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Paper 101 - DESIGN GUIDELINES FOR INLAND WATERWAYS: Applying Concept Design Method – Practice Approach – Case by Case Design

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ABSTRACT: The PIANC INCOM WG 141 has undertaken a great review on guidelines and practice examples as well as analyzed methods for detailed design. International standards as well as practice examples show a wide variety of design cases. One main reason for the differences is the great variety in shipping traffic. Furthermore a river is 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 design method was developed leading to three recommended design steps: "Concept Design Method", "Practice Approach" and "Case by Case Design". This approach is illustrated by three examples of fairway design: Canal, Free Flowing River, Lock Approach will show the applicability of the method.

1 INTRODUCTION

The PIANC INCOM WG 141 has undertaken a great review on guidelines and practice examples as well as analyzed methods for detailed design. International standards as well as practice examples show a wide variety of design cases. One main reason for the differences is the great variety in traffic density and vessel types (especially the hull shape, beam, length and draught, propulsion types) as well as cargo types. Furthermore a river is a complex system and the variety in its dimensions and currents is wide and continuous, due to possibly ongoing changes in the watercourse. So it is not appropriate to give just "one" number for the waterway dimension to be designed. Instead a design method was developed leading to generally three recommended design steps: Application of the "Concept Design Method", the "Practice Approach" and a "Case by Case Design".

This approach will be illustrated in this paper by three examples of fairway design in a Canal, a Free Flowing River and a Lock Approach. They will show the applicability of the method. It is important to mention, that this paper can't provide all aspects WG 141 considered. So, for more detail other papers of the workshop have to be considered (see reference list). This paper can only provide a small fraction of the entire design process. Especially the consideration of the ease quality in design will not be discussed herein and are assumed to be specified elsewhere, although they play a major role in fairway design (see e.g. Söhngen & Eloot 2014, Söhngen, 2015).

2 GENERAL APPROACH IN WATERWAY DESIGN

Once the designer has examined all the relevant studies and documents as well as clarified all open questions with the client he can start with the nautical design. That is when he starts to apply the "Design Guidelines for Inland Waterways", see e.g. Söhngen (2015), which is focusing on nautical aspects only.

The design should be performed generally in three steps as mentioned earlier. But in every case, one has to specify the aimed quality of navigation standards and all the relevant design aspects before and if necessary after the design has been performed again (see e.g. Söhngen & Eloot 2014). This may be necessary to account for possible drawbacks on the design case or generally on the planned waterway improvement.

3 RECCOMANDED STEPS IN WATERWAY DESIGN

3.1 *General Approach*

After an adequate safety and ease of navigation quality is chosen, the first step in waterway design is to look at existing guidelines (Concept Design Method). If guidelines are available, e.g. on a national basis, the choice is specified. Nevertheless – and this is the main reason for setting up additional PIANC guidelines on an international basis –, some countries don't have their own regulations or the national recommendations do not give advice for all design cases to be considered,

Besides, existing guidelines are generally only applicable to a small number of boundary conditions as for canals. But this is mostly not the case in rivers and in particular not in free-flowing alluvial rivers with their typical variety of depths, flow velocities and irregular shorelines. In these cases, the Concept Design Method fails. So, existing guidelines, even if they may treat all the relevant design aspects, have to be used carefully to find appropriate waterway dimensions and to avoid overdesigning or designing below the necessary standard.

The Practice Approach can be used if the design case under consideration is not handled in existing guidelines, or if there are doubts about the applicability of their recommendations. This means, one is looking for comparable existing design cases. This can be helpful e.g. for fairway design in rivers.

Hence, when the spread of data from different guidelines or practice examples seems too large, instead of specifying any additional values provided by WG 141, e.g. averages of multiples of L and B for harbor lengths and widths, appropriate process recommendations should be provided. These will help to support a detailed study for the design case under consideration, especially if the local boundary conditions are different from existing knowledge, see e.g. Söhngen (2015).

A detailed or "Case by Case Design" study, as it will called in the future report of WG 141, is acceptable as the costs of a detailed nautical study are generally only a little fraction of the construction costs – and the study may reduce the latter significantly. WG 141 therefore gives advice to possibilities and restrictions of modern simulation software, especially ship handling simulators for these purposes – and what should be the necessary inputs and results of simulations (see Söhngen 2015 and Eloot 2015 for more detail).

3.2 *Concept Design Method*

The Concept Design approach is generally the same as if existing national guidelines will be used. The latter reflect the special demands for waterway use and improvement of the country, especially accounting for the national fleet, the tradition of shipping, the politico-and socio-economical boundary conditions and the national and international laws to be considered. National guidelines correspond therefore with generally accepted waterway standards and practice in this country. Its application also fulfils the requirements of standardization, which is one of the methods to simplify the design processes, to support proved and sustainable solutions and so on, to reduce construction and especially maintenance expenses. So, applying national guidelines is therefore the first choice for design concepts.

Using the example of fairway design in canals and rivers, Table 1 gives an overview of design recommendations regarding the appropriate fairway width for selected international guidelines. It shows that there are only a few specifications available concerning appropriate fairway increments to account for cross-flow velocities, extra width in curves or wind effects in rivers with significant flow velocities.

country	canals and still waters				rivers with significant flow velocities				
	min. width incl. in-stabilities and safety distances to banks	extra width in curves	cross-flow increment	wind increments	min. width incl. in-stabilities and safety distances to banks	extra width in curves	cross-flow increment	wind increments	safety distances for groynes
China	x	x	x	x	x	x	x		
Nether-lands	x	x	x	x					
Russia	x	x	x	x	x	x	x	x	
Canada	x	x	x	x					
France	x	x			x	x			
Germany	x	x	x						

Table 1: Available design recommendations (x) in selected guidelines concerning different aspects of appropriate fairway width in canals and rivers

Besides possible application limits of all the guidelines, e.g. concerning the design of fairways in rivers with significant flow velocities (SRC 2013 Conference Paper), there are also some general disadvantages in using guidelines: 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. 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.

But even if one has a broader view, taking not only the national guidelines but taking also e.g. the Chinese or the US guidelines for the design of fairway width in rivers with significant flow velocities, because there are only a few guidelines available treating this design case, one might get confused. There are partly huge differences in recommended special waterway dimensions, e.g. the length of lock approaches. These may be caused e.g. by different safety and ease of navigation standards or by different ship types, to mention just two aspects. So, taking into account existing guidelines only does not solve the design problem in many cases.

For this reason, WG 141 proposes the following steps when applying the Concept Design Method:

(1) Look into national guidelines for all design cases covered by these guidelines.
(2) Compare with the extract of the review of existing guidelines (Rettemeier 2013) and with recommendations of WG 141.
(3) Extend the design if necessary and possible, using adequate formulae for so called "increments".
(4) Verify design case, compare desired and achieved category of quality of driving, and check if Concept Design Method provides suitable results.

3.3 *Practice Approach*

As indicated in Table 1 only little design information is available regarding fairways in rivers. This concerns e.g. the lengths and widths of lock approaches or the necessary fairways in rivers. Especially in river situations, one has to be very careful in comparing. Besides that, there is the great variety in shipping traffic. Intensity and composition of the traffic, ship-dimensions, propulsion types and cargo are the most relevant variables.

Another important finding is that safe navigation seems still possible, even in case of very narrow conditions as in case of lock approaches or the fairway widths on the free flowing. This may be possible due to very restrictive licensing of the corresponding vessels, demanding e.g. for efficient active bow thrusters.

Thus, the search for comparable cases is not easy in the case of river situations and must be executed with care. This also explains the very few existing guidelines for inland fairway design in rivers. Examples of existing river situations were collected from different countries. Especially because of lacking data and the sometimes unknown real usage of the fairways, those examples were examined on only a few aspects and in a rough way (see Koedijk, 2013). Nevertheless, they show the range of fairway data from waterways in use.

For this reason it is difficult to compare the design case with practice examples. Nevertheless it is important especially if the Concept Design Method fails to get an idea of the proper dimension and evaluate the restrictions. Hence WG 141 evaluated examples of fairway width in rivers and provides accordingly dimensionless graphs as Figure 2 for two-lane traffic.

Looking at lock approaches the variety of data practice examples is even higher. There hardly seem to be any compelling reasons why one specific lock harbour is so much longer than another one. But one of the main findings from this wide spread of existing dimensions is that, planners of lock approaches probably tried to make the harbour length as long as feasible, in order to optimize the quality of navigation standard – and accepted a lower standard if there was obviously no chance to realize larger dimensions. Even in cases of very short harbor lengths safe navigation seems still possible, but clearly the ease of navigation is reduced. This underlines the need for an adequate choice of necessary ease standards and the assignment of ease of navigation categories to practice examples.

The problem of assessing the harbor length becomes more relevant if an existing waterway has to be adapted to larger vessels. These enlargements are generally indicated, especially because of the wider swept area width of longer ships in the strong cross currents in front of harbors and the need of an adapted length with reduced flow velocities inside harbors. If these information gaps cannot be closed by looking at practice examples of lock approaches in rivers, the practice approach fails. The detailed design (Case by Case Design) has to be adopted.

The task is to find out existing examples that are comparable to the unique design situation considered. For this reason, WG 141 proposes the following steps when applying the Practice Approach:

(1) Define the category of driving quality desired, assess the safety and easiness of navigation desired respectively.
(2) Analyze the boundary conditions of the design case and select an appropriate practice case, applying the dimensionless graph or tables.

(3) Compare the results to practice examples provided and verify the driving quality and boundary conditions.

3.4 *Case by Case Design*

Examples of existing harbor lengths demonstrate impressively the partly large range of uncertainty regarding appropriate waterway dimensions (Söhngen & Eloot 2014). Thus, as mentioned above, the performance of a Case by Case Study seems necessary especially for lock approaches in rivers with significant flow velocities.

Because ship handling simulators are more and more in use today, not only for training of nautical personal, but also for waterway design purposes, WG 141 provides some process recommendations on the optimal usage of such simulators. They shall include (Söhngen 2015):

- Choosing the optimal investigation method (bridge simulator, where a human being steers the ship; fast-time simulation, using autopilots to steer the vessels; traffic simulations, taking simplified driving dynamics or scale model tests),
- Choosing, collecting and appropriately processing the required minimum bathymetric, flow, construction and calibration data, especially for the design vessels,
- Calibration of the flow models and the parameters of the design vessels, taking field data or/and scale model tests and comparing them with simulation results, if possible having similar conditions as the design case,
- Validation of the models by performing runs to compare them with measurements that are not used for calibration,
- Conducting simulations, especially with respect to human factor effects, which may require many simulation runs for one variant,
- Choosing and conducting adequate sensitivity analyses concerning critical design parameters,
- Statistical elaboration and interpretation of results from different runs with the same boundary conditions, but with different drivers, to account for human factor effects and
- Assessment of application limits and unavoidable uncertainties of the used simulation technique.

The last-mentioned process recommendations seem to be somewhat academically, if one looks on the practice of using ship handling simulators, especially because the available data are often very rough or incomplete and the budget is limited. Nevertheless, it seems necessary to show what is really necessary to perform a successful study.

There is also the fact that users of ship handling simulators tend to overrate the applicability of simulators just as clients of the navigational study tend to mix up real life and virtual reality in the simulator. Consequently the application limits of standard ship handling simulators must be considered. Generally speaking, the limits are presently reached in the case of ship-induced currents and when the water level drawdown interferes significantly with the water body and with other ships. Future developments which are under way at several developers of ship handling simulators may be able to overcome these application limits by simulating ship-induced currents and waves simultaneously with the ship motion.

4 APPLYING THE THREE STEP DESIGN BY EXAMPLES

4.1 *Outline of the design case*

The design case will show the general applicability of the design procedure recommended by WG 141. Thus an example of fairway design in Germany for the design of canals, free flowing river and lock approach is chosen. Generally speaking Germany focuses on the enlargement of waterways. Here usually CEMT Class IV waterways will be improved for CEMT Class V traffic.

Let us assume the design case is the dammed river, which is licensed for traffic CEMT Class IV. We are looking at the part of the river with a side canal approaching the lock, the lock approach and a free flowing part downstream of the lock. The client wants to license CEMT Class Va vessels. The designer has to look at the following aspects:

- canal dimensions
- free flowing River
- lock approach

The actual category of quality of driving is B ("moderate to strongly restricted drive", it is the average between A and C, definitions see e.g. Söhngen & Eloot, 2014); traffic analysis indicates that the category of quality of driving could be C ("strongly restricted drive on short distances", lowest category) The aspects of choosing the proper category of quality of driving is not part of the discussion of this paper.

4.2 *Fairway Design in Canals*

The starting point in the fairway design should be the width in a straight section. What has to be considered first is that all the values specified in existing guidelines are generally multiples of ship's breadth B, measured in the depth of a ship's draught (Table 2).

[m]	actual situation	design case
Canal Profile	trapezoid (1:3)	
driving	one lane two lane	one lane
wind condition	3-4 Bf	
Cross flow [m/s]	0.3	
design vessel		
CEMT Class	IV	V
traffic density [vessel/a]	5.000	5.000
quality of navigation	B	C
length	165	110
beam	9.60	11.45
drought	2.50	2.80
squat	0.50	0.20
Cf (turning point)	1.0	0.8
fairway dimension		
width	36.0	36.0
depth/draught	1.6	1.4
min depth	4.00	4.00
Radius	1,000	1,000
extra width	13.4	3.8

Table 2: Fairway design case canals

Bear in mind that the additional increments coming from cross-flow, wind, curvature and quality of driving scale by the length of the ship taking the swept path into account.

Concept Design Method:

Step (1) – look at national guidelines:

Germany has national guidelines for the design of fairways in canals for CEMT Class V vessels. So the planner has to design the fairway according to these standards (table 3).

[m]	Canal width		Fairway width (incl. s)	
depth	Two-lane	One-lane	Two-lane	One-lane
Trapezoid Section (1:3)				
4	55	42	36	21.4

Table 3: German design guidelines fairways in canals

The actual fairway width is 36.0 m. So, if the design demands for two-lane traffic the fairway is sufficient in a straight section. The category of quality of driving for a two-lane enlargement will result in category B.

The actual depth is equivalent to the design depth. No further investigation is required (see also table 4 for international comparison).

Increments:

But there is another aspect that has to be considered: The canal considered is located in a curve. German guidelines give advice to extra width in curves (category B). The radius should be larger than 500 m. In case the bend radius is less than 2,000 m an extra width has to be considered (C_f is the position of the vessel's turning point, measured from stern to bow and related to vessel length, usually 0.8 – 1.0):

$$\Delta w_R = \sqrt{(R+B)^2 + (Cf \cdot L)^2} - R - B$$

The actual radius of 1,000 m demands an extra width in curves of 3.8 m applying national guidelines. The present situation would even demand an extra width of 13.8 m which can only be met in a one lane driving situation.

Step (2) – compare with WG 141 advice:

As the desired category of ease is C, and comparing the results to WG 141 recommendation for two-lane traffic an extra width in curves can be avoided if R is bigger than 4 L (440 m). Thus applying WG 141 recommendations the extra width in curves is not necessarily required (Table 5). So two-lane traffic can be achieved.

Step (3) – increments:

There is no indication for any other increments with respect to cross flow, wind, high traffic density, etc.

Step (4) – verify design case:

The design ship can drive using the present fairway only by changing from two-lane to one-lane traffic. The design case for the canal is finished; a detailed study is not necessary (Figure 1).

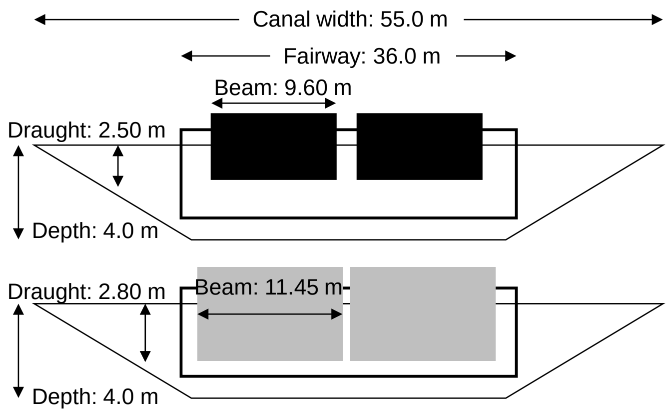

Figure 1: Design case Fairway width in canals

	Ship (BxLxD)	two-lane			one-lane		Driving quality
		F/B	D/d	n	F/B	D/d	category
China Canal	Average (Class III – VII)	4,4	1,3	7	-	-	A-B
China Channel	Average (Class II – VII)	4,4	1,4	6-7	-	-	A-B
China River	Average (Class I – VII)	4,4	1,2	-	2,3	1,2	A-B
Dutch normal	11.45x185x3.5	4.0	1.4	8.7	2	1.3	A-B
Dutch narrow	11.45x185x2.8	3.0	1.3	6.7	-	-	B-C
France	11.45x185x2.5	3.1	1.4	5.8	-	-	B-C
Germany	*11.45x185x2.8*	*3.3*	*1.4*	*5.6*	*1.8*	*1.4*	*B-C*
Russia	16.5x135x3.5	2.6	1.3	-	1.5	1.3	C
US River	10.7x59.5x2.7	~3.3	~1.3	~4.9	~2.2	1.3	B-C

Table 4: Fairway dimension as a factor of ship dimension

Waterway	Fairway width for alternate one-lane				Fairway width for two-lane			
	Ease quality			Remarks	Ease quality			Remarks
	C	B	A		C	B	A	
min F	2.0 B			for security reasons	3 B	4 B		2.5 B can damage the canal
min n	2.5	3.5	4.5	to keep speed	3.5	5	7	to keep on speed
min D	1.3 d			because of squat & efficiency of bow-thrusters	1.3 d	1.4 d		because of squat & efficiency of bow-thrusters
min R	4 L	7 L	10 L	to avoid dW	4 L	7 L	10 L	
max v_{flow}	0.5 m/s				0.5 m/s			
max v_{cross}	0.5 m/s				0.5 m/s			
design v_W (inland)	5-6 Bf				5-6 Bf			
design v_W (costal)	6-7 Bf				6-7 Bf			

Table 5: Concept Design Method, Fairway width up to 30,000 cargo vessels a year (WG 141 recommendation)

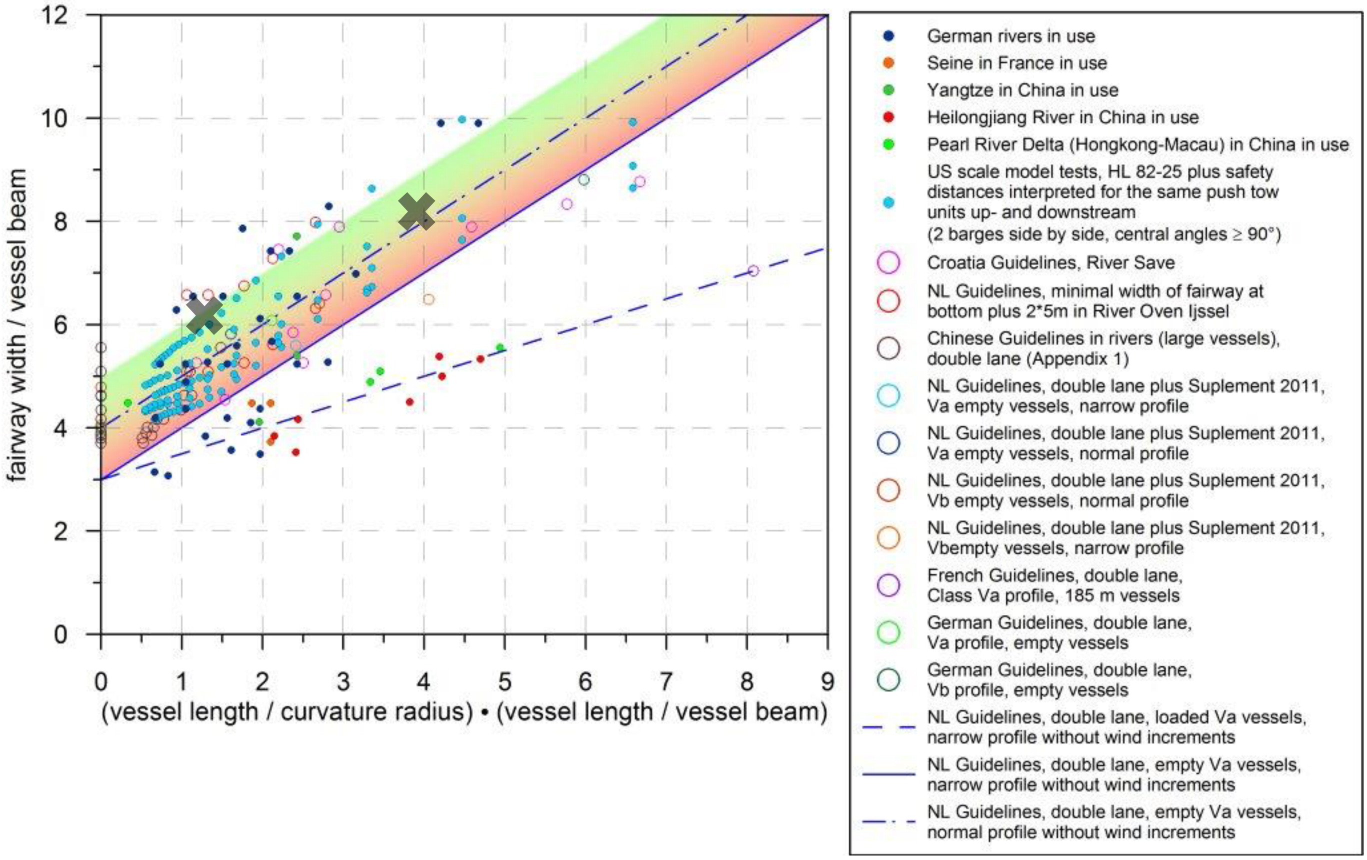

Figure 2: Existing fairway widths in rivers and from guidelines (width in draught depths), interpreted as to be limited by buoys, related to vessel breadth for two-lane traffic

4.3 *Free Flowing River*

The second part of the design case is a free flowing river situation. Typical local boundary conditions to be considered for analyzing or dimensioning the fairway in a free flowing river are given in Söhngen & Eloot 2014.

We are looking at a free flowing river situation downstream of a lock. It is located in a curve, the fairway width is 150 m. More details and boundary conditions can be taken from table 6. Besides the aspects of widths, the depths have to be considered too. In river situation one has to give special attention to this aspect of design, since in a free flowing river situation the water level can change significantly at different water stages. So, one has to choose the design depth with respect to economic aspects as well.

Concept Design Method:

Germany has no national guidelines for the design of fairways in rivers. China and the US are the only countries providing guidelines with the clear disadvantage of totally different assessment of quality of navigation. So the concept design method fails in this case, although the Chinese guidelines maybe useful in general.

Practice Approach:

Fairway widths:

The fairway widths on the free flowing Upper Rhine River or those on the Main River prove that safe navigation seems still possible; even in case of very narrow conditions. This may be possible due to the very restrictive licensing of the corresponding vessels, demanding e.g. for efficient active bow thrusters. It may be necessary to sail with high attention and to use all the navigational means available.

Figure 2 shows a dimensionless graph comparing existing fairway widths F and related ship beam B at typical narrow reaches for two way driving (for more details see Söhngen & Eloot, 2014). German rivers in use range between 3 B and 10 B. The corresponding flow velocities are around 1.5 m/s. So generally speaking two aspects are important:

1.) Even looking on the smallest values of F/B, they are bigger than those of canals. This means that there is generally a need for larger navigable widths in rivers than in canals, e.g. because of stronger influences of cross flows, turbulence, wind and also the orientation is generally worse in case of rivers compared to canals with their clear bank lines. Furthermore the data for canals include safety distances to banks (in draught depth), but the fairway data of rivers do not. Hence, the nautically usable width in rivers is still bigger than the "official" fairway width.

2.) There is a significant influence of the curvature of the river on the necessary fairway width. This can be shown even in case of constant fairway widths over long reaches as from the Rhine, because the permitted vessels are smaller in case of a narrow curve as it is the case in the Middle Rhine reach near the Loreley Rock than in more or less straight river reaches.

Our design case is indicated in Figure 2. Presently the fairway width (150 m) to ship beam (9.6 m) ration is 7.8 (Fairway width 150 m). In the future the ration would drop to 6.5 if the fairway will stay in place (fairway width 150 m, ship beam 11.45 m). Compared to a typical German river situation it corresponds well with other reaches with respect to quality of driving. The vessel length to curvature ration drops from 3.8 to 1.4 respectively. Still a safe driving is possible so the fairway width enlargement will not be necessary.

[m]	actual situation	design case
water body	free flowing river	
SLWL 95%	1.80	2.00
AWL	3.25	3.50
flow velocity [m/s]	1.50	1.50
river bottom	gravel	
extra depth	0.00	0.50
design vessel		
CEMT Class	IV	Va
traffic density [vessel/a]	10.000	8.000
quality of navigation	B	C
length	165	110
beam	9.60	11.45
drought	2.50	2.80
squat	0.50	0.20
Fairway dimension		
width	150	150
depth/draught	1.30	1.25
min depth	3.00	3.50
Radius	750	750
width/beam	7.8	6.5
l/R · l/b	3.8	1.4

Table 6: Fairway design case free flowing river

<u>Fairway depths:</u>

The design channel depth depends on design craft draught and underkeel clearance. The clearance is a kind of safety margin, depending on craft types (squat) and nature of river bottom etc. It also participates on driving dynamics. Moreover, two values are of interest: the depth at standard low water category, also called guaranteed depth, and the depth at average water level.

Water Level:

The standard low water level (SLWL), or the design lowest navigable water level, is the level below which the water seldom falls. It is usually defined as reached 346 days a year (95%). It can be defined between 90%~98% of guaranteed rate of annual duration according to national demands.

The guaranteed depth below SLWL is essential for the design of a craft operating all year round. This is especially important for tugs and pushers, and in free-flowing waterways often leads to design pushers of less than 1.5 m draught. It also limits the diameter of screws in self-propelled barges design, and leads to the use of tunnels to retain a sizable diameter.

But the depth below average water level (AWL) is of more relevance in the economic study of a prospective traffic. It is calculated with reference to the yearly hydrograph of a river, and excludes the shallow period (below SLWL) when the draught is not sufficient, as well as the extreme flood period, (usually 10 days) which generates hindrances to navigation either due to the speed of the current or to low bridges.

Underkeel Clearance:

WG 141 proposes a channel depth of at least 1.3 times the draught. This value assures a good quality of driving accounting for sufficient underkeel clearance. The ratio can be decreased with respect to quality of driving and taking the nature of the river into account. In this case the designer has to define the underkeel clearance which depends on the nature of the river bottom as well as the ship type and equipment. The following aspects have to be considered:

- The squat increases with vessel speed relative to water. So, easy driving at high velocities demands sufficient underkeel clearance.
- With decreasing depth/draught ratio the possible ship speed decreases. This may lead to extra width in curves and wind in case of maneuvering situations. A minimum of 0.2 m of squat has to be considered.
- If an increasing fairway width can't be achieved an extra minimum underkeel clearance is

necessary for safe navigation so bow thrusters or twin rudders are fully effective:

0.4 m river bottom solid rock;
0.5 m gravel bottom;
0.5 m fully effective bow thruster.

The actual average depth of 3.25 m is not sufficient for the new situation if a draught of 2.8 m should be met in average. Thus the draught of 2.8 m, the underkeel clearance of 0.2 m and the extra depths to use fully effective bow thruster of 0.5 m demands for an increase of the depths (3.5 m).

While the fairway width of 150 m is sufficient for the new design vessel and desired design standard, the depth of the fairway has to be improved by 25 cm for safety and economic reason (see Table 6). A detailed design is not necessary.

4.4 *Lock Approach*

The general applicability of the three step approach applying concept design and practice approach has been shown. Looking at the lock approach, the harbor located between the lock and the free flowing river situation will demonstrate the complete three step design.

The actual situation the approach channel is dimensioned according to the CEMT Class IV design convoy (see table 7 for all details):

[m]	actual situation	design case
Lock	double lock	
wind condition	3-4 Bf	
Cross flow [m/s]	0.3	
design vessel		
CEMT Class	IV	V
traffic density [vessel/a]	5.000	5.000
quality of navigation	B	C
length	165	110
beam	9.60	11.45
drought	2.50	2.80
Lock approach		
total harbor width B/b	3.5	2.9
breadth	33.5	33.5
total harbor length L/l	1.5	2.2
Length	250	250
straight section L/l	1.0	1.5
straight Section	165	165
entrance funnel L/l	0.5	0.8
entrance funnel	80	80
min depth	3.5	3.5
safety margin	5.0	4.0

Table 7: Design of lock approach

Concept Design Method:

National guidelines:

Germany provides guidelines for lock approaches, although they should only be taken in case of high traffic situation (reflecting level of quality of navigation A-B).

Here the length of the area for the lock approach is subdivided into the length of the inlet with a ratio of 1:4 to the width (> 110 (80) m) and the mooring area (Figure 3). The length of the mooring area depends on the traffic density and should be at least 2 times the length of the design vessel (2.0 times the length of the design convoy). The total length of the approach channel should thus be at least 2.8 L. The straight section (no curves) should be 1.5 the length of the design vessel and 1.0 the length of the design convoy.

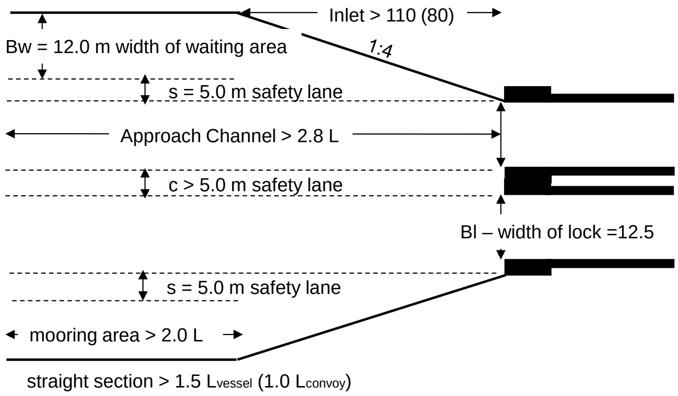

Figure 3: German lock approaches

The total width takes the width of the waiting area (12.0 m) and the lock (12.5 m) as well as a safety lane of 5.0 m (4.0 m in exception) into account. Thus the approach width should be at least 2.5 B for single locks and 3.5 B for double locks.

The demanded length of the harbor of 308 m, there of 165 m in straight section can't be realized if server impact in banks should be avoided. Thus the guidelines fail with respect to harbor length.

Furthermore at the entrance funnel the widths can't be met (2.9 B for a double lock instead of the required 3.5 B), especially taking the curve situation into account. In this case, further investigation is needed.

WG 141 recommendation / guidelines:

Since harbor dimensions/lock approaches vary greatly throughout the studied guidelines (table 9), the working group did not come up with a straight recommendation and recommends a detailed study instead. But the inlet should be at least 2.0 B (single lock) wide and 1.0 L long. The first number corresponds to the minimum width for one-lane canals and the latter ensures that the vessel stays inside still water while it enters the lock chamber. These values thus can be used as a good starting point for further investigation.

Lock Approach	B_{LA}/b	L_{LA}/l
China	3.5 - 4.5 (s)	3.5 - 4.0
	7.0 (d)	3.0 - 3.5*
Dutch	2.2 (s)	1.0 - 1.2
French	2.9 (s)	0.5*
Germany	3.0 - 4.0 (s)	2.8
	4.5 - 6.0 (d)	

Table 8: Lock approach (LA) as a factor of ship dimension (*from top of jetty to lock entry)

Practice Approach:

Next it is appropriate to look at practice examples in Germany. As indicated earlier the harbor length and breadth vary significantly (see table 9). Still one can see that the design case would not lead to an unusual situation in Germany. Especially the river Neckar has even smaller values.

Still the curvature situation should be investigated further thus a detailed study is appropriate.

River	B/b (u)	B/b (l)	L/l (u)	L/l (l)
Main	2.8 (d) 1.8 (s)	2.8 (d) 2.4 (s)	~ 2.5	
Neckar	8.3 (t) 2.6 (d) 2.3 (s)	4.2 (t) 2.5 (d) 2.0 (s)	0.7 – 1.4	1.0 – 2.1

Table 9: Existing harbor length in German dammed rivers

B(L) = breadth (length) harbour – breadth (length) berthed ship(s), b(l) = beam ship, u = upper harbour, l = lower harbour, d = double lock, s = single lock, t = triple lock

Detailed Design:

The variety of possible methods for the detailed design ranges from simple analytical methods to numerical simulation and ship handle simulators. Details are provided in (Söhngen 2015).

Looking at the Practice Approach there is only a small gap of verification left. Both cross flow in wind play a minor role. So it seems to be appropriate to start the detailed design, using an analytical method. Here the designer should vary the best way of entering and exiting the lock and the extra widths in curves (swept path) is potted (Germany provides a simple routing program accounting for extra widths in curves analogous to the a.m. formula to do this exercise, Figure 4).

Looking at the results of the design process one can state that, the design vessel (CEMT Class V) can navigate in the lock approach designed for CEMT Class IV convoys. The safety distance indicated in German guidelines can even be met.

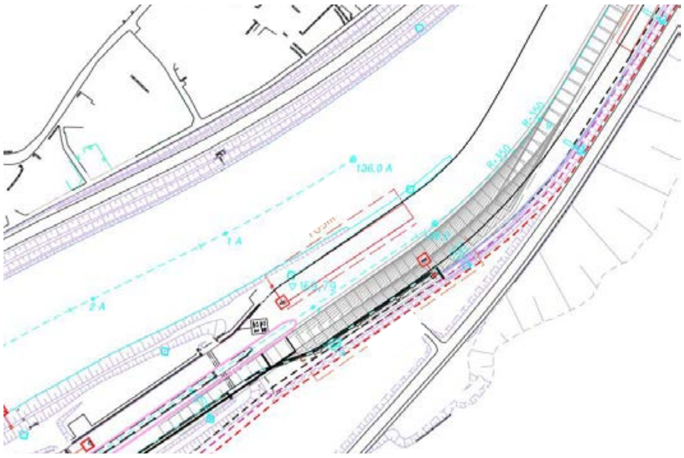

Figure 4: Detailed design lock approach (class Va vessel 110 m)

5 CONCLUSION

All three design cases considered show the general applicability of the proposed design method. Special attention has to be taken with respect to the limits of each step of the three step design method.

If the Concept Design Method fails, which should be the first choice otherwise, the Practice Approach will help the designer to get a better understanding of his design case. He has a good starting point for any detailed study limiting the costs of further investigation.

Although one could come up with the assumption anyone can perform the design of fairways, one has to look at the approach with great care and experience. Especially the desired quality of driving and the aspects of traffic play an important role as well. So the designer needs good understanding of nautical aspects as well as water engineering to select the correct boundary conditions.

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