current, systematic variation, configurations A, B and C.](image)

The results of the vessel in configuration A (autopilot without delay) show that the ship is first sucked towards the bump, and is then pushed in the direction of the centreline soon after the hollow. The track deviation induced by the obstacle remains limited. A few vessels approaching close to the bank collide with the obstacle. The ship returns to an equilibrium state at $x_{\text{end}}$, all the tracks are parallel once again.

In configuration B (delay), the y-position deviation seems greater for the tracks that are the closest to the bank at $x_{\text{begin}}$. Nonetheless, the ship seems to always steer back to an equilibrium state at $x_{\text{end}}$. More tracks show a collision with the bump of the obstacle.

Configuration C represents the extreme case in which the rudder does not react to the autopilot near the obstacle. Track deviations are very large and for most cases the ship has crossed the fairway.
centreline before $x = 1000$ m. The vessels approaching close to the centreline are not influenced by the obstacle. Therefore, their track is not changed as those ships do not leave their equilibrium state.

The simulations show that the range of rudder angles during one run remains limited. In configuration A, the difference between the minimum and maximum rudder angles during a run never exceeds 15 deg, which is reached when the ship sails the closest to the bank. In configuration B, the range of rudder angles is about 20 deg at any position in the fairway.

4. Conclusion

Important conclusions demonstrated by the research presented here are:

- Time-domain simulations presented here demonstrate the effect of the interaction between an inland ship and a bank with a representative obstacle.
- The results show that the rudder movements decrease if the distance of desired track to the shore increases.
- The effect of the obstacle considered is large enough for the ship to deviate from its initial trajectory and cause a collision with another vessel, a bridge or one of the fairway banks - in case of inadequate reaction of helmsman. However, the inland ship under consideration has enough manoeuvring capacity to cope with such obstacle with limited helm angles.
- The reaction of the helmsman to obstacle-induced ship motions is so dominant that a better quantification is recommended to model realistic helmsman behaviour more accurately. Investigations of the reaction time and the steering action are suggested.

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Evolution du dimensionnement des voies navigables

Pour s’adapter à la concurrence des autres modes, la voie d’eau doit permettre la navigation en sécurité d’unités de taille plus importante et le développement de nouveaux usages pour les loisirs (plaisance, tourisme, …), avec également des objectifs de performance.

La conception des voies navigables ne peut cependant viser une perfection technique sans rapport avec le trafic attendu, ni à l’inverse imposer un référentiel moyen uniforme sans tenir compte des conditions locales, de la flotte et des nouveaux usages. Dans ce but, le Groupe de Travail 141 de l’AIPCN a proposé en 2019 des recommandations sur les dimensions du chenal des voies navigables intérieures, qu’il est intéressant d’appliquer au contexte français.

Par ailleurs, il est utile d’étudier d’une part l’application stricte d’une réglementation (telle que la circulaire française datant de 1976), approche en apparence géométrique et binaire (la voie est conforme ou non), et d’autre part les résultats des études de simulation de la trajectographie ou d’essais de navigation réelle.

Un précédent rapport au 34ème Congrès de l’AIPCN (Deplaix, 2018) a détaillé le cas de la liaison Bray-Nogent, prévue pour des automoteurs (Classe ITF1 Va). On va présenter ici une voie d’eau fictive (inspirée de configurations existantes simplifiées) destinée à recevoir des convois poussés de 180 m (Classe ITF Vb).

On déroulera la méthodologie du GT 141 pour déterminer dans quel groupe de qualité (sécurité+aisance) cette voie se situe-t-elle aujourd’hui, puis dans quel groupe le projet devra se situer, enfin les dimensions impliquées.

Pour les décideurs désireux de comprendre ce qu’ils signent, pour les ingénieurs confrontés pour la première fois à une conception de voie navigable, ou pour les béotiens, le tableau résumé montrant les dimensions recommandées des voies navigables en fonction de la largeur du bateau (voir Tableau en Annexe, et Söhngen, 2015) est d’un grand intérêt, mais ils risquent de manquer de compréhension sur la façon de choisir une valeur plutôt que l’autre, et comment on en était arrivé à ces chiffres. Le présent document vise à les éclairer.

1 L’International Transport Forum (ITF) a remplacé la Conférence Européenne des Ministres des Transports (CEMT)
Éléments-clé d’analyse

Il y a quatre éléments essentiels à définir avant de commencer un projet.

- **le bateau de projet**, sa largeur, son tirant d'eau, sa longueur et son "tirant d'air". Presque tous les calculs dépendent de ce bateau de projet. (Mais pour choisir la taille du bateau de projet, vous devrez peut-être étudier le cours d'eau, d'abord, voir ci-dessous). Ici, ce sera le convoi poussé ou l'automoteur pousseur de 180x 11,40 m.

- **La voie d'eau**: rivière à courant libre, rivière canalisée ou canal? Le tableau à utiliser est différent dans chaque cas, bien que la référence habituelle soit le tableau pour les canaux.

- **le trafic de projet**, calculé en bateaux/année. En effet, alors que les marges de sécurité ne sont pas les mêmes pour un trafic léger ou très élevé, ces tableaux sont souvent utilisés comme si le trafic était de 200Mt/an (qui nécessite une qualité A), alors qu'il peut être largement inférieur à un million (qui peut se contenter d’une qualité C).

- **La forme**, lorsqu'il s'agit d’un canal, Trapézoïdal, rectangulaire, RT² ? Pour chacun, la vitesse obtenue par le bateau de projet pour une même consommation sera différente.

Par ailleurs, nous connaissons parfois la taille de la voie navigable plutôt que celle du bateau. Nous essayons alors de déterminer le plus grand bateau de projet pouvant y naviguer. Les mêmes tableaux s'appliquent en sens inverse.

**Application à un projet de mise au gabarit ITF³ Vb**

Pour bien expliquer cela, on va appliquer la méthodologie à un exemple hypothétique, le projet de mise à grand gabarit Vb d’une voie d’eau ayant aujourd’hui un gabarit inférieur. Après avoir exposé en détail les éléments et les calculs de la méthodologie, il sera facile pour les nouveaux venus d'utiliser pleinement le rapport 141, où ils trouveront tous les détails des calculs, des formules, du processus de modélisation, etc. En effet, la méthodologie appliquée pour déterminer le niveau de qualité et de sécurité nécessaire pour toute voie navigable est assez simple, et peut être appliquée à cette voie d’eau hypothétique.

Il convient d’abord de distinguer les parties du trajet en canal et celles en rivière, et ensuite de déterminer le niveau actuel de qualité et de sécurité. En deuxième lieu, on détermine le niveau nécessaire pour atteindre les objectifs visés sur le plan du gabarit. On positionne ensuite le résultat dans le tableau explicitant les 3 classes :

<table>
<thead>
<tr>
<th>presque aucune</th>
<th>légères à notables</th>
<th>fortes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>facilité de navigation</td>
<td>pas vraiment facile</td>
<td>secteur piégeux</td>
</tr>
</tbody>
</table>

Note

| +1,0 | +0,8 | +0,6 | +0,34 | +0,2 | 0,0 | -0,2 | -0,33 | -0,6 | -0,8 | -1 |

Enfin, on applique ce niveau dans le tableau synthétique qui permet d’en déduire les dimensions du chenal à respecter sur l’itinéraire, selon que l’on recherche un chenal à voie unique ou à double sens.

Il est nécessaire par ailleurs de situer le projet au sein d’un itinéraire, afin d’éviter de se fixer des normes trop élevées par rapport au reste de l’itinéraire, tout en respectant les possibilités d’évolution futures.

---

2 Profils proposés par les recommandations allemandes, vertical d’un côté et trapézoïdal de l’autre
3 L’International Transport Forum (ITF) a remplacé la Conférence Européenne des Ministres des Transports (CEMT).
Par opposition avec la méthodologie actuelle de la circulaire 76-38, le référentiel technique n’est donc connu qu’après l’analyse de la voie d’eau actuelle et la détermination de la qualité nécessaire du projet. C’est donc pour l’essentiel une analyse qualitative, dont on dérive ensuite les paramètres techniques.

**Qualité actuelle de la voie d’eau**

On remplit un tableau complexe, qui détaillle les particularités de la voie selon 3 groupes de critères : ceux liés à la voie d’eau, ceux liés à la vitesse, et enfin ceux liés au trafic. Ici, vu la faible longueur des parties en canal, on décrira seulement les parties en rivières canalisées. Dans le rapport précédent, les résultats avec les pondérations “WG141” aboutissaient à des notes beaucoup trop favorables. On avait donc dû modifier certains critères et certaines pondérations pour que la note reflète bien l’opinion des marins. Ici également, les critères “ter” sont plus adaptés.

Dans l’état actuel, il peut y avoir un certain nombre de points noirs, tels des ponts étroits ou des virages très serrés. Mais, dans cette analyse de l’état actuel, ils seront évalués en fonction de la navigation actuelle, avec des bateaux ou des convois ne dépassant pas 135 m, et non de la navigation future avec des convois de 180 m. On teste ainsi si les paramètres choisis sont adaptés à cette voie d’eau en vérifiant qu’ils obtiennent une note qui reflète l’opinion des navagers. Il serait possible de choisir une autre approche, rendant compte par exemple d’essais en vraie grandeur avec des bateaux plus grands que ceux autorisés. Le WG141 ne l’avait pas retenu, mais une telle logique pourrait parfaitement s’appliquer ici.

![Tableau des critères de navigation](image)

La vitesse limitée et la présence d’écluses, ainsi que le manque de profondeur par rapport au mouillage théorique, font que cette voie ne peut pas recevoir une très bonne note pour le passage des bateaux.
En effet, malgré la faible taille individuelle des bateaux (640 t de chargement moyen), des convois poussés de 2 000 t circulent déjà couramment. Ceci explique le relatif manque d’aisance, surtout si on y rajoute le franchissement délicat de certains ponts.

Une application aux convois de 180 m aurait conduit à prendre en compte le manque fréquent de surlargeur dans les courbes, rendant nécessaire des alternatifs fréquents, avec parfois une largeur proche du minimum même en alternat. Les ralentissements et manoeuvres délicats qui s’ensuivent réduiront la vitesse et la distance parcourue. De ce fait les notes 4,6, 8 et 9 en seront diminuées, et la note globale sans doute inférieure à 0 et dans la partie inférieure de la classe B.

**Qualité future de la voie d’eau**

Ensuite, on définit ce qui sera nécessaire pour atteindre l’état attendu en remplissant un deuxième tableau, dans lequel tout ce qui était positif dans le tableau précédent devient une incitation à moins agir, puisque le niveau attendu est déjà atteint. À l’inverse, tout ce qui était négatif devient une incitation à rechercher une qualité supérieure pour atteindre le niveau de qualité attendu. Une bonne voie d’eau, comme c’est le cas ici, n’aura donc pas une très forte note, puisqu’il y aura peu de chose à faire pour atteindre le niveau requis.

Puisqu’il s’agit essentiellement de passer à des convois de 4 400 t au lieu de grands automoteurs ou de petits convois, beaucoup des commentaires de ce tableau “projet” vont rester identiques à ceux de l’actuel, mais avec des notes inversées. Les seules différences porteront sur les courbes, et donc sur la facilité de navigation. Il faut cependant tenir compte des différences de clientèles induites par ce changement de gabarit.

Une fois trouvée la note de qualité désirée de cette voie d’eau, on utilise le tableau proposé dans un rapport antérieur pour les rivières canalisées afin de trouver les dimensions adéquates pour cette mise à grand gabarit.
Le tableau est le suivant:

<table>
<thead>
<tr>
<th>Rivières Canalisées</th>
<th>Largeur du chenal pour voie unique en alternat</th>
<th>Largeur du chenal pour double sens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>degré de facilité</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>Largeur minimale - $W_f$ en ligne droite</td>
<td>$2B^1$</td>
<td>$2B^3$</td>
</tr>
<tr>
<td>profondeur $D$ minimale au plafond</td>
<td>$1,15d$</td>
<td>$1,2d$</td>
</tr>
<tr>
<td>Rectangle de navigation</td>
<td>$W_{pd}$</td>
<td></td>
</tr>
<tr>
<td>rayon $R$ minimal (ΑF si $R \neq \infty$)</td>
<td>$2L$</td>
<td>$3L$</td>
</tr>
</tbody>
</table>

On appliquera les dimensions en suivant les tableaux d’interpolation suivants:

<table>
<thead>
<tr>
<th>note</th>
<th>Largeur</th>
<th>1</th>
<th>0,9</th>
<th>0,8</th>
<th>0,7</th>
<th>0,6</th>
<th>0,5</th>
<th>0,4</th>
<th>0,3</th>
<th>0,2</th>
<th>0,1</th>
<th>0</th>
<th>-0,33</th>
<th>-0,66</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4,89</td>
<td>4,78</td>
<td>4,67</td>
<td>4,56</td>
<td>4,45</td>
<td>4,34</td>
<td>4,23</td>
<td>4,12</td>
<td>4,01</td>
<td>3,9</td>
<td>3,7</td>
<td>3,5</td>
<td>3,3</td>
<td></td>
</tr>
</tbody>
</table>

Et pour les rivières unidirectionnelles:

<table>
<thead>
<tr>
<th>note</th>
<th>Largeur unidirection</th>
<th>1</th>
<th>0,9</th>
<th>0,8</th>
<th>0,7</th>
<th>0,6</th>
<th>0,5</th>
<th>0,4</th>
<th>0,3</th>
<th>0,2</th>
<th>0,1</th>
<th>0</th>
<th>-0,33</th>
<th>-0,66</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2,5</td>
<td>2,48</td>
<td>2,46</td>
<td>2,44</td>
<td>2,42</td>
<td>2,40</td>
<td>2,38</td>
<td>2,36</td>
<td>2,34</td>
<td>2,32</td>
<td>2,3</td>
<td>2,20</td>
<td>2,30</td>
<td>2,0</td>
</tr>
</tbody>
</table>

Si l’objectif cherché conduit à une note assez forte, on se rend compte qu’il sera nécessaire d’intervenir de façon relativement conséquente sur la voie d’eau actuelle.

C’est seulement à ce moment qu’on peut fixer le référentiel technique, en version “concept design”, et commencer les analyses détaillées: d’abord “extended concept design”, en tenant compte des surlargeurs nécessaires pour les courbes, le vent, les courants traversiers, la vitesse, le trafic, puis “detailed design” à chaque endroit où les normes ne sont pas respectées, comme les ponts, les traversées entre îles, etc., dans les cas où la pratique actuelle (“practice approach”) ne suffit pas à garantir le passage des bateaux avec le degré de sécurité et d’aisance voulu.

On aboutir alors à une largeur de chenal de 49,8 m, calculée à la profondeur de la quille du bateau de projet, hors squat.

Le rectangle de navigation selon cette méthodologie sera donc de 49,8x3 m, dans un chenal d’une profondeur de 4 m, ce qui correspond à un plafond de 45,8 m et un miroir de 61,8 m (berges à 2/1), en ligne droite. Ces dimensions au miroir sont souvent atteintes, et nécessiteront un simple calibrage en profondeur pour atteindre le rectangle de navigation désiré. Restera le problème des points noirs (ponts, virages prononcés, etc.) qui devront être traités par une étude du modèle, très vraisemblablement. Les nombreux points noir s’ils ne sont pas améliorés, vont diminuer l’ambition affichée sur les critères 4, 6, 8 & 9.
**Autres méthodes d’analyse**

- **Application de la Circulaire 76/38**

Le même type d’analyse aurait pu s’appuyer sur une autre réglementation.

De manière schématique la réglementation française exige des valeurs normales pour les voies de classe VI (classe ITF Vb)

- 42 m de large en rivières en double sens, et 22 m en sens unique hors passage sous les ponts (ces valeurs sont supérieures de 10% à celles des canaux à cause du courant)
- une surlargeur en courbe de 16000/R en double sens ou les 2/3 de cette valeur en sens unique
- sous les ponts, par sécurité vis à vis des piles, une largeur plus importante est préconisée (…)
- un rapport section de la voie/section du bateau (n) de 6 (pour permettre une vitesse satisfaisante)

Les connaissances générales sur le comportement des bateaux permettent d’indiquer que :

- les grands convois de 11,4 m de large ont une largeur balayée statistique de 16 m (ligne droite et sans courant), qui peut être considérée comme un minimum absolu en dessous duquel leur sécurité dans un passage étroit ne peut être garantie
- la présence d’un courant rajoute une surlargeur pour les bateaux avalants à cause d’une plus forte dérive, qui peut être estimée approximativement par des abaques si on ne se contente pas d’appliquer la surlargeur supplémentaire de 10% en rivières

Ainsi à partir de la comparaison des dimensions de la rivières avec les dimensions requises par ce référentiel, on peut évaluer la marge de sécurité ou au contraire la largeur manquante, par rapport aux standards normaux ou minimums, sur des points particuliers, et distinguer ceux ou on a une largeur de chenal

- légèrement inférieure, égal ou supérieur au standard préconisé
- entre le normal et le minimum
- inférieur au minimum

Il est alors utile de découper la voie en tronçons homogènes de petites dimensions, pour lesquels on examinera chaque élément (courbes, ponts) un par un et on déterminera les croisements possibles en sécurité ou non :

- croisement possible de deux unités de classe ITF Vb
- croisements sélectifs d’une unité de classe ITF Vb avec d’autres unités de plus petites dimensions
- alternat strict de l’unité de classe ITF Vb
- alternat strict de l’unité de classe ITF Vb présentant des risques vis-à-vis de la sécurité de la navigation

Dans le cas considéré, les situations particulières suivantes sont rencontrées avec ou non la largeur requise

- passage étroit sous un pont en courbe
- courbe et contre courbes se suivant ne permettant pas le rétablissement de l’orientation du bateau
- zones d’alternats ou le passage d’un grand convoi seul est possible en sécurité, quelles que soient les conditions
- zones d’alternats ou le passage d’un grand convoi seul n’est possible qu’à l’étiage et dans de très bonnes conditions (visibilité, pas de vent, pilote expérimenté)

Pour ne pas s’en tenir à une approche uniquement géométrique, une appréciation qualitative peut compléter cette première analyse, en prenant en compte les autres informations sur la navigation, notamment celles qui sont proposées par le rapport de l’AIPCN, et les commentaires des pilotes.
Cette approche permet de repérer les « points durs » pour lesquels le passage en sécurité ne peut être a priori garanti, et une trajectographie sera utile, notamment afin de déterminer le courant maximum acceptable.

- **Trajectographie**

Une trajectographie peut être réalisée sur modèle. Ses résultats sont généralement un peu plus optimistes, y compris avec du courant, à condition d’utiliser des bateaux très manœuvrant munis de propulseurs d’étrave. De ce fait, l’habileté du pilote et l’utilisation du propulseur d’étrave permettent d’avoir une trajectoire en courbe moins perturbée par le courant.

- **Essai en vraie grandeur**

Un essai réel peut être réalisé, mais il est souhaitable qu’il soit instrumenté pour comparer avec la trajectographie.

**Respect des tirants d’air et tirant d’eau**

Étant fondé sur les dimensions en plan, les analyses précédentes ne tiennent pas explicitement compte des problèmes de tirant d’air ni de tirant d’eau.

Le tirant d’eau est très lié à la trajectographie, puisque les bateaux naviguent de préférence dans les zones les plus profondes, et que tout haut-fond se traduit par un rétrécissement du chenal. On ne le détaillera donc pas davantage, puisqu’en situation actuelle, le rétrécissement est pris en compte, et qu’on supposera, en situation future, que le dragage, aux cotes définies selon le référentiel technique, sera bien réalisé.

Le tirant d’air est par contre plus problématique. Beaucoup de voies d’eau françaises ont été conçues avant que les normes n’aient été édictées, et ne dégagent pas le tirant d’air voulu par la circulaire de 1995. C’est le cas, selon la nouvelle norme, d’une majorité des ponts de la voie étudiée : un pont sur deux ne dégage pas 5,25 m au-dessus des PHEN4, et il est vraisemblable qu’il en va de même par rapport aux 7 m au-dessus de la ligne d’eau de référence. De plus, les ponts anciens sont très souvent en arc outrepasé, et n’atteignent au mieux la valeur de référence que sur une largeur réduite, ce qui complique la navigation et rend la navigation des bateaux porte-coneneurs très difficile.

Cet aspect ne faisant pas spéciﬁquement partie des termes de référence du Groupe d’étude 141, le rapport en a donc assez peu parlé et il n’a été donné aucune recommandation sur le gabarit en hauteur. Il a, par contre, été indiqué des ouvertures minimales pour les passes des ponts, en précisant que la hauteur, à définir, doit régner sur toute la largeur de la passe.

Dans beaucoup de voies d’eau françaises, ces deux grandeurs sont notoirement insufﬁsantes, et obèrent la rentabilité et la sécurité des bateaux qui y naviguent.

Ces aspects sont traités dans la méthodologie complète (“detailed design”), qui fait intervenir des essais sur modèle ou en vraie grandeur pour tenir compte de la courantométrie et des turbulences, éventuellement du vent et/ou du brouillard. Les études de trajectographie peuvent être plus ou moins détaillées, 2D ou 3D, et doivent être validées par des pilotes expérimentés.

C’est à ce stade qu’on peut avancer des préconisations d’aménagement ou d’exploitation sur les zones à risque, tout en restant avec le niveau de qualité précédemment calculé. Ici, il faudra en particulier tenir compte de bateaux étrangers ne connaissant pas cette voie d’eau, imposant par exemple une surabondance de panneaux de signalisation pour s’assurer que chacun comprenne bien quelle est la trajectoire à suivre, et éviter les incidents du type de celui du barrage de Pompey, un bateau étranger ayant manqué l’entrée d’un canal de dérivation.
C’est alors qu’on arrive à la quantification des travaux à réaliser, tant sur le plan monétaire que sur le plan physique, en suivant le référentiel, qui lui a été choisi par une approche qualitative.

**Valeur minimum des ouvertures de ponts, et marges de sécurité, en ligne droite**

(H = hauteur du bateau au dessus du plan de plus grand enfoncement, tirant d’air - B = largeur du bateau, bau – W = largeur du chenal à l’enfoncement de projet)

**Remarque :** Ces valeurs supposent que les pilotes naviguent avec précaution et à vitesse réduite en franchissant les ponts.

<table>
<thead>
<tr>
<th>Voie d’eau</th>
<th>Ouverture sens unique (2 passes)</th>
<th>Ouverture double sens (passe unique)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Qualité S&amp;E</td>
<td>Remarques</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>min H_B</td>
<td>1.0 H + s</td>
<td></td>
</tr>
</tbody>
</table>


**Conclusion**

Ces différentes approches sont complémentaires et permettent d’évaluer le niveau de sécurité et de performance de la voie actuelle ou les travaux à faire pour arriver à un niveau souhaité.

Nous avons ici un cas où le passage des grands convois est à peine possible physiquement sans risques inacceptables, ce qui est mis en évidence par l’ensemble des méthodes.

- L’approche du GT 141 de l’AIPCN permet d’une part de qualifier de manière globale une voie d’eau existante et sa facilité/sécurité de navigation, et d’autre part d’évaluer le niveau d’aménagement à faire pour l’améliorer, sans procéder à un examen point par point, mais en prenant en compte l’ensemble des éléments qualitatifs liés à la navigation.

- Une approche par application d’un référentiel géométrique à une voie d’eau existante permet d’évaluer les marges de sécurité et de recenser les points ou séquences difficiles où la sécurité et le passage sont incertains.

- L’avis des pilotes et l’examen des conditions permet de confirmer (ou non), pondérer et affiner cette analyse, et d’identifier les difficultés de pilotage et les nécessités de manœuvre spécifique.

- La trajectographie dans plusieurs conditions permet d’analyser finement chaque point difficile et de déterminer les possiblités de passage ou croisement selon diverses conditions (sens, courant, chargement).

- L’essai en grandeur réelle, autant que possible instrumenté, permet de comparer avec la trajectographie et de confirmer la représentativité de celle-ci, mais a priori dans un ou deux cas seulement.
ANNEXE:
Valeurs pour un canal

<table>
<thead>
<tr>
<th>Voie d’eau</th>
<th>Largeur du chenal pour voie unique en alternat</th>
<th>Largeur du chenal pour double sens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>degré de facilité</td>
<td>Remarques</td>
</tr>
<tr>
<td>L</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>L</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>section droite en canal</td>
<td>1.95</td>
<td>2.18</td>
</tr>
<tr>
<td>n minimal</td>
<td>1.3</td>
<td>d</td>
</tr>
<tr>
<td></td>
<td>4 L</td>
<td>7 L</td>
</tr>
<tr>
<td>courant max (v_{max}) (longitudinal)</td>
<td>0.5 m/s</td>
<td>0.5 m/s</td>
</tr>
<tr>
<td>courant max (v_{cross}) (transversal)</td>
<td>0.3 m/s (moyenne sur L)</td>
<td>(\Delta F) requis si (v_{cross} = 0)</td>
</tr>
<tr>
<td>vent de projet (v_w) dans les terres</td>
<td>5-6 BF (8.0 – 13.9 m/s; 10.5 m/s; normes hollandaises)</td>
<td>(\Delta F) requis pour bateau vide ou ballasté ou porte-conteneur si (v_w = 0)</td>
</tr>
<tr>
<td>vent de projet (v_w) près des côtes</td>
<td>6-7 BF (10.8 – 17.2 m/s; 13.5 m/s; normes hollandaises)</td>
<td>(\Delta F) requis pour bateau vide ou ballasté ou porte-conteneur si (v_w = 0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>note</th>
<th>Largeur</th>
<th>Largeur sans unique</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9</td>
<td>2.3</td>
</tr>
<tr>
<td>0.8</td>
<td>4.4</td>
<td>2.27</td>
</tr>
<tr>
<td>0.7</td>
<td>4.3</td>
<td>2.23</td>
</tr>
<tr>
<td>0.6</td>
<td>4.2</td>
<td>2.2</td>
</tr>
<tr>
<td>0.5</td>
<td>4.1</td>
<td>2.18</td>
</tr>
<tr>
<td>0.4</td>
<td>3.9</td>
<td>2.15</td>
</tr>
<tr>
<td>0.3</td>
<td>3.8</td>
<td>2.13</td>
</tr>
<tr>
<td>0.2</td>
<td>3.7</td>
<td>2.1</td>
</tr>
<tr>
<td>0.1</td>
<td>3.6</td>
<td>2.08</td>
</tr>
<tr>
<td>0</td>
<td>3.5</td>
<td>2.065</td>
</tr>
<tr>
<td>-0.33</td>
<td>3.2</td>
<td>2.05</td>
</tr>
<tr>
<td>-0.66</td>
<td>3.0</td>
<td>1.95</td>
</tr>
<tr>
<td>-1</td>
<td>2.8</td>
<td>1.9</td>
</tr>
</tbody>
</table>