DESIGN GUIDELINES FOR INLAND WATERWAY DIMENSIONS

by

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ABSTRACT

The PIANC INCOM WG 141 was founded in 2010 to provide planners of inland waterways with design standards for inland waterways. The report with the title "Design Guidelines for of Inland Waterway Dimensions" will be published in 2018. In 18 meetings and three interim meetings on special questions, the group has undertaken a comprehensive view on guidelines and practice examples as well as methods for detailed design. International standards as well as practice examples show a wide scatter of recommended waterway dimensions. One reason for the differences is the great variety in traffic density but also the tradition of shipping in different countries. Furthermore, especially waterways with significant flow velocities as rivers are a complex system influenced by its varying bathymetry and currents to mention just a few aspects. So it is not appropriate to give just "one" design waterway dimension. Instead a special design method was developed, basing generally on the application of three design methods: "Concept Design Method" (coming from concept*ual*), "Practice Approach" and "Detailed Design". Special recommendations will be provided for designing fairways in canals and rivers, bridge opening widths, lock approach length's and widths and the dimensions of turning basins, junctions and berthing places.

The "Concept Design Method" provides basic dimensions for designing the necessary waterway dimensions. The data come mostly from existing guidelines. In a next step, called "Extended Concept Design Method", special aspects as wind or currents will be accounted for by providing formulae, derived from approximations of the driving dynamics of inland vessels. The "Practice Approach" collects and interprets data from existing waterways. It is mostly used for comparing and evaluating the results of the other design methods. If the design problem considered cannot be solved with the Concept Design Method, a Detailed Design will be recommended. It is generally basing on simulation techniques as Ship Handling Simulators. Both Concept and Detailed Design will be supported by a new approach to account for the safety and ease of navigation demands on waterway design (shortly S&E). The report provides also Guide Notes on the optimal use of ship handling simulators for waterway design. This paper provides a brief introduction into the structure of the report of WG 141. It outlines the main findings, especially concerning the consideration of the necessary S&E quality. Selected results will be presented concerning the Concept Design Method of fairways in canals, the Practice Approach for rivers and the Detailed Design for bridge openings.

1. **INTRODUCTION**

1.1 Motivation to install WG 141

One of the motives for founding PIANC-INCOM WG 141 "Design Guidelines for Inland Waterways" was the lack of internationally accepted guidelines for inland waterway dimensions, in contrast to regulations for sea-going ships. Another reason to update existing knowledge of waterway design corresponds to the change in fleet, especially with an increasing part of longer, wider, deeper going and stronger powered vessels and consequently the dimensions of the design vessels. These new vessels are generally the reason why wider lock chambers, lock approaches and fairways are needed.

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On the contrary, these new vessels are generally better equipped than traditional vessels, e.g. with two thrusters instead of one, with twin rudders instead of single ones or with bow thrusters and passive bow rudders in some cases. This development, combined with a general reduction of the number of ships sailing on inland waterways and better information services, which are available now and will be more capable in future, provides an opportunity to potentially restrict the lateral dimensions of the navigation channels despite the larger widths of the vessels.

1.3 Differences to sea-going Vessels

Furthermore, in contrast to sea-going ships, the traffic with inland vessels is generally less dangerous, for example collisions with bank protections are more or less a normal situation when travelling in inland canals. One reason is that sea-going ships are less powered and worse steerable related to their dead weight and drive with comparatively high ship speeds, forcing high safety standards. Thus, design standards for sea-going ships as those of PIANC MARCOM WG 49, have to be more spacious for safety reasons and are thus generally not applicable to inland-going ships. But, of course, the safety and ease of inland navigation must be ensured nevertheless and restricts the possibilities of “narrow solutions”, which will be demanded for e.g. from ecological and politico-economic reasons.

1.4 Minimum Waterway Dimensions

Therefore, there is a need to specify the minimum necessary requirements on waterway dimensions, especially from the nautical point of view. This does not mean that WG 141 proposes these minimum dimensions. In contrary, looking on the aspects of safety and ease of navigation (in the following shortly “S&E”) and the operational economy of shipping, the design should be generally as generous as possible taking into account for example a possibly changed traffic density in future, but, looking especially on impacts on the environment, socio-economic aspects or the politico-economics of the waterway improvement, the design should be as narrow as necessary - but not more than that. So, it makes sense to define just these lower limits to avoid needless discussions with opponents of waterway improvement measures. This is the main task of PIANC-INCOM WG 141.

2. OBJECTIVES OF THE REPORT AND GENERAL REMARKS ON THE APPROACH

2.1 Target Group

The report of WG 141 aims mainly on planners of inland waterways and the infrastructure. The planners will be supported

(1) By providing concrete numbers on nautically necessary minimum waterway dimensions for selected types of infrastructure (results of the so-called "Concept Design Method" and "Practice Approach" and
(2) Process recommendations for performing a detailed study for specifying necessary minimum waterway dimensions, using field data, scale model test or in most cases simulation techniques as Full Bridge Ship Handling Simulators.

Decision-makers are the 2nd important part of the target group. They will benefit mainly from

(1) The provision of generally applicable design rules as the procedure to perform the design in a structured and objectified way ("General Approach in Waterway Design", Figure 3) or
(2) Information on the necessary effort to follow this procedure, especially on appropriate data, hydrodynamic and nautical models as well as number of simulations runs to obtain results in the desired quality.

The report supports also experts developing and applying simulators, especially concerning the proposed optimal way to perform a detailed nautical study up to all the possible stakeholders involved in a waterway design project (including layman) who are interested in all the problems or special features related to e.g. he driving dynamics of inland vessels and its impact on waterway infrastructure design. So, the report offers information for a large target group concerning nautical aspects of design.

2.2 Main Objectives

The central problem of the working group process was to consider the partly huge differences in recommended waterway dimension in relevant international guidelines (results of the Concept Design Method). These differences can be interpreted as to be mainly caused by varying necessary safety and ease of navigation demands and corresponding traditions of shipping in these countries. This problem was overcome by the objectification of different necessary ease qualities in waterway design. The corresponding design approach will be called "Safety and Ease of Navigation Approach” or shortly "S&E" in the following. Correctly applied, it matches the different recommendations to a large extent. Hence, the main and primary objective of the report is to ensure that the results of the Concept Design Method proposed in the report are rationally understandable and comparable to the application of different national guidelines and its different S&E demands.

In addition, the design of inland waterway infrastructure according to its main dimensions should follow a structured, standardized procedure, considering all the necessary information e.g. on relevant local boundary conditions and the quality of methods to be used. This is, to ensure that the most suitable design approach including corresponding methods will be used and not e.g. the by accident available methods. Finally, the report promotes understanding of required funds and efforts to perform the design approach in the recommended way, especially if simulations will be used. This concerns e.g.

- the necessary data base,
- the type and capabilities of models,
- the need to calibrate and verify the models and
- the way to apply models in a comparative way as it is usual in applying hydraulic models but not commonly accepted standard in using Ship Handling Simulators (“SHS” shortly in the following),

up to the way how model results can be interpreted in an optimal way to eliminate modelling inaccuracies to a large extent. This, because the efforts and funds for designing waterway infrastructure measures are generally higher compared to the use of simulators for pilot training. On the other hand, the expenses for a comprehensive nautical study are generally only a small fraction of the construction costs and seem thus to be justified from the viewpoint of experts involved in WG 141.

2.3 Waterway Dimensions considered

The report focuses on waterway infrastructure measures that cause generally the highest construction and compensatory expenses (economic view) as well as the highest ecological footprint. These are

- the width and depth of canals,
- the width and course of fairways in rivers,
- the width and height of bridge openings,
- the length and width of lock approaches (not the harbor or the lock),
- the navigational space at junctions,
- the dimensions of turning basins and
- the length, width and layback of berthing areas.

The report focuses on nautically design aspects and minimum dimensions only. These limitations were necessary in order not to exceed the framework of the report, but economic and ecologic demands will be considered fulfilled in this way too.

2.4 Application Limits of the Report

The report gives no answer, *whether* a waterway infrastructure project shall be realized or not. This fundamental decision is part of an intensive justification procedure, including the politico-economical appraisal and the tolerability concerning water management, land use and ecology, that must be carried out before the nautical design can start. This part of the design process is illustrated in the following sketch, Figure 1. But the report provides answers on *how* the infrastructure should be realized, if the fundamental decision was made – and especially considering the necessary demands of S&E. Note also that, the report provides answers to design questions only up to a certain degree of concretization, not more, but also not less. This restriction is necessary because of the generally highly complexity of each waterway design problem with all its different local boundary conditions and constraints.

Therefore, the WG 141 report provides in many design cases no specific numbers, e.g. of the necessary width of a lock approach, but “process considerations” on *how* to perform the design in a structured manner. Therefore, the report doesn’t replace detailed engineering works. But it explains in detail the proposed approach how to obtain appropriate waterway dimensions, e.g. by considering and filtering all nautically relevant design aspects and giving hints on data and models needed and how they can be used in an optimal way. This contribution of the guidelines to the planning process is illustrated in Figure 1.

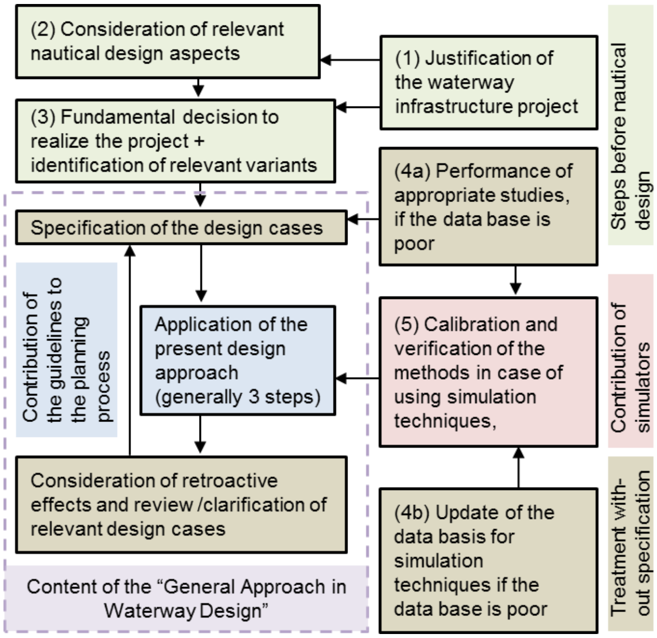


Figure 1: Contribution of the WG 141 report to the planning process of a waterway infrastructure project

2.5 Types of Recommendations

Nevertheless, there are several design cases, allowing to specify selected waterway dimensions by considering existing guidelines only, that is, without looking additionally on practice data or without performing a detailed study. This is e.g. the case for the necessary widths and depths of canals, if the necessary S&E demands can be chosen very accurately. The corresponding design approach (1st type of recommendation) is rated to be the most concrete and precise one, see Table 1, illustrating this ranking in comparison to the other types of recommendations, explained in the following.

By contrast, the design of waterway dimensions, where the local boundary conditions as the course of the river, the bathymetry and the flow velocities in a lock approach area are different from case to case, demand for a Detailed Study and thus for process recommendations only. Although these are within themselves very specific, e.g. concerning the check of the applicability of the models used, they may be ranked according to its degree of concretization to be very low (type 3, less concrete).

Between these poles, recommendations are derived from practice data (type 3 in table 1). They may be very concrete as the fairway widths in rivers, but the scatter of the available data is very large and thus the recommendations are less accurate compared to data from canals. Because of this fact and because local boundary conditions as the course of the river and its flow distribution may vary from case to case, these recommendations demand generally for further detailed considerations.

A 4th type of recommendation to choose appropriate waterway dimensions may be used as a first step in applying simulation techniques. The reason for this step is that e.g. the hydraulic model, specifying inter alia the flow velocities in the design, but also the visual model in a SHS needs the to be specified and corresponding hydraulic calculations have to be made before the actual simulation can start. These recommendations are of course less specific and inaccurate, but nevertheless necessary to start the design process.

Type	Description	Example	Degree of concretization and rating
1	Recommendation derived from applicable existing guidelines	Concept Design Method of canal dimensions	Highly concrete and accurate
2	Recommendation derived from practice data	Concept Design Method of fairways in Rivers	Concrete, but less accurate compared to canals - requires generally a Detailed Design
3	Process recommendations for performing the Detailed Design	Usage of simulators for lock approaches	Highly concrete concerning the approach, but no numbers
4	Preliminary Design - waterway dimension derived from driving dynamics - 1st step of the Detailed Design	Lock approach width accounting for cross currents to specify bathymetry and flow field for subsequent simulations	Concrete, but less accurate because only a few influencing parameters considered

Table 1: Types of recommendations and rating according to the degree of concretization and precision for waterway design

3. REVIEW OF THE WG PROCESS

The WG was founded in the year 2007 within the framework of the PIANC World Congress in Liverpool. After 18 meetings, 3 interim meetings, 4 participations to PIANC conferences with 2 workshops and 16 publications, the group prepared the last, from INCOM members reviewed version end of March 2018. The publication is expected in summer 2018. The reason for the long-lasting working process is the complexity of the design problems, related to the various boundary conditions in inland navigation. A special problem was the way how to account for the huge number of influencing parameters, which led to the S&E approach.

The working group consists of experts from China, Europe and the USA. Involved were by profession civil engineers, naval engineers and a former captain. They are employed at waterway administrations, engineering bureaus, institutes of applied science and developers and users of ship handling simulators.

Starting with the discussion and specification of the Terms of Reference, given by INCOM, the group dealt with the following points:

- Viewing, preparation and evaluation of existing international waterway guidelines according to minimum waterway dimensions and corresponding safety and ease quality.
- Development of an experience-based design from the interpretation of existing guidelines, called Concept Design Method, and assignation of corresponding S&E qualities.
- Definition of S&E categories and development of an assessment scheme for necessary minimum S&E standards with a scoring system to support the Concept Design Method, called “Simplified S&E Approach”.
- Evaluation of guidelines, relevant literature and approaches, basing on the driving dynamics of inland vessels with regard to extra widths (generally called increments”) as wind surcharges.
- Collection and analysis of existing waterway infrastructure, leading to the Practice Approach.
- Evaluation of criteria concerning the application limits of the Concept Design Method, together with European developers and appliers of SHSs (BAW, DST, Flanders Hydraulics, MARIN, SIPORT21).
- Development of an approach to optimize the application of SHSs for waterway design purposes, called “Detailed S&E Approach” and coordination with the aforementioned appliers of SHSs.

A testable draft of the report was worked out in the end of 2016, leading to first comments by INCOM. A second draft was worked out to be checked by a reviewer group in summer 2017. Basing on these comments, a second last version was worked out up to January 2018 and was the basis of final comments from INCOM members. The version, which is discussed here, is dated end of March 2018. It is the basis for the expected final approval from PIANC.

4. STRUCTURE OF THE REPORT

Before going into details of the report, whereby the content of each important chapter will be presented briefly, the headings of the major chapters are given as follows:

1 INTRODUCTION
2 TECHNICAL INFORMATION
3 APPROPRIATE ASSESSMENT OF SAFETY AND EASE QUALITY AND ITS USAGE FOR DESIGN
4 RECOMMENDED METHODS FOR WATERWAY DESIGN
5 RECOMMENDATIONS FOR SELECTED DESIGN ASPECTS
6 CONCLUSIONS
REFERENCES
GLOSSARY
APPENDIX A: SUMMARY ON EXISTING GUIDELINES
APPENDIX B: DIMENSIONS OF EXISTING WATERWAYS - PRACTICE
APPENDIX C: APPROPRIATE ASSESSMENT OF SAFETY AND EASE QUALITY AND ITS USAGE FOR DESIGN
APPENDIX D: DETAILED OR CASE BY CASE DESIGN – USING SIMULATION TECHNIQUES OR FIELD INVESTIGATIONS
APPENDIX E: EXTENDED CONCEPT DESIGN METHOD – ACCOUNT FOR EXTRA WIDTHS
APPENDIX F: APPLICATION OF THE DETAILED DESIGN APPROACH TO AN EXAMPLE

It should be noted that the report is written in a way to be read selectively. So, experts, e.g. planners of waterways, may extract their specific information only from Chapter 5. It collects the results of the Concept Design Method and Practice and provides hints for Detailed Design for selected waterway dimensions. Maybe experts will have a look into the appendixes too, which go into further detail, e.g. how use the Extended Concept Design Method (APPENDIX E) or the recommended approach for optimal usage of SHSs (APPENDIX D). Decision-makers may be interested also in Chapter 4, which shows the recommended design procedure in detail, especially concerning the main questions to be answered and who should be involved in waterway design. Readers, who demand for understanding the recommended approaches, may have a special look into chapters 1 - 3 and 6, as well as appendix E. They will find comprehensive information about the relation between minimum waterway dimensions and the driving dynamics of inland vessels. Hundreds of links between the chapters facilitate the selective reading.

5. EXAMPLES FROM THE CONTENT OF THE REPORT

5.1 Chapter 1, Introduction

The main content of Chapter 1 was already reflected in this paper in the chapters 1.1, 1.3, 2.1, 2.2 and 2.4. The main issues are be outlined again in the following:

- Because of the strong demand to consider hydraulic engineering, economic and ecologic aspects all together and the general request from waterway planners for narrowly standards, the report focuses on minimum waterway dimensions and from the nautical point of view only, because the other aspects will be accounted for to a high extent automatically. This does not mean that WG 141 recommends these minimum standards. By contrast, the waterway design should generally be as generous as possible to facilitate shipping. But there are often unavoidable strong constraints demanding for minimum standards, but they should not be smaller than those proposed in this report to ensure the safety and ease of navigation.
- Because of the numerous influencing parameters and the complexity of inland waterway design aspects in general, a “Three Methods Approach” was proposed, basing on the traditional Concept Design Method, extended by the Practice Approach and Detailed Design where appropriate. So, not only specific numbers will be provided in the report as in existing guidelines, but also process recommendations how to proceed in an optimal way, especially concerning the use of ship handling simulators if application limits of the Concept Design Method are exceeded.
- Because of the large target group of the report, it was written to allow for selective reading.

From the content of Chapter 1, it should be additionally mentioned that,

- It was relevant to limit the review of existing guidelines and practice examples to commercial navigation, since large vessels scale generally the waterway infrastructure dimensions.
- The restriction to minimum waterway dimensions accounts for the very important issues of Climate Change, e.g. mitigation measures for flood and drought to a large extent automatically too and thus, did not have to be considered separately.
- Special attention will be paid to the MARCOM approach for Harbour Approach Channels (PIANC, 2014). It was used as a basis for the proposed Concept and Detailed Design for inland navigation, but for special design cases only and – of course – with somewhat other figures concerning the necessary minimum waterway dimensions.

5.2 Chapter 2, Technical Information

This chapter is mainly written to understand the relationship between the design of waterway dimensions and the special properties and features of waterways, its infrastructure and the properties of vessels and its driving dynamics. The chapter starts by looking on vessel types, the typical features of free flowing rivers, over impounded rivers up to canals, explained by examples as the various construction details of locks in rivers. One example shows the following details. One extreme example concerning a strongly reduced safety and ease of navigation is shown in Figure 2. It’s a lock without an upper or lower harbor, that is, without a quiet-water zone, but with a “gliding pear” to facilitate the intake into the lock. Such a solution will – of course – not be recommended by WG 141, but it shows the variety of existing waterway infrastructure. To match this variety of possible solutions was the main concern to be solved in the report.

Figure 2: Multiple locking of a pushed convoy in the USA

The chapter then provides comprehensive information about the physics behind the vessel behavior, e.g. the strong increase in resistance in shallow and sideways confined waters as canals. This increase has consequences e.g. concerning the optimal way to be considered in simulations. If e.g. formulae will be used made for shallow water, but not taking into account the sideways constraints, the rudder forces at the same vessel speed may be underrated and thus the navigability of the modelled vessel. Finally, information about ship-induced waves and currents will be given to understand the various constraints of vessels driving close to banks, to other vessels or close to infrastructure elements as spur dykes, which lead to accordingly safety distances.

Chapter 2 provides also check lists of boundary conditions to find out and specify relevant design cases. According to Figure 4, this is one of the most important steps in waterway design, because there is generally a huge number of influencing parameters as water levels, flow velocities, environmental conditions like wind and fog, ship types and loading, traffic situations and so on. Considering the probability of occurrence, criteria will be given to extract possibly decisive design cases in order to reduce the design expenses, because the design approach recommended herein with different steps should then be applied to all these cases. Thus, Chapter 2 is written not for experts, who are of course familiar with this information, but for laymen or decision makers, who want to know more about the special problems of waterway infrastructure design and to assess the possible expenses of a nautical study.

5.3 Chapter 3, Appropriate Assessment of Safety and Ease Quality and its usage for Design

As stated earlier in chapter 2.2 of this paper, there are partly huge differences in recommended waterway dimensions in different national guidelines (Concept Design Method), e.g. lock approach lengths, which reach from about 4 times the vessel length L for some waterway classes in China down to 0.5·L in France – and practice data show even lower values as demonstrated in Figure 2. But there are of course objective reasons for these differences and the different S&E qualities may be associated with it. Therefore, the problems to be solved by WG 141 in order to end up with an appropriate consideration of S&E for applying the Concept Design Method, called "Simplified S&E Approach" were,

1. to explain these differences, e.g. by looking on the traditions of shipping in these countries,
2. to learn from the different guidelines to find out *appropriate* S&E qualities and
3. to cope with the generally huge number of design criteria and influencing parameters.

Some of these parameters are shown in the following Figure 3. They determine the existing (analysis case) or the necessary (design case) S&E quality of a driving situation considered. They are collected into waterway-related parameters (blue boxes, containing fairway and environmental conditions), vessel- and speed-related aspects (red boxes, collecting loading, vessel types and instrumentations as well as information systems) and traffic/human-factor related design criteria. You can find these parameter groups in the final table of the S&E approach, see here Table 4. Note that all these parameters don't act in the same direction. E.g. challenging fairway condition speak for a higher necessary ease category in design, whereas a lower ease quality may be acceptable for design, if good on-board information systems are available. Therefore the usual way to cope such influences as in the MARCOM Approach for sea-going vessels, by adding increments to basic waterway dimensions in case if the driving conditions get more complicated, seems not to work optimally in our cases.

The evaluation of these influencing parameters forms the backbone of the Simplified S&E Approach to be used for the Concept Design Method. It leads in the end to an S&E score and thus, to a specific S&E category. If this S&E approach works properly, it should explain the differences in the various guidelines and thus fit with these guidelines to a large extent. This was the main objective to develop the approach – and, each member of the WG must be able to recognise himself in the report!

The solution of the aforementioned problems lead to,

- the definition of S&E categories (qualities), three in total for simplification, named:
    - Category A: Nearly unrestricted drive (as on the Lower Rhine River),
    - Category B: Moderate to strongly restricted drive (as the Upper Rhine, The Mississippi, Dutch "normal" Canals etc.)and
    - Category C: Strongly restricted drive (as Dutch "narrow" Canals and German Canal cross sections, narrow bridge openings, sailing at lock approaches etc.),
    - whereby the *safety* should be ensured also in the lowest category so that extreme conditions as low speed manoeuvring situations while e.g. entering a lock chamber were not considered as well as very comfortable conditions as one-lane traffic in a channel designed for two-way,
- the allocation of recommended waterway dimensions from different guidelines and practice to the aforementioned three categories, see application example in Chapter 6 of this paper,
- the assessment of the S&E category by
    - using a catalogue of different criteria, reflecting the influencing parameters of Figure 3 (see Figure 10), and
    - creating and adjusting a scoring system to end up with a comprehensive "Simplified S&E Score", which will be assigned to the three ease categories,
- the calibration of the scores by checking, whether the evaluated ease categories fits with the expected ease quality from experience and the assessment of the WG members and, finally,
- the linking between the categories and appropriate waterway dimensions by comparing with existing guidelines and practice.

In the end, the Simplified S&E Approach objectifies (by different criteria) and quantifies (by the score and the assignation of score to ease category) the demands of safety and ease of navigation for applying the Concept Design Method. The application will be shown in Chapter 6 with Figure 10 of this paper by an example.

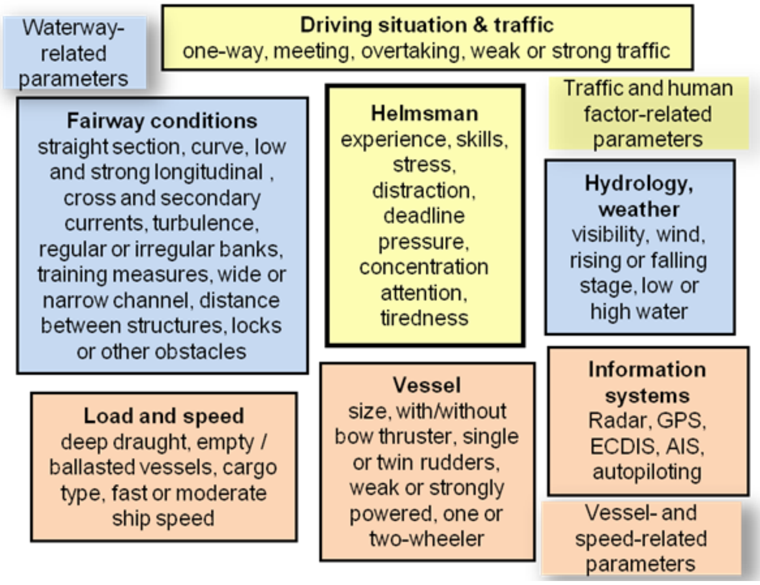


Figure 3: Influencing parameters in waterway design

The Simplified S&E Approach replaces the application of existing national guidelines in cases where they are not applicable or for countries having no own guidelines according to the main objectives of PIANC reports. The approach replaces also a risk based design which is commonly used nowadays especially in maritime waterway design. If there are e.g. buildings, quay walls, floating facilities or vessel berths in the vicinity of the navigational area compared to a sloped bank, the necessary S&E category will be higher and thus the necessary fairway evaluated with the Concept Design Method. So, safety allowances will be met indirectly by demanding for a higher ease quality.

A similar way to objectify and quantify the S&E demands will be recommended in the WG 141 report also for the Detailed Design (performing a detailed study), especially if it is performed by using simulation techniques or field investigations. The corresponding approach will be called “Detailed S&E Approach”. It bases on the following principles:

- The S&E quality of a driving situation, either observed in reality or in virtual reality, will be quantified by evaluating time series of relevant (simulated or measured) parameters
  - as rudder angles, scaling the effort to control the driving situation and
  - e.g. ship-bank distances, which are associated with the exploitation of existing resources or the deviation from a desired way of driving,
  - using a scoring system to allocate e.g. the difficulty of a driving system to a score, to average the time-series of these scores in design-relevant waterway stretches
  - and matching the score-averages of different parameters to one comprehensive score, named “Detailed S&E Score” analogous to the Simplified S&E Score.
- For assessing the S&E of the driving situation considered, the latter will generally not be evaluated directly, but by comparing it to a reference case (principle of comparative variant analyses), see also Figure 6 (dashed frame collects the methods used to perform the Detailed S&E Approach). By this means, unavoidable inaccuracies of the simulations will be eliminated to a large extent. So, always just two variants will be considered, e.g. the design case and an appropriate “ease reference case”, whereby
  - the ease reference case may be chosen by applying the Simplified S&E Approach first to the design case, in order to assess the striven S&E quality, and then to different possible reference cases, to check, which reference case fits best with the Simplified S&E score of the design case (often identical to a special situation of the present nautical conditions, whose S&E standard should be reached also after design),
- and comparing the comprehensive Detailed S&E Scores of both the design and reference cases, which are evaluated from the results of e.g. the simulations with a SHS of both variants, using the aforementioned procedure to quantify the S&E.

- Also the influence of e.g. the skills, the attentiveness or destruction of the helmsman, usually called “human factor”, can be quantified to make it comparable between variants. The report proposes for this purpose the NASA TLX-Test (Task Load Index).

But not only these quantified S&E scores of the design and reference case should be used for assessing the acceptance of the design (relative results), of course also the simulated results *directly*, even if the inaccuracies are larger than by applying the principle of comparative analyses, e.g. the minimum bank distances (absolute results), together with the comments of the pilots and local experts facing the results (“weak design criteria”) are very important. Thus, the last and most important step in performing a detailed study is the proper *interpretation* of all available results, where appropriate also in comparison to previous projects, but of course with special respect to the application of the Detailed S&E Approach.

5.4 Chapter 4, Recommended Methods for Waterway Design

Because of the large number of influencing parameters as visualized in Figure 3, the different parties and stakeholders involved, the strong impact on the water sector and its ecology in general and the numerous interconnections to different investigations and studies, inland waterway design is generally not a standalone or straightforward procedure. By contrast, it is embedded in the planning concept as indicated in Figure 2 and it needs generally several adaptions during the planning process. But even the waterway design itself needs adaptions, e.g. concerning the determination and specification of decisive design cases or the feasibility of boundary conditions as the spacious consideration of wind effects, looking on local constraints or economical limits. Therefore, waterway design is generally a “looped approach” as indicated in the flow chart of Figure 4, meaning that the feedback after performing the design may lead to question the boundary condition of the design and especially the chosen decisive design cases. The WG 141 report offers several of these flow charts as shown in Figure 4 to visualize the recommended procedures with its interconnections to other design-relevant activities and aspects. One of the most important charts is presented here somewhat simplified in Figure 5. It shows how the aforementioned “Thee Methods Design Approach” works and in which cases the performance of the Detailed Design can be dispensed. Because the flow chart is almost self-explaining, only some remarks should be added here.

After specification of the special design case considered, the application of the “Three Methods Design Approach” procedure starts with the application of the Concept Design Method (upper and right part of Figure 5) It is generally the same as if existing national guidelines will be used. National Guidelines reflect the best practice in this country. Its application also fulfils the requirements of standardisation. Therefore, Countries with their own guidelines may insist to use their guidelines only and the design may end here without additionally applying the other two design methods additionally. But in the opinion of the authors of the WG 141 report, it makes sense to look even in this case to look additionally into applicable international guidelines, to consider practice examples (Practice Approach) or design results from previous projects and, – of course – to use the recommendations of WG 141 in Chapter 5 of the report, considering the S&E approach outlined above to objectify the design. If the results are about the same and if there remain no doubts about the applicability of the methods, the design may end here also after the recommendations of WG 141 (recommendation type 1 in Table 1). This is generally the case for canal design, also because simulations are not that accurate for driving situations in shallow water and additionally in strong sideways confined water because of the strong influence of ship-induced currents on the driving dynamics.

One reason for the recommendation to compare all these results is that, Guidelines will be adapted often too late to account for new developments e.g. of a changing fleet. Hence, they are sometimes backward looking and they may hinder or hold back necessary developments. And, as not all relevant design aspects will be treated in the guidelines, this fact may narrow possible innovations and hinder adapted solutions regarding locally different boundary conditions. To point it out once again, the WG 141 report expands the usual Concept Design Method by considering both national and international guidelines, together with own recommendations and combines it with the Practice Approach. This is, above all, to increase the reliability of the results.

If there are large differences between the determined numbers, especially between Concept Design and Practice, if application limits are exceeded or generally if the there are other good arguments for more detailed investigations, the next step should be carried out, which may base on field investigations, scale model tests or nautical simulations as shown on the left hand side and the bottom of Figure 5.

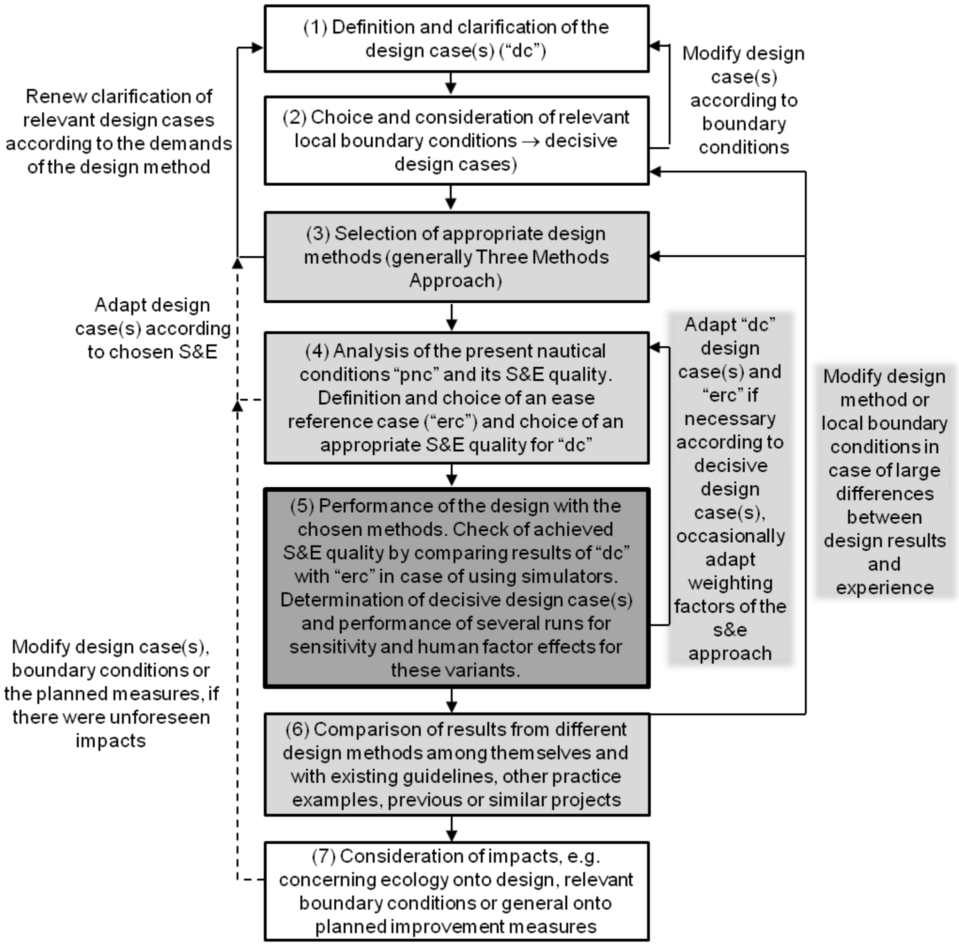


Figure 4: General Approach in Nautical Waterway Design

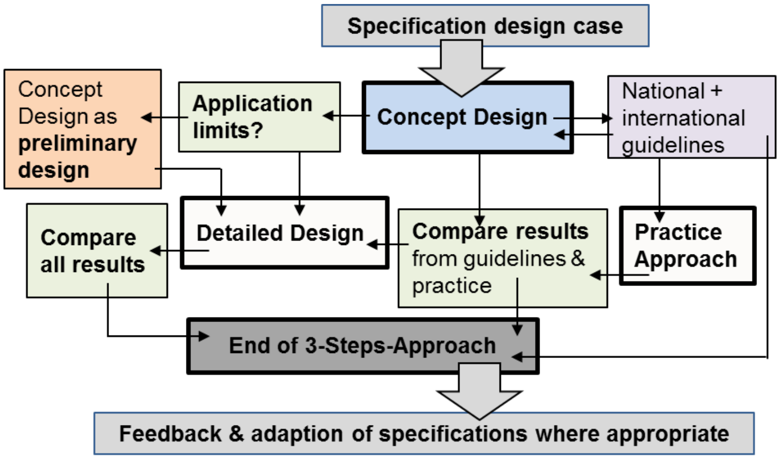


Figure 5: Overview for applying the Three Methods Approach

The results of the Concept Design, if necessary extended by increments (Extended Concept Design), may then be used as a preliminary design for the detailed study (recommendation type 4 in Table 1), because, as mentioned earlier, the latter needs the waterway dimension to be designed first before it can be checked e.g. by using e.g. simulations. This is, because e.g. the bathymetry and the flow models of the relevant waterway stretch are generally depending on the waterway dimensions to be designed itself.

The next step of the “Three Methods Approach” is to choose the methods for performing the Detailed Design, e.g. scale model tests compared to Ship Handling Simulators. For this purpose, the report provides corresponding check lists in Chapter 4. If e.g. the ship-induced wave and current system dominates the vessel behaviour as in very narrow canals, the Method of choice are scale model tests. Then the chosen method should be applied with special respect to the Safety and Ease of navigation as outlined in Chapter 5.3 of this paper. For this purpose, the report provides detailed process recommendations (Type 3 in Table 1) how to perform a detailed study in an optimal way, especially to reduce modelling inaccuracies (Figure 6). To finish the “Three Methods Approach”, the results of the Detailed Design should be compared with those from Concept Design and Practice, even if application limits of the simplified methods were exceeded - and if possible with similar available projects! Only if the differences of the results may be acceptable or explainable and if there were no doubts about the applicability of the chosen design methods, the Three Methods Approach may end here. It follows the consideration of retroactive effects on the planning process and thus the feedback to the planners as illustrated in Figure 5 below, which may lead to rethink the relevant boundary conditions and thus the design cases itself, see also Figure 4 (arc running backwards from step 7 to 1). Note at this point that the report provides particularized descriptions on the optimal way how to perform detailed studies, especially using SHS, not only in Chapter 4 of the report, but also more comprehensively in Appendix D. In this paper, only a highly simplified flow chart will be presented, Figure 6. It shows e.g. the steps which are required to account for the Detailed S&E Approach as outlined above (dashed frame).

Without going into details, Figure 6 demonstrates impressively that the performance of simulation runs in e.g. a Full Bridge Simulator, needs a lot of things have to be done first, in parallel and after the runs and in a structured procedure. Some aspects may be highlighted as follows:

- Check the data base for simulations before starting with simulations, inter alia the bathymetry, because the forces of the underwater body of a vessel strongly depend on the draught to water depth ratio, but also on the flow field. This especially concerns to the influence of water level slopes and secondary currents if relevant. Remember the saying “garbage in, garbage out” of experienced modellers in case of insufficient data.
- Calibrate (e.g. by simulating well-known driving situations, comparing results and adjusting modelling parameters where necessary) and verify (using data that are not taken for calibration) the models using appropriate, well-known driving situations! Generally, the present nautical conditions can be used for model verification, because local skippers and authorities, who should take an active part in the simulations, are very familiar with the local conditions and know how the vessels behave in reality. But please use *quantitative* information, e.g. measured swept area widths, not only the “feel” of local skippers for verification.
- Choose appropriate reference cases, e.g. for simplification a driving situation from the present nautical conditions (often the nowadays largest permitted vessel under the most critical, but “just drivable” conditions, whose S&E quality should at least be reached in design), if the driving situation is comparable to the design case (waterway structure, e.g. lock approach area, vessel type and loading and draught to water depth ratio, traffic situation as encounter or overhauling) and compare each design case with its corresponding reference case.
- “Scan” possible design cases (e.g. water levels, together with loading conditions, vessel types, traffic situations, extra forces as those from wind etc.) by simulations with less effort, e.g. without comparing them to reference cases (trust the “absolute” results in this phase if the results are clear) and perform only one run instead of several runs as for the decisive design cases. The results of the latter should be supported by several runs (needed to verify results and to account for human-related effects – “one run is no run”).
- Interpret the results properly, looking not only the Detailed S&E Approach, but also on *differences* e.g. in the bank distances between design and reference case, on *absolute results* as well as “weak” information as the “feel” of skippers and comments of local experts. As outlined here in Chapter 5.3, a proper *interpretation* of results is just as important as the proper modelling of the driving situation considered.

Addressed to the clients of detailed studies, the WG 141 authors would wish that additional expenses according to this approach will be reimbursed in order to end up with reliable waterway dimensions. Note that expenses for nautical studies are generally minor to construction costs, but may lead to neither undersized nor oversized solutions. Addressed to the users of simulators, the authors would wish that they offer these extra services to their clients and convincing them to pay the extra costs.

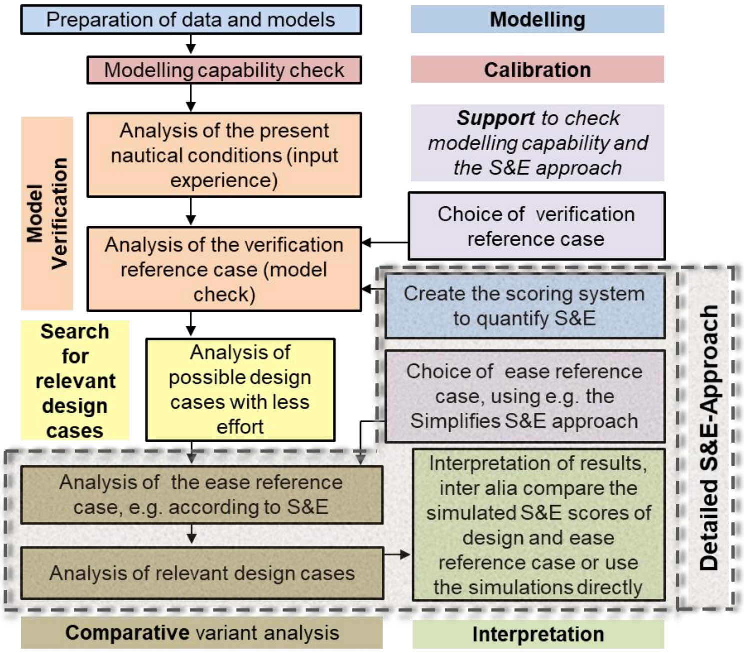


Figure 6: General recommendations and steps to follow using SHSs for waterway design with special respect to Safety and Ease of navigation (dashed frame)

The authors of WG 141 report are of course aware, that the reality is often different to this "ideal approach", meaning that simulation will be run in many cases without proper verification of the models or without comparison to appropriate reference cases. Nevertheless, the authors hope that, if PIANC demands for an appropriate modelling procedure, the opportunity to use simulators for waterway design purposes – and we only talk about this application area of e.g. simulators, not e.g. for training of pilots – will be taken in a more sophisticated way than is customary today, so that the quality of nautical studies can be increased. Note again that waterway dimensions generally "scale" the expenses and consequence of waterway improvement measures, so that possible somewhat higher modelling expenses may be justified in any case.

5.5 Recommendations for selected design aspects

As mentioned above, the waterway dimensions of fairways in canals and rivers, bridge openings, lock approaches, turning basins, junctions and berthing places will be considered in detail in subchapters of Chapter 5.5. Each subchapter starts with the definition and clarification of variables as the coverage ratio n (cross section area, divided by vessel's midship cross section) in case of canal design. Then existing guidelines will be analysed according to the waterway dimension considered. From this, the recommended numbers of the Concept Design Method will be extracted and put in corresponding design tables. One example shows Table 2, containing data referred to fairway dimensions of canals (fairway width W_F, water depth h). Note again, that these values are minimum figures from nautical aspects only and that they are valid for restricted boundary conditions only.

In case of Table 2, these restrictions are as follows:

- Vessels with average equipment and average instrumentation, sailing cautiously, regardful and with moderate vessel speeds (relative to water) around v = 0.5 (encounters) up to 0.7 (normal drive) times the critical speed in a straight canal section. The assumed speed reduction at manoeuvres is important to restrict interaction forces and thus corresponding safety distances, which are included in the basic widths in the design situation considered.
- The application is further restricted to the limits of minimum curvature Radii R, maximum flow velocities v_{flow}, cross flow velocities and so on as well as traffic densities up to about 30,000 cargo vessels/year. But even if the specified minimum radii, maximum cross flow and wind velocities are not exceeded, corresponding extra widths must nevertheless be accounted for, because the basic widths are valid for straight canal sections without crossflow and crosswind only. Also extra widths are recommended for higher traffic densities than specified.

Waterway	Fairway width for alternate single-lane				Fairway width for two-way (approximately also for two-lane, including overtaking manoeuvres)			
	Ease quality			Remarks	Ease quality			Remarks
	C	B	A		C	B	A	
min W_F (straight canal sections)	**2·B** *1.9·B*	*2.1·B*	*2.3·B*	For security reasons	3·B *2.8·B*	4·B *3.5·B*	*4.5·B*	2.5 B can damage the canal
min n	2.5	3.5	4.5	To keep on speed	3.5	5	7	To keep on speed
min h (over bottom width)	1.3 T		1.4 T	Considering squat & bow thruster efficiency	1.3 T		1.4 T	Considering squat & bow thruster efficiency
min R (ΔF needed for $R \neq \infty$)	4 L	7 L	10 L		4 L	7 L	10 L	
max v_{flow} (longitudinal)	0.5 m/s				0.5 m/s			

Table 2: Extract from the comprehensive table in the WG 141 report concerning the Concept Design Method for canals - "basic dimensions" for straight sections

This extension of the "basic dimensions" will be accounted for in the next subchapter (application of the Extended Concept Design). In our example of fairways in canals, extra widths will be specified for crosswind attack, cross currents from e.g. intake or outlet structures, higher vessel speed as assumed in Table 2 and a higher traffic density. Let's look here on the extra width in curves only:

The basic formula is $\Delta F_C = c_C \cdot L^2/R \leq L$, with ΔF_C = extra width of one vessel in a curve, c_C = a parameter, depending on the vessel type (the more "slender", the smaller c_C), the loading conditions (larger c_C for empty, smaller for loaded vessels) and the S&E category. L denotes the overall length of the vessel. In case of two-way traffic, the ΔF_C of both vessels must be added, considering e.g possibly different loading conditions or driving directions in case of longitudinal flow. Specific numbers of the parameter c_C will be provided in Appendix E, not only for canals, but also for rivers with its typical flow velocities and vessel types. For canals, concrete numbers will be recommended e.g. for Class Va vessels. For Class Va vessels and a S&E category better than C, the parameter c_C should be chosen to be 0.3/0.6 for loaded/empty vessels and 0.2/0.4 accordingly for Class Vb vessels, if significant longitudinal flow velocities of max. 0.5 m/s cannot be avoided. Analogous to the Dutch guidelines, the recommended standard manoeuvre in case of two-way traffic is an encounter of an empty vessel with a fully loaded vessel, if there are no other arguments speaking for a different traffic situation. This must be considered in choosing the c_C of each of both vessels.

The next subchapter of Chapter 5 resumes results from collected practice examples if applicable. This is important especially for fairways in rivers. In case of canals, practice examples are generally identical to the application of guidelines and will thus not be regarded.

Special considerations concerning the use of simulators follow in the next subchapter. In case of canals, several hints will be given to account for e.g. the strong increase in vessel resistance close to the critical ship speed (by assessing this speed limit with provided formulae and by recommending to stay significantly below during simulation runs) or the effect of strongly confined conditions on the decrease of bow thruster efficiency by the return current velocity, which must be added to the vessel speed. Because especially the strong and altered interaction of ship-induced wave fields in canals compared to shallow water seriously affects the driving dynamics of inland vessels in narrow canals, and because these effects are considered by semi-empirical formulae only in most simulators, basing in most cases even aggravating on shallow water data with some adaptions to sideways restricted waters, the application of the principle of comparative variant analyses is mandatory especially for canals. This is, to mentions this important point again, to reduce modelling inaccuracies as those from parameterized bank and ship-ship interaction forces as far as possible.

The last subchapter draws conclusions from all these considerations. In our example of canal design, the following statement may be cited: *"In most cases the Concept Design Method and the Extended Concept Design will be sufficient for the design of fairway in canals. Additionally a wide variety on guidelines covers these aspects of design. Only exceptional design situations demand a detailed study."* These are e.g. entrance and exit manoeuvres at lock approaches or turning manoeuvres.

5.6 Conclusions

This chapter outlines again inter alia the following points:

- The proposed design approach should be as objectively, rational and quantitatively as possible, leading to the Three Methods Approach with the core element S&E Approach.
- The design should be restricted to reasonable cases. This means e.g. that restrictions concerning the ease of navigation, e.g. in case of strong wind (the empty vessel may have to moor to let another less wind-sensitive vessel pass by) or seldom occurring traffic situations, if they can be avoided in practice, may be accepted.
- To restrict modelling expenses, the Detailed Design should focus on decisive design cases. The latter may be found by “scanning” all possible relevant variants with less simulation effort or by using the Concept Design Method where appropriate.
- Decisive design case should be run several times to account for e.g. human-related effects, using averages of relevant parameters and in comparison to reference cases. This comparison should be made as far as possible by using quantified criteria as those from the Detailed S&E Approach.
- Interpret results, especially from simulations, with care, because even the best nowadays available methods may be inaccurate in critical design cases. The inaccuracies may also come from flow models, e.g. because of unconsidered secondary currents using depth-averaged 2D models, which is often the case.

5.7 Appendix A: Summary of existing guidelines

The WG analysed guidelines from Belgium, China, The Netherlands (also called Dutch guidelines), France, Germany, Russia and the USA according to the a.m. waterway dimensions. As mentioned earlier, the WG members assigned adequate S&E categories to recommended figures and used averages of those with the same ease category as a basis for the recommended Concept Design Approach. Without going into details, comments to the chosen guidelines may be made as follows:

- Belgium guidelines consider basic dimensions of canals only (extension by Dutch guidelines).
- Chinese guidelines regard all waterway dimensions considered here, also rivers for different vessel categories and flow velocities. They offer numerous design formulae, e.g. for cross flow and lead, compared e.g. to the German or French guidelines, to a relative generous design.
- Dutch guidelines offer very comprehensive and detailed design rules. This concerns e.g. to traffic density or wind effects, which were adopted to a large extent in the WG 141 report.
- French guidelines lead, compared to the average of the other guidelines, to relatively “narrow” waterway dimensions, especially concerning fairways in rivers or bridge openings.
- German Guidelines consider waterway dimensions for canals only as in the Belgian and Dutch guidelines. Unique is how to compose fairway widths by different components as vessel breadths, extra widths due to human factor and the more precise consideration of curve increments.
- Russian guidelines were evaluated because numerous influencing parameters were considered as the influence of flow velocities at lock approaches.
- US guidelines lead to smallest fairway widths in large rivers compared to the other guidelines. Reasons are the generally very low operation speed of large US push tow units, together with highly powered and manoeuvrable pushers (2-wheeler).

As mentioned earlier, the national guidelines reflect the typical boundary conditions as fleet composition and waterway types with its unique water depths and flow velocities and the tradition of shipping in these countries. They lead to different S&E demands and thus, to different waterway dimensions. Note again that these differences were the starting point of the special S&E approach.

5.8 Appendix B: Dimensions of existing waterways - practice

The evaluation of practice data shows the partly huge differences in existing waterway dimensions. Looking e.g. on realized bridge opening widths (one bridge field): The averages of different waterways vary between 2·B (B = largest vessel breadth) and 6.6·B with averages over the different waterway considered of around 4·B for upstream and 2.9·B for a downstream drive. Averages of different waterways of lock approach widths show a similar variation, e.g. figures between 2.5·B and 4.9·B for double locks. This shows that, realized waterway dimensions are rather reflecting the “possibilities” of construction than the nautical “necessities”. Hence, practice data should be interpreted with care, but they are – of course – very helpful for comparing and thus evaluating designed waterway dimensions.

5.9 Appendix C: Appropriate assessment of safety and ease quality and its usage for design

This appendix goes in more detail than Chapter 3 in the main report, especially concerning the way to quantify S&E using selected time series of relevant parameters from the results of simulation runs or the direct quantification of human influences and shall be outlined here in a bit more detail as follows:

As mentioned earlier, the report proposes the standardized NASA TLX-Test (Task Load Index) for this purpose. The index scales the "work load" by steering the vessel. The index can be used in the same way as the Detailed S&E Score to compare variants as the design case with the ease reference case. The test presupposes that the *same* pilot steers the vessel in the reference cases and the design cases as well. What he has to do, e.g. during the usual coffee breaks between two simulation runs, is, to answer six questions in a similar way as using the table of the Simplified S&E Approach, assessing a score between 0 and 1 for each question. If, for example, the question: "How insecure, discouraged, irritated, stressed and annoyed were you?" could be answered with "low", meaning, the pilot had everything under control even during a critical manoeuvre, the corresponding score is very low too and thus the work load. The different scores will be matched together using different weighting factors of each single score. The weighting factors result from comparison of six other criteria with each other by assessing, which criterion is more important in the direct comparison of 2 criteria, the one or the other. The answering of these questions may last about 5 minutes. This is less than the usual coffee break time between two drives in a ship handling simulator of about 15 minutes. So, the TLX test may not extend the usual time required to use SHSs and thus don't increase the expenses, but the results of the TLX test support, together with the other aforementioned criteria, the interpretation of simulated results.

5.10 Appendix D: Detailed or case by case design – using simulation techniques

In this appendix, the approach to perform an "ideal study" as outlined here in Chapter 5.4 and Figure 6 will be justified, explained and worked out in more detail. Note that these recommendations focus on waterway infrastructure design only. So, especially concerning the usage of SHSs, the report does not look on general demands to ensure its applicability as described in numerous existing and arising documents as the PLATINA II CESNI-report. It is rather presupposed that these demands are fulfilled and that the provider of SHS services checks the applicability of his simulator before preparing an offer for services and the client is responsible to ask for documents verifying the general applicability of the simulator. So, the report doesn't give answers on *what* a simulator is capable of – this is the objective of e.g. the CESNI-report –, only *how* its application can be checked (verification) and *how* it can be used optimally regarding the quantification of necessary waterway infrastructure dimensions.

5.11 Appendix E: Extended Concept Design Method – account for extra widths

As mentioned here in Chapter 5.5 by example of the fairway design in canals, the "basic dimensions" which are given in tables as those in Table 2, must be extended by so-called "increments" to account for special influences. Additionally to the recommendations given in the subchapters of Chapter 5 concerning the Extended Concept Design, Appendix E provides more information on that matter, e.g. formulae with wider application ranges, tables of calculated extra widths or corresponding parameters as the c_C in the formula for curve increments for practically relevant boundary conditions in canals and rivers. The approaches behind the formulae are comprehensively explained too.

As an example, the approach how to determine extra width to account for cross wind are explained and prepared for practical application. The corresponding subchapter is very comprehensive because the authors of the report recognized the lack of appropriate information on this subject. Therefore, information from existing guidelines, e.g. from Spain (inter alia concerning the wind profile and the gust factor), from The Netherlands (inter alia concerning the design wind speed), the USA (e.g. concerning crosswise wind forces and forces on the underwater body of the vessel while drifting), together with relevant standards to assess e.g. the influence of the roughness of the surrounding area on the vertical wind profile and gusts etc., were evaluated and matched together to end up with appropriate design formulae. The latter support the "Dutch Rule" for wind increments ΔF_W to be multiples (factor c_W) of the vessel length L ($\Delta F_W = c_W \cdot L$, $c_W = 0.05$ for inland waterway stretches for empty vessels).

The way to ascertain these numbers for various other conditions as different loaded container carrying vessels is illustrated in this paper in Figure 7. An extract of a large table in the report, containing calculated c_W, is presented here in Table 3 too. The calculations were made making (among others) the following assumptions:

- The reference wind speed for an inland stretch is 10.5 m/s according to the Dutch guidelines (5-6 Bft, measured in 10 m height and averaged over 10 minutes).
- This wind speed will be first reduced according to the wind-exposed height of the vessel, assuming a surface roughness of agricultural terrain (scrublands, heath or meadows, no windshield) and then increased again by 1 minutes lasting gusts (leading to 13.3 m/s for an empty vessels or vessels with 2 layers and 13.6 m/s for 3 layers) – valid for S&E quality A.
- The vessels sail in unidirectional traffic, compensating the wind forces by drifting.

The listed c_W in Table 3 show that, depending especially on the number of container layers and water depths, the extra widths may be larger than according to the Dutch 5% rule. Note additionally that the extra widths were calculated without bow thruster usage. The latter would reduce the c_W (safe side).

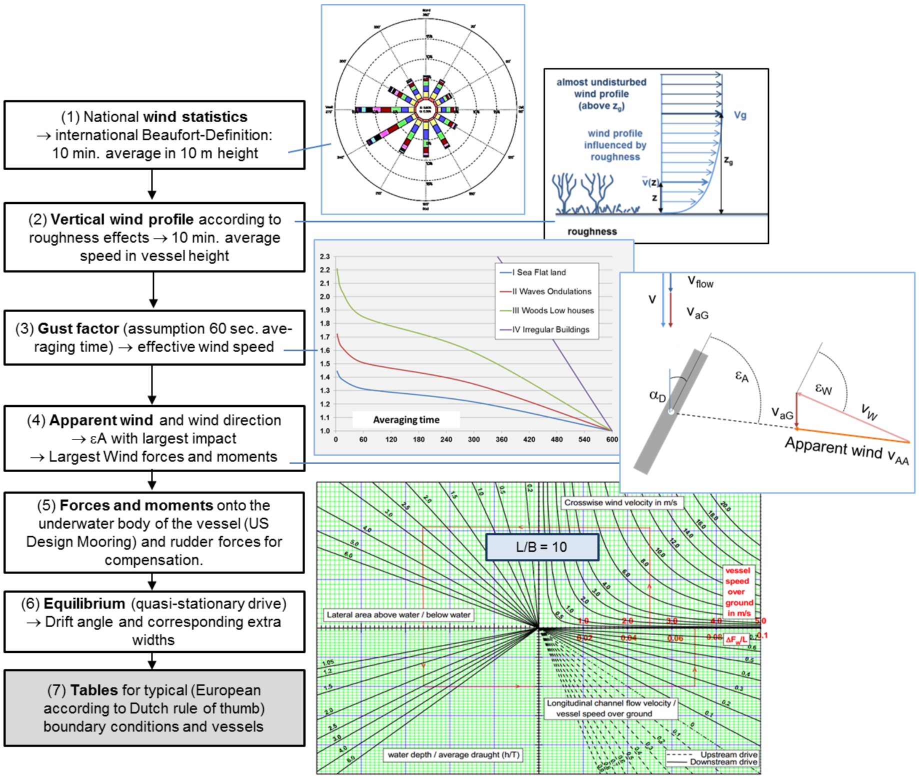


Figure 7: Visualization of the approach to determine extra width to drift against the wind

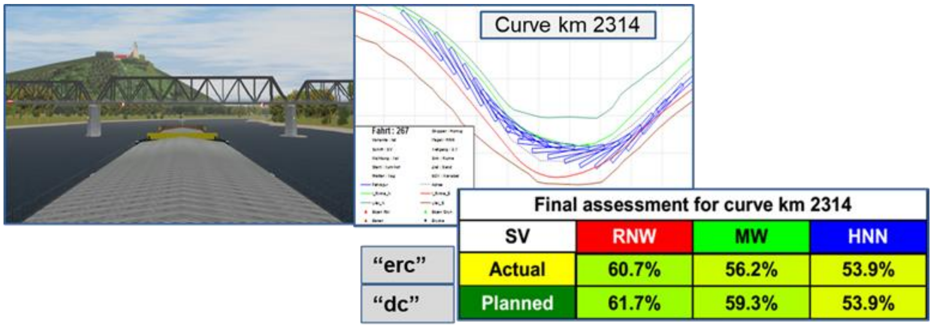
vessels and average draughts for empty vessels & 2 container layers (T2) respectively 3 layers of containers (T3)	flow velocities, waterway types, loading condition respectively number of container layers and corresponding wind-exposed height h_{SW}, driving direction							
	Canal, $v_{Flow} \le 0.5$ m/s, acting always in driving direction: $v \approx 9$ km/h), $v_{aG} \approx 10.8$ km/h		$v_{Flow} \le 1.0$ m/s ≈ **impounded river** $v_{Flow}/v = 0.4$, $v_{ag} \approx 5.4$ km/h upwards and 12.6 km/h downwards		$v_{Flow} \le 1.5$ m/s ≈ **free flowing river**, $v_{Flow}/v = 0.4$ upstream and 0.5 downstream, $v_{aG} \approx 8.1$ km/h upwards and 16.2 km/h downwards			
	empty/ 2 layers h_{SW} = 4.5 m	3 layers h_{SW} = 7 m	empty/ 2 layers h_{SW} = 4.5 m	3 layers h_{SW} = 7 m	downstream drive		upstream drive	
					h_{SW} = 4.5 m	h_{SW} = 7 m	h_{SW} = 4.5 m	h_{SW} = 7 m
GMS (110x11.4, **Class Va**), T2 = 1.6m; T3 = 1.8 m	h = 4 m: **0.060**	h = 4 m: **0.08**	h=3 m: **0.05** h=6 m **0.08**	h=3 m: **0.06** h=6 m **0.11**	h=3 m: **0.04** h=6 m **0.06**	h=3 m: **0.05** h=6 m **0.08**	h=3 m: **0.02** h=6 m **0.04**	h=3 m: **0.03** h=6 m **0.05**

Table 3: Extra widths c_W due to drifting against the wind – Class Va vessel for different loading conditions (T2=empty vessel or 2 layers of partly loaded containers, T3 = 3 layers)

5.12 Appendix F: Application of the Detailed Design Approach to an example

In this appendix, the Detailed S&E Approach will be applied to nautical investigations on the River Danube by Real Time Simulations. The example follows strictly the recommended approach outlined here in Figures 5 and 6.

Referring e.g. to Figure 5, the check of a possible application of the Concept Design method was made in previous studies, showing that the existing fairway dimensions in the German free flowing Danube river stretch downstream Straubing are far away from recommendations in existing guidelines – and in narrow curves also from the figures given by evaluating practice data in the WG 141 report. So, the performance of a detailed study was inevitable. The “Modelling Capability Check” in Figure 6, to mention just another important step, was carried out by referring to previous nautical studies concerning the Danube River with the largest approved vessels, where data for comparing e.g. the swept area widths were available. The models used could thus be verified by observed field data. The reference cases refer simply to the existing situation, but for different water levels between average low water and highest navigable water. The investigation of different water levels and loading conditions as well were unavoidable because low up to mean water levels may be relevant especially in areas with small fairway widths as between spur dykes and buoys, and high levels may be relevant even if larger navigable widths are available, because the high flow velocities increase the navigation space needed, especially sailing downstream. Therefore, always three relevant water levels were considered, both for the reference and the design case. The latter refers to the Danube River after improvement by planned training measures. The investigations were carried out with a Full Bridge Simulator, because especially the human factor is very important in case of the stressful driving situations, especially while passing a very narrow bridge and a very narrow bend.



Final assessment for curve km 2314

	SV	RNW	MW	HNN
“erc”	Actual	60.7%	56.2%	53.9%
“dc”	Planned	61.7%	59.3%	53.9%

Figure 8: Selected results (numerical values = averaged navigational “reserves”) of the application example in the WG 141 report, using the Detailed S&E approach

The simulation results were then quantified with the Detailed S&E Approach, whereby especially the way how to ascertain reasonable scores from relevant simulated parameters will be explained in detail. The study use so-called “reserves” for selected parameters as rudder angles, engine power, bow thruster use, distances to obstacles as bridge piers or buoys, path widths etc. The reserves are defined as follows: reserve = characteristic value (e.g. actual bank distance or actual rudder angle), minus some critical value (as the usual safety distance or the rudder angle, producing the maximum crosswise force), divided by a scaling parameter (as e.g. the available navigational besides a vessel at a centric ship path of a bridge opening or the maximum rudder angle by construction). The application example of the Danube River improvement shows impressively how the Detailed S&E Design Approach works and which explicit results can be achieved. It could be demonstrated that difficult driving situations, as the downstream drive in the narrow “Reibersdorf” curve (numbers in the table of Figure 8) can be made with about the same safety and ease quality after waterway improvement, leading to higher possible draughts (design case) compared to the existing situation (reference case).

6 Application example of the Concept Design

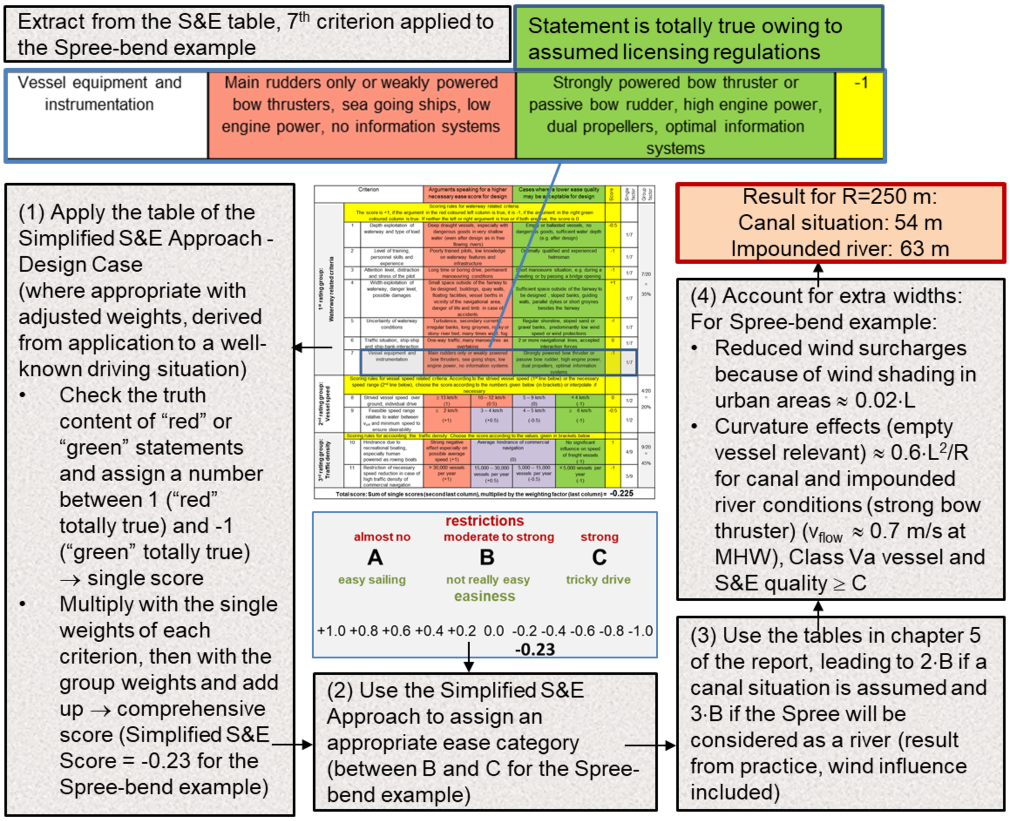
The recommended design procedure outlined especially in Chapter 5.4 of this paper will be applied in the following by an example. Without going into details concerning the formulae or the simulation technique used – this would go beyond the scope of this paper –, the main steps needed to obtain the results will be outlined. The example refers to very narrow fairway conditions in an impounded river. The approach recommended in the report will be used to check, whether larger, but modern vessels may be approved in future. This is a typical area of application of the WG 141 report. As shown in Figure 9, a narrow Spree-bend (curvature radius R ≈ 250 m) in the urban area of the government district of Germans Capital Berlin will be considered. The banks are almost vertical and the net width in draught depth is about 40 m in the narrowest reaches. The impounded Spree River has generally low flow velocities of about 0.3 m/s at mean water (canal situation), but around 0.7 m/s at mean high water (MHW), which will be considered here (≈ highest navigable water level HSW).

Nowadays, small push tow units, which are typical for the waterways around Berlin, with L = 91 m length and B = 9 m breadth are approved, but the most traffic results of course from passenger boats, but the adjoining locks would (geometrically) allow for navigation with Class Va vessels (L=110 m, B=11.4 m). So, the chosen design case refers to this vessel type, and, because of the larger swept area width in a narrow curve, to an empty ship sailing downstream in the direction shown in Figure 9.

Figure 9: Map and pilot's view on the German Spree River (government district, Berlin)

According to Figure 5, the design starts, after specification of the design case with its unique boundary conditions (driving situation: one-lane downstream, vessel type: Class Va, loading condition: empty, bathymetry: river stretch with vertical walls and sufficient depth at high water levels, flow field: small but significant flow velocity, wind exposure: not that much because of urban area), by looking on relevant national and international guidelines. In our example, the German Guidelines and several others are generally not applicable. They treat canals up to flow velocities of max. 0.5 m/s only and the curvature radius should be larger than 500 m. So, the application limits are exceeded both because of flow and curvature. But because the formulae given for extra widths in curves are also valid for smaller R and 0.7 m/s is not so far away from the "canal-limit" 0.5 m/s, the German Guidelines may be used at least for comparisons. They lead to a necessary width of approx. 49 m (almost half of it refer to the "basic with" including safety distances and the other half to the curve increment). This figure is without extra wind increments, which are not explicitly identified in the German guidelines. For comparison, the Dutch Guidelines lead to approx. 52 m (ca. 45 % refer to basic width and curve allowances and ca. 10 % to wind influence) if a "narrow profile" (low S&E quality) will be assumed. Other guidelines lead to about the same results. So, even if we assume canal conditions and follow corresponding guidelines, the existing navigable space would be too small for the new ship.

The next step is to use the WG 141 recommendations for Concept Design. For this purpose, the necessary S&E quality must be assessed first, using the approach outlined in Chapter 5.3 and illustrated for the application example in Figure 9. The corresponding table with criteria is scaled down in the middle of Figure 9. The main components of the table are two coloured columns with opposed arguments. The red coloured arguments or statements speak for a higher necessary ease quality and the other arguments in the 2nd column, which is marked in green colour, specify cases, where a lower ease quality may be acceptable. The applier of the Simplified S&E Approach has to check the truth content of both opposed arguments and assign a number (score) between +1, if the red argument is completely correct or -1, if the green statement is absolutely true, otherwise a score between them must be chosen, e.g. 0, if both arguments are true or neither the red or green argument, see step (1) on the left side in Figure 9. These single scores of in total 11 criteria have to be multiplied first with so-called "single factors", then with "group weighting factors" and finally added up, forming the comprehensive Simplified S&E Score. If there are doubts about this approach, e.g. about the group weights, the approach should be applied to a well-known driving situation, e.g. the present nautical conditions (called "Analysis Case" in the report with its own table) and compare the expected S&E category with the one from applying the approach. Maybe adapted weights where appropriate, but it must be assured that the sum of weights is always 1 – or the sum of scores has to be divided by the sum of weights, so that the entire score stays between +1 and -1. In our example, such an adaption was not necessary. To show how the scoring system works, let us look on the 7th criterion concerning the influence of the vessel equipment and instrumentation. It is displayed larger on top of Figure 9: Because the vessel is assumed to be empty and because the Waterway Authorities may demand for restrictive approval conditions for the vessel's equipment as strong bow thrusters and highly powered main thrusters as well as modern information systems, the single score is clearly -1, meaning, a lower ease quality may be acceptable because of this criterion.



Extract from the S&E table, 7th criterion applied to the Spree-bend example

Statement is totally true owing to assumed licensing regulations

Vessel equipment and instrumentation	Main rudders only or weakly powered bow thrusters, sea going ships, low engine power, no information systems	Strongly powered bow thruster or passive bow rudder, high engine power, dual propellers, optimal information systems	-1

(1) Apply the table of the Simplified S&E Approach - Design Case (where appropriate with adjusted weights, derived from application to a well-known driving situation)

- Check the truth content of "red" or "green" statements and assign a number between 1 ("red" totally true) and -1 ("green" totally true) → single score
- Multiply with the single weights of each criterion, then with the group weights and add up → comprehensive score (Simplified S&E Score = -0.23 for the Spree-bend example)

(2) Use the Simplified S&E Approach to assign an appropriate ease category (between B and C for the Spree-bend example)

(3) Use the tables in chapter 5 of the report, leading to 2·B if a canal situation is assumed and 3·B if the Spree will be considered as a river (result from practice, wind influence included)

(4) Account for extra widths: For Spree-bend example:

- Reduced wind surcharges because of wind shading in urban areas ≈ 0.02·L
- Curvature effects (empty vessel relevant) ≈ $0.6 \cdot L^2/R$ for canal and impounded river conditions (strong bow thruster) (v_{flow} ≈ 0.7 m/s at MHW), Class Va vessel and S&E quality ≥ C

Result for R=250 m:
Canal situation: 54 m
Impounded river: 63 m

Figure 9: Flow chart concerning the Simplified S&E Approach to the Spree-bend example

The corresponding comprehensive Detailed S&E Score equals to -0.23, which can now assigned to an ease category, see step (2) in Figure 9. The report proposes for this purpose a graph, shown here below the table of criteria in Figure 9. It was "designed" by applying the approach to different examples and compare it to expected results. It turns out that the S&E is between B ("moderate to strong restriction", "not really easy sailing") to C ("strong restrictions", "tricky drive"). Now the Concept-Design of the report can be applied, e.g. using Table 2 of this paper, if canal conditions will be assumed, leading to a "basic width" of 2·B. This result is indicated in Figure 9 bottom right (step 3). If the Spree stretch will be will be considered to be an impounded river, the evaluation of practice data in the report leads to 3·B for a S&E quality between B and C. This figure includes extra widths due to wind attack. Now relevant increments have to be added to this basic widths, see step (4) in Figure 9. For a Class Va vessels without using bow thrusters, the figures in Appendix E of the report lead to c_C = 0.6 in a canal with significant longitudinal flow velocities up to 0.5 m/s. For an impounded river, c_C = 0.8 will be given. This figure may be reduced in case of strong bow thrusters as assumed here to again 0.6. So, the extra width in curves is for both cases – canal and river situation, equals to about 29 m. For the canal-case wind influences may be added too. Without proof here, the consideration of the larger roughness-effects in urban areas (lower average wind speed, but somewhat increased gust influence), reduce the factor c_W in of Table 3 of this paper of about 0.06 for agricultural terrain surrounding the waterway to only 0.02. The corresponding extra width is thus around 2 m only. In the end, the necessary fairway width totals up to 54 m in assuming canal conditions and 63 m for assuming an impounded river. Also this result shows that the 110 m long vessels may not be approved according to the results of Concept Design. It should be added that, the same approach, applied to the approved vessel types of the existing situation, fits with the existing width at the narrowest point of 40 m, if canal conditions will be assumed. So, the approval of larger vessels demand for a detailed study.

REFERENCES

The present paper refers mainly to the report of PIANC INCOM WG 141 on "Design Guidelines for Inland Waterway Dimensions", to appear probably summer 2018. Further references may be related papers submitted to the Smart Rivers Conferences of 2013 and 2015 and to the PIANC World Congress in 2014.