Best Practice Approach for Layouting Technical-Biological Bank Protections for Inland Waterways – PIANC WG 128

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Abstract. The worldwide increasing number of national guidelines and growing experience with realized green bank protections (constructions using insofar possible living or at least wooden construction material) in navigable waters, led to install a PIANC INCOM Working Group (WG) to collect and condense expert knowledge in this field of work and prepare it for practitioners for design purposes. The corresponding PIANC report, called "Technical-Biological Bank Protections for Inland Waterways", is foreseen to be released this year.

The report, whose structure, content, key findings and approach will be highlighted briefly in this contribution to the Smart Rivers Conference, tries to overcome the usual problems in design cases, which need knowledge and experience of civil engineers, eco-engineers and ecologists altogether and the way how the success of bank stabilization measures will be noticed and rated. The WG members had to notice that functionality assessment is not that simple, whereby partly huge differences between those who designed, realized and maintained measures and external parties as well as cultural differences occurred.

To overcome these problems and thus to objectivize the choice and layout of alternative solutions, which may help to convince people responsible for waterway development and maintenance to use green measures instead of traditional bank protections as riprap, a Best Practice Approach was developed, based on a catalogue of numerous realized measures, which are described e.g. in so-called Fact Files. The content of these descriptions, especially the local boundary conditions (BCs shortly in the following) and the balance between

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aims and achieved functionality issues, was used to assess the possible suitability of a chosen measure under generally different design conditions than those in the described realizations.

This was achieved inter alia by a scoring system, assessing differences between Design- (DC) and Analysis Cases (shortly ACs from the catalogue of measures), which is called Feasibility Check (it answers the question, whether experiences made with the AC-cases can be transferred to the DC) and differences between user-specified aims in the DC and expected performance issues from the ACs, called "Suitability Check" (answers the question, how far expected functionality issues may probably be achievable). This was done both for technical and ecological issues, whereby the scores were chosen and reviewed interdisciplinary and internationally to overcome the aforementioned assessment differences.

Keywords: Bank protection · Bioengineering · Multi-criteria analyses · Analytic hierarchy process

1 Introduction

The report of WG 128 offers a Best Practice Approach (BPA shortly in the following) to layout alternatives, so-called Technical-Biological Bank Protections (TBP shortly in the following). These measures use as far as possible vegetable construction elements as living plants or dead wood. Conventional construction components as sheet-piling or riprap (revetment made from heavy loose stones) shall be avoided as far as possible. This shall lead to bank protections, which are only as strong as really necessary and as weak or "green" as possible. Optimally, natural vegetation and succession shall take over the desired protection function short and long-term.

It is obvious that such "green" bank protections, whereby a collection is shown in Figs. 1, 3 and 5 cannot be designed in the same way as their technical counterparts. This is, as the latter need very much less information for design as TBPs. These are in principle the magnitude of ship-induced impacts and some properties of the bank to be protected as the slope inclination and of the friction angle only. These restricted design parameters allow also the standardisation of conventional bank protections to a large extent.

By contrast, the functionality of TBPs is depending generally on a huge number of influencing parameters.

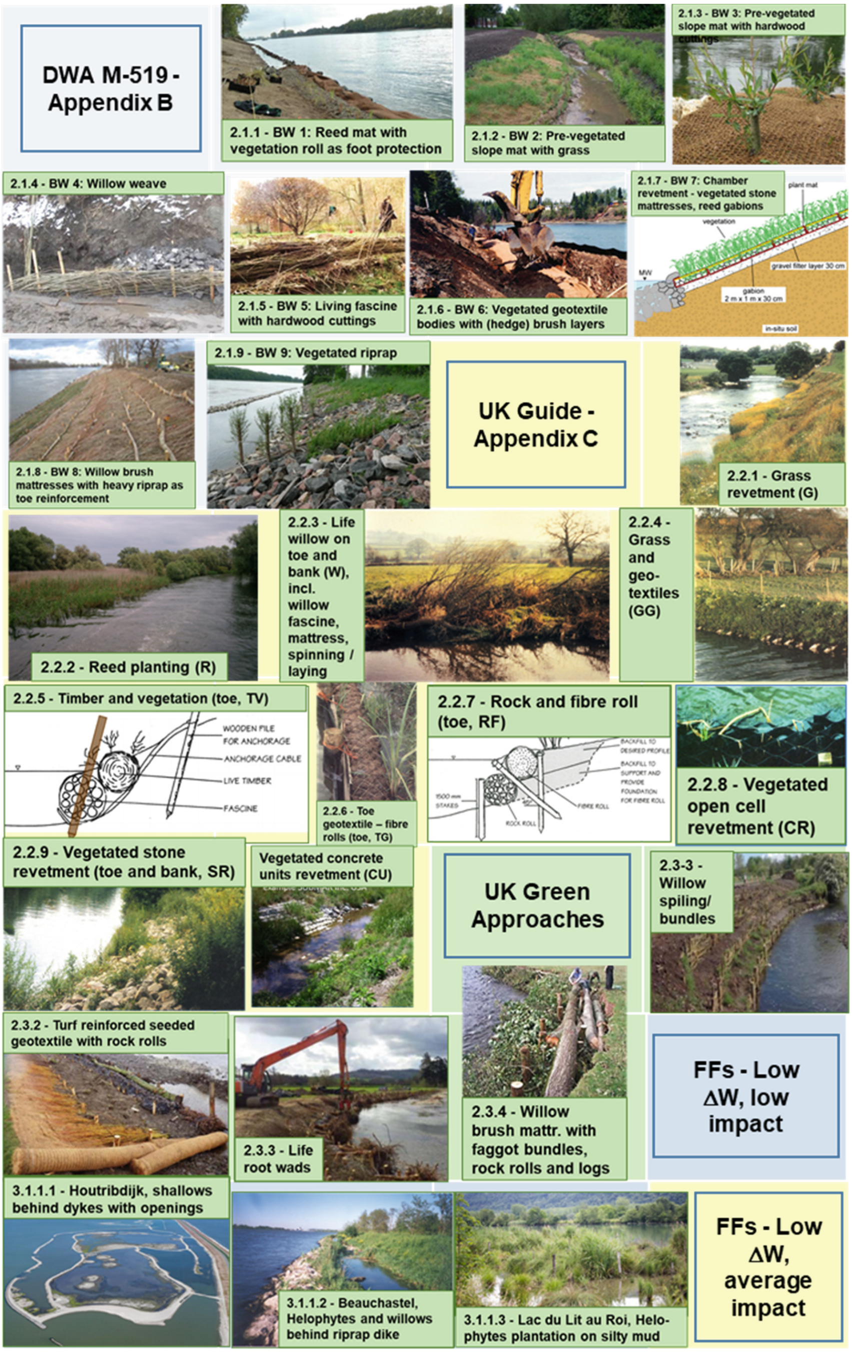

Fig. 1. Visualisation of all measures described comprehensively in Part 2 of the WG 128 report: From DWA-M-519, over the UK Guide up to FFs for low water level changes (ΔW) and low ship-induced impact – the designations of the measures are abbreviated

These are e.g. the local BCs as the magnitude of water level changes, especially the duration of draught and flood periods, which influence the possible vegetation or the altitude difference between mean water (MW) and the highest shipping level (HSW), which determines the efficiency of wave-breaking pre-embankment constructions. Other important local boundary conditions determine the vitality of vegetation, e.g. the precipitation, the slope (inclination), the width of the vegetation zone or possible shading by buildings or large trees. Other impacts – besides those from navigation – such as frost heaving or ice drift are also relevant.

But also different planner's aims are design-relevant as the necessary stability, e.g. against the dominant navigation-related loads or the fulfilment of ecological demands as the enhancement of water-bound and terrestrial ecosystems, the creation of ecological stepping stones up to social or legal demands as the enabling of recreational activities.

This means, the design of TBPs is generally very much more complex compared to technical protections and led to the decision to develop a design approach, basing on experiences gained from numerous realized measures (collected in Part 2 of the report and visualized here in Figs. 1, 4 and 5). These experiences were analysed and extended by expert knowledge coming from the members of the PIANC WG, which are called "projections". They include the assessment of "worst case" BCs, where the measures may sill wok according to the expert's assessment and the higher functionality, if adaptions to the realized measures would be taken.

The challenge is, and this is the main purpose of the so-called Best Practice Design Approach, to "transfer" the experiences made e.g. concerning the achieved stability and sustainability, the potential ecological upgrade or other planner's aims at the site of realisation (called Analysis Case or AC shortly in the following), to the boundary conditions and planner's aims at the site, where a new measure is planned (called "Design Case or DC shortly), by tackling all relevant design criteria in a preferably quantitative way. This is a multi-criterion approach, which should be facilitated as far as possible for practitioners in a PIANC report.

2 Outline of the Best Practice Approach

This BPA bases on the following points, depending on the type of reader and applier (from a decision-maker in a waterway authority, which needs an overview of possible alternatives to riprap or sheet piling only, up to a planner in an engineering bureau) of the report and which is visualized in Fig. 2:

It is recommended to read Part 1 of the report first, maybe in different study depth as indicated in the coloured frames on the left on Fig. 2 according to the profession and interests of the reader. Also the application of the report may be more or less comprehensive for different appliers, as indicated by the dotted, coloured frames on the right hand side of Fig. 2.

It is recommended to read for this purpose at least

Chapter 2, reviewing relevant literature with focus on existing guidelines (Fig. 2), Chapter 3, offering short descriptions and common design features of TBPs and general design rules, Chapter 4, which discusses the content of Part 2 with descriptions of all the collected measures and explaining the "Screening Method" for pre-selection, which uses only a few characteristics of BCs and design features and which are collected in a big Overview Table.

Then it is recommended to have a first look into Part 2 next. This is very important, as the applier learns a lot about possible solutions with its various construction details and application ranges.

Then the applier is forced to go into details of Chapter 5, which presents the most important and very comprehensive pre-selection tools, developed from the WG and which are explained in the next paragraph of this paper in more detail. They tackle both technical and ecological issues as well as differences in BCs of the DC and the various AC(s), as well as possible discrepancies between demands and functionality issues of the measures considered. Social and legal aims are not tackled in the pre-selection tools as the focus is on answering the questions: What is feasible and what works! But these aims will be of course accounted for in the end while comparing selected variants by using the multi-criteria tool AHP (Analytic Hierarchy Process).

Then the applier is demanded to read Appendix B, which describes comprehensively an important part of a German Code of Practice, the DWA M-519 Bioengineering Approach, tackling a very restricted number of design criteria, that are all related to local boundary conditions and may be used as alternatives to other pre-selection tools and

Appendix C, which describes a reviewed and extended British Waterway Management Guide (1999), using a larger number of criteria than the DWA approach, but they are again mostly boundary-related. The UK Guide offers a very stringent, technological approach as the one of the DWA Guideline, whereby it is recommended to use it as a fourth alternative for pre-selection.

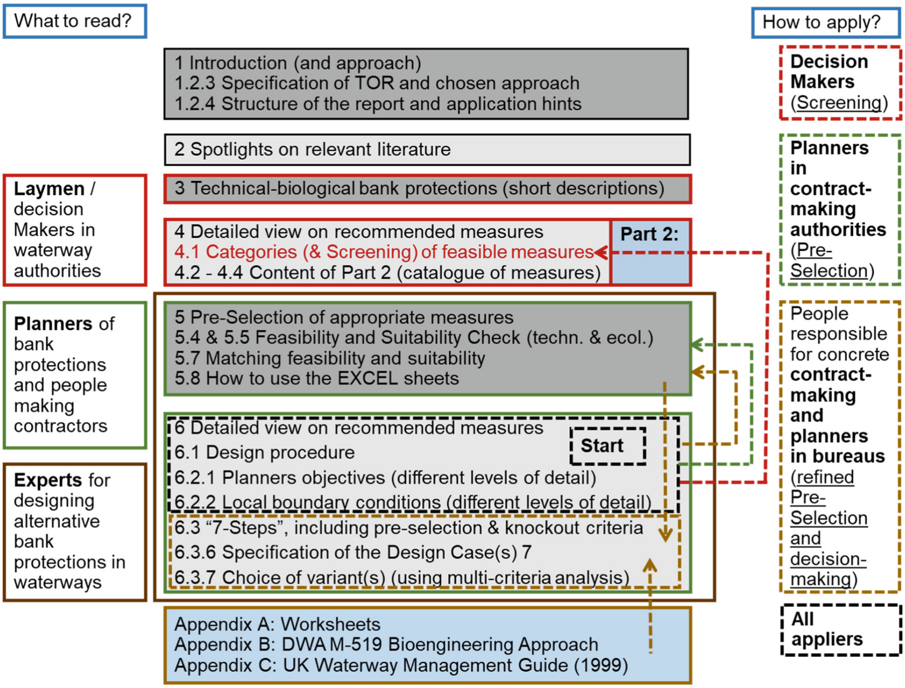

Fig. 2. How to read (hints on the left for laymen up to experts) and apply (from decision-makers up to planners on the right) the WG 128 report (Part 1) for different users – chapter names abbreviated

Then it is recommended to read and finally to apply the approach outlined in Chapter 6, which guides the user through the design process in the sense of process recommendations. Its kernel forms the procedure called "7 Steps" for design, which includes the aforementioned pre-selection tools.

The 7 Steps start with the discussion and specification of planner's aims (Step 1) and relevant local BCs (Step 2), whereby the applier is always forced to specify the boundary conditions and demands verbally in order to reduce the number of relevant design criteria as far as possible, whereby the report offers numerous tables with hints, on how the criteria will affect the design (also in Appendix A).

Then all the pre-selection tools (Screening, comprehensive Pre-Selection according to Chapter 5, DWA M-519 and UK Guide) shall be applied (Step 3), which end up e.g. in ranking lists of appropriate measures, which should be "matched", especially to account for both technical and ecological issues.

Then the applier should have a look, now more purposeful, into Part 2 (Step 4), e.g. concerning only the measures from the ranking lists, both from technical and ecological issues. A condensed overview on all the measures considered in the report provide, as mentioned earlier, Figs. 1, 4 and 5 in this paper. It is very important that the applier recognizes the various construction details, possible improvements to account for the various planner's aims and possible adaptations to relevant BCs.

Next, so-called "knockout criteria" as ice-effects in northern parts e.g. of Europe or the discussion of excess pore water pressure, which occurs if the drawdown speed of a passing vessels overtops the permeability and which demands for ballasting the bank slope e.g. with riprap or gabions, are discussed (Step 5). This important step may reduce the number of appropriate measures even more.

This leads to Step 6, where the applier is forced to specify "his" Design Case as far as possible, of course based on the collection of measures in Part 2. Again, the applier will be forced to specify the Design Case verbally, because it helps to concentrate on really important features.

The final design Step 7 is now to compare selected variants in a structured way. For this reason, the Analytic Hierarchy Process is recommended, see next paragraph for more details. The latter allows to match relevant technical design aspects as the congruence of BCs of DC and AC and the corresponding adaptability of the selected measures to different BCs, stability-related issues, whereby a first choice of the assessment may come from the pre-selection tools as well as those concerning the avoidance of efforts as to minimize the construction and maintenance costs, ecological aims as – again – the congruence of ecologically-relevant boundary conditions, the potential enhancement of selected taxa and aquatic as well as terrestrial habitats up to the consideration of social demands as those related to human activities, to landscape and preservation as well as legal demands, whereby all relevant design aspects will be supported by numerous tables, delivering comprehensive information, especially to knockout criteria (Appendix A).

It should be mentioned at this point that, designing of TBPs demands generally a "looped approach". This is because it is almost impossible to recognize all design aspects in the beginning. Therefore, after performing the pre-selection, including matching the technical and ecological ranking lists or at least after finally comparing variants, it is very probable that the chosen variants contradict the ideas from the beginning of the design. So, feedback on all planning results should be provided especially to decision makers in waterway authorities, if objectives sought and those which can realistically be achieved are not in agreement.

3 Selection Techniques and Decision Making

The AHP Multi-Criteria-Approach uses in principle a weighted average of several scores, which quantify the importance (by the weight) and the degree of fulfilment (by a score) of the different criteria, leading to a final score s_{AHP}, which is used to compare selected variants.

As its name implies, the AHP should base on hierarchically structured criteria. Here, three criteria groups were chosen, which are related to technical, social, and ecological issues. Each group contains three subgroups, which contain in principle a large number of single criteria that are tackled in the report by providing numerous scoring hints, but they will be tackled in applying the AHP as one sub-criterion only.

The subgroups of the technical and ecological issues describe in principle the accordance to boundary conditions and the assessed degree of fulfilment of functionality demands related to different aspects, e.g. to stability and economy in the technical group or to selected taxa and habitats in the ecological group (see Table 1), where the structure of the AHP and the scoring-system is shown.

The main purpose of the mathematical background of the AHP Approach is to objectify the weights. This is realized by pairwise comparisons of the importance of one criterion related to the other and supported by verbal specifications as "the first criterion is three times more important than the second one". This means mathematically that the weight of criterion 1 should be three times bigger than the weight of the second. Together with the reasonable rule that the sum of weights should be 1, this results generally in an overdetermined equation system for evaluating the weights, which is solved by the AHP algorithms. The advantage of this approach is that the most important criteria are carved out, so that the final weighted average result is not "diluted" as if the appliers assess the weights directly.

But even if the applier of the WG 128 approach gets assistance by choosing the weights, he is generally not an expert and needs at least assistance for choosing the scores. Besides several scoring hints in form of numerous tables, discussing all relevant criteria, the report offers the possibility to use results from the comprehensive pre-selection tools described in Chapter 5. This is, to get a first proposal (as the pre-selection uses of course a strongly reduced number of criteria only) for all the technical and ecological scores in Table 1, as they are directly related to those from the pre-selection – and the latter are the outcome of the evaluation of all the realized measures in Part 2 of the report – and this evaluation, including "projections", was performed from the experts of WG 128. So, the aim of the Best Practice Approach to "transfer" experience from realized measures to a planned measure will be supported in many ways in the report, inter alia by the comprehensive pre-selection schemes.

The applier of the BPA will also be supported by several EXCEL tools, tackling the Screening, the comprehensive Pre-Selection up to the application of AHP altogether, and delivers the aforementioned proposal for the AHP-scores by linking the results of pre-selection and AHP automatically.

Concerning the most important step for assessing the AHP-scores, the applying of the comprehensive pre-selection, he is forced to fill in four tables:

Table 1. Structure of the Analytic Hierarchy Process (AHP) for comparing TBP-variants with scoring and weighting hints. The weights of the criteria in each subgroup and those between groups are assessed by pairwise comparisons of the importance of the one criterion related to the other, using the AHP-algorithm.

Crite-rion group	Group weight	Single (subgroup) criterion	Weight related to (sub)group	Single (sub-group) score	Remarks concerning scoring	Weighted group score	Final score
1: Technical performance	W1 This weight quanti-fies the impor-tance of criterion group 1 related to groups 2 and 3	Degree of fit to site and adap-tability	$W_{1.1}$ This weight quantifies the importance of criterion 1.1 related to 1.2 and 1.2	$S_{1.1}$	The score scales *differences* in BCs between the DC-site and those at the AC (where the example of the variant was already realized) - analogous to the scoring in Tables DFT and AFT, which should form the basis	Technical perfor-mance score: $S_1 = W_{1.1} \cdot S_{1.1} + W_{1.2} \cdot S_{1.2} + W_{1.3} \cdot S_{1.3}$	Overall perfor-mance score $S_{AHP} = W_1 \cdot S_1 + W_2 \cdot S_2 + W_3 \cdot S_3$
		Performance concerning stability and sustainability	$W_{1..2}$	$S_{1.2}$	The score assesses, up to which degree demands of the DC will be fulfilled by the variant - analogous to the scoring in Tables DST and AST, which should form the basis		
		Performance related to avoid technical efforts	$W_{1..3}$	$S_{1.2}$	The score assesses up to which degree demands of the DC will be fulfilled by the variant - analogous to the scoring in Tables DST and AST, which should form the basis		
2: Social and legal performance	W_2	Fulfilment of human demands	$W_{2.1}$	$S_{2.1}$	The score must be assessed from the applier directly, but in the sense of the degree of fulfilment of demands	Socilal and legal performance score: $S_1 = W_{2.1} \cdot S_{2.1} + W_{2.2} \cdot S_{2.2} + W_{2.3} \cdot S_{2.3}$	
		Performance concerning landscape and preservation issues	$W_{2.2}$	$S_{2.2}$	The score must be assessed from the applier directly, but in the sense of the degree of fulfilment of demands		
		Fulfilment of legal demands and accep-tance	$W_{2.3}$	$S_{2.3}$	The score must be assessed from the applier directly, but in the sense of the degree of fulfilment of demands		
3: Ecological performance	$W_{1.1}$	Degree of fit to site conditions and adaptability	$W_{3.1}$	$S_{3.1}$	The score scales *differences* in BCs between the DC-site and those at the AC (where the example of the variant was already realized) - analogous to the scoring in Tables DFE and AFE, which should form the basis	Ecolo-gical perfor-mance score: $S_1 = W_{3.1} \cdot S_{3.1} + W_{3.2} \cdot S_{3.2} + W_{3.3} \cdot S_{3.3}$	
		Performance related to selected taxa	$W_{3.2}$	$S_{3.2}$	The score assesses, up to which potential degree demands of the DC will be fulfilled by the variant - analogous to the scoring in Tables DSE and ASE, which should form the basis		
		Performance related to selected habitats	$W_{3.3}$	$S_{3.3}$	The score assesses, up to which degree demands of the DC will be fulfilled by the variant - analogous to the scoring in Tables DSE and ASE, which should form the basis		

The first table, called DFT (Design Case, feasibility, technical issues), tackles the boundary conditions at the site of the planned measures with 8 selected single criteria: ship-induced impacts, slope inclination, erodibility, excess pore water pressure, hinterland space, water level changes (ΔW) between mean water MW (as vegetation with bank protection function can establish generally only above MW) and HSW (where navigational impact vanishes), vegetation growth conditions and ice-effects. The applier is demanded to assess the importance of each criterion, e.g. the ship-induced impacts in relation to the other criteria first. Then the scores have to be assessed between 0 (demanding for strong, more technical measures, e.g. very strong navigational impact) up to 1 (e.g. low ship-induced impact, speaking for "green" measures), whereby all scores will be explained by example of a selected Design Case, which is visualized in Fig. 5: A bank slope to be protected at the impounded Weser River. The scoring rules are explained comprehensively and supported by several tables, using easy-to-achieve data only that are e.g. the CEMT class or the fairway-bank distance to assess the ship-induced impact score. It is not necessary – even if of course helpful – to have e.g. wave data.

The scores in the DFT-table will be compared to analogous data in the AFT-Table, which contains the expert-rated scores (including projections) of all the realized measures in Part 2. The score of each criterion is calculated by using *differences* between the scores of DC and AC and leads to numbers between −1 (not feasible), 0 ("just O.K") and +1 (feasible). The final so-called Feasibility Score S_{FT}, which is a weighted average of all 8 differences, assesses therefore possible differences in BCs at DC and the various AC sites. If the differences are large (the final score is negative), even if the extended BCs from projections will be used, it is unlikely that the AC measure considered will "work" at DC site and the Feasibility Check fails.

The results of the Technical Feasibility Check will be offered in different ways by the EXCEL sheet, e.g. in form of ranking lists of the most appropriate measures, that are those with the highest feasibility scores.

The second table to be filled-in is called DST (DC, suitability, technical). The user is asked to specify his technical demands (by weights and scores) to the measure by 9 selected criteria. The latter concern the administrative support, access, erosion resistance, stability/durability, duration of initial phase, sustainability reflecting local conditions and materials, investment and maintenance expenses. The scores should be chosen again between 0 and 1, whereby a score of 0 means that e.g. the expenses may be very much higher than comparable technical solutions and 1 that the budget is low and thus low-cost solutions should be preferred.

The DST-scores will be compared with analogous scores from the various ACs (Table AST), where the experts in the WG assessed analogous functionality issues. If the demands are fulfilled entirely, the score is +1, if it totally fails it is −1, if the AC offers some positive properties, even if not demanded for, the score is 0.5 and so on. A weighted average of these comparison-scores is called "Suitability Score" and quantifies, up to which extent the diverse ACs will fulfil the demanded functionality issuers of the planned measure. Again, a "hit list" of the AC-measures with the best suitability scores will be provided from the EXCEL sheet.

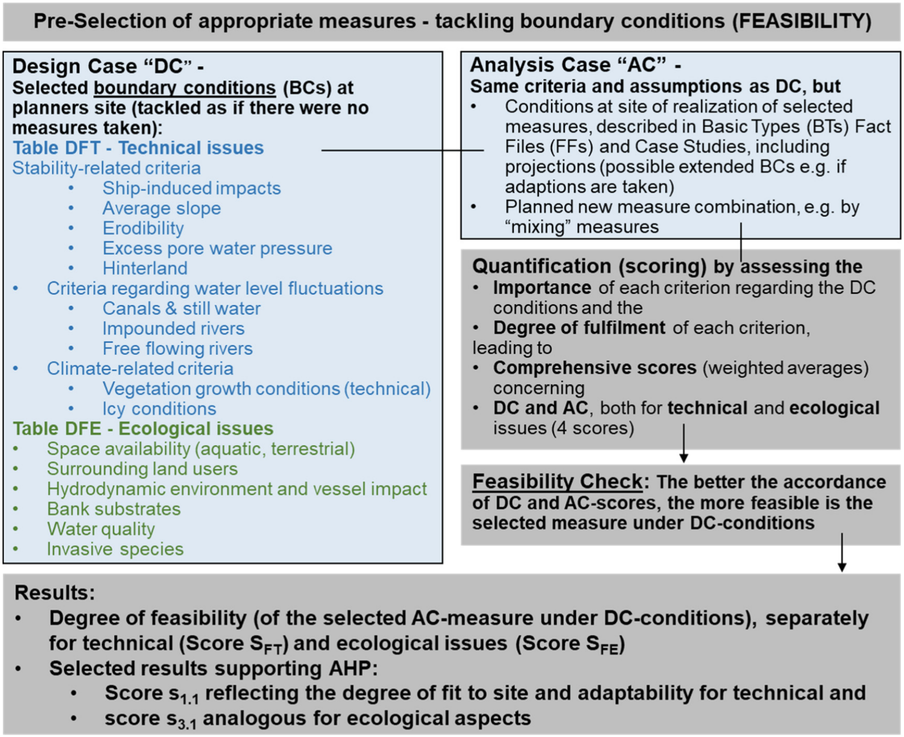

Fig. 3. Definition sketch showing the main features of the Feasibility Check for tackling the importance of role of possibly different boundary conditions at planners site (Design Case DC) and at the site of realized measures (Analysis Case AC) for pre-selection.

In the same way as the technical aspects, also the ecological issues are tackled:

In Table DFE (DC, feasibility, ecological), the next table to be filled-in from the user, together with its AC counterpart AFE, the following boundary conditions were quantified and compared to each other to form the Ecological Feasibility Score S_{FE}: Space availability in the aquatic and terrestrial zone, land use behind the bank, hydraulic environment, vessel impacts (ecological view), bank substrate (e.g. according to vegetation growth conditions), water quality and the existence of invasive plant species.

The Ecological Suitability Check (Score S_{SE}) is based on the Tables DSE (DC, suitability, ecological), defining the *demands* to selected ecological issues at DC site (species: macrophytes, riparian vegetation, arthropods, benthic invertebrates, fish fauna, birds; selected habitats: bed and banks, riparian vegetation, connectivity), which are assessed by the approach itself (taking the maximum potentially achievable according to the boundary conditions), so that the user has to specify the *importance* of each criterion only and the Table ASE, containing all the expert-rated scores of the measures. Comparing and quantifying the potential degree of fulfilment of demands by the properties of the measures, leads to the Ecological Suitability Score.

The distinction between Feasibility and Suitability was methodologically necessary, even if both aspects are matched in numerous ways – as of course the functionality is linked to the local boundary conditions – because the number of cases to be distinguished in case of a combination of both criteria groups would be far too large. Therefore, the results of Feasibility and Suitability Checks have to be matched in some way, both for technical and ecological issues.

For this purpose, the EXCEL tools offer several matching techniques, e.g. the "Logical Matching", which offers the same result as an arithmetic "fifty-fifty-average" of both scores, but if only one of the both criteria is not fulfilled (the score is bad), meaning that either the boundary conditions are not comparable at all (despite of projections) or the AC doesn't fulfil the demands, the final score will be bad too.

From this matched results concerning feasibility and suitability, ranking lists can be constructed again, which can then be used, together with previous ranking lists, in Step 5 of the 7 Steps", to support a purposeful view into the collection of measures in Part 2 of the report. The aforementioned EXCEL tools allow also to match the technical and ecological results of pre-selection and construct according ranking lists. This is very useful, as technical and ecological aspects often contradict to each other, so that it can happen that there is no accordance at all in the different ranking lists.

Thus, before starting with the aforementioned Step 6, the concretion of the Design Cases (variants) to be compared by using AHP, the combined consideration of both technical and ecological issues, makes sense for these Design Cases, even if they are not tackled directly in the collection of measures, because the EXCEL sheets offer several "mixing tools" of variant properties. If e.g. ecological deficits of a preferred AC shall be upgraded, construction elements of another measure can be combined with the preferred solution. E.g. the example of willow brush mattresses protecting the bank slope above MW level (measure 4.3.3 in Fig. 5) could be upgraded by erecting a small dam on the riprap-covered bank in water depths below MW to create a shallow water zone as in the Rhone River close to Beauchastel (measure 3.1.1.2 in Fig. 1). This may be a good solution for the DC example at the impounded Weser River. These "mixing" algorithms, even if technically questionable, allow to check, which construction elements may be appropriate to achieve the most positive effects and thus, to constrict the best solutions.

4 Detailed View on the Collection of Measures

Regardless of the different design approaches outlined above, the collection of measures in Part 2 of the report, which are visualized here in Figs. 1, 4 and 5, has also an inestimable value in itself. Simply looking into Part 2 of the report and recognizing which solutions were used regarded the different conditions, helps to select and adapt appropriate measures for the DC considered.

Part 2 is divided into three categories of measures:

The first category is not related to a special measure with its unique environment. These measures are called "Basic Types" (BTs). There was no template prescribed to write the texts of the Basic Types as the sources of information varied widely. Thus, the authors were free to present the information in an appropriate way. Nevertheless, the scoring rules for filling-in the pre-selection tables were the same as for Fact Files and Case Studies with one exception: As the Basic Types don't reflect a special measure at a unique site as all the other measures described in FFs and CSs, the corresponding scores for boundary conditions and functionality issues must be assessed from the experts, that is, they could not extracted from the conditions at AC-site. The "scorer" considered therefore the measures as to be realized under "typical conditions", which were extracted from the sources of information. The same holds true for the "projections" concerning the applicability ranges of boundary conditions and functionality issues. Hence, the scores of the Basic Types are of course less accurate than those for FFs and CSs.

Nine BTs were extracted from the German DWA-M 519 code of practice on technical-biological bank protections for inland waterways. They are: Grass revetment, reed plantings, life willow, reed mat with vegetation roll as foot protection, pre-vegetated slope mat with grass, pre-vegetated slope mat with hardwood cuttings, willow weave, living fascine with hardwood cuttings, vegetated geotextile bodies with (hedge) brush (bush) layers, chamber revetment (vegetated stone mattresses, reed gabions), willow brush mattresses with heavy riprap as toe reinforcement and vegetated riprap, see Fig. 1.

Ten Basic Types were chosen from the numerous measures described in the UK Waterway Management Guide. As at least some ecological upgrade should be possible, "pure" technical measures were not selected. Note that all recommended measures are valid predominantly for UK or Middle Europe with a mild humid climate. They include: Grass revetment, reed planting, life willow on toe and bank, grass and geotextiles, timber and vegetation, rock and fibre rolls, toe-geotextile – fibre rolls, rock and fibre roll, vegetated open cell revetment, vegetated stone revetment and vegetated concrete units revetment, see again Fig. 1 for visualization.

The last group of Basic Types were extracted from the UK guideline "Green Approaches in River Engineering". Twelve case studies are presented that illustrate different types of measures and different types of rivers. The BTs (single measures) of the mostly described measure combinations were filtered out and used for the WG 128 report. Also measures that were implemented in tide-influenced river systems were not taken into account. The considered cases are: Willow spilling/bundles, turf/vegetated reinforced mattresses/seeded geotextile (e.g. seeded coir matting) with rock rolls as toe protection, life root wads and willow brush mattresses on coir matting with faggot bundles, rock rolls and logs as toe protection.

The second measure category contains so-called Fact Files (FFs).

In total, 34 Fact Files of realized measures from across Europe and China were collected and grouped according to the waterway type, where the measures were realized. This is, because the magnitude of water level fluctuations, which are associated with the waterway type (canals, impounded rivers, free flowing rivers), is generally the most important boundary condition to be considered in the design. A second categorization was chosen according to the strength of ship-induced impacts, which is the second most important criterion for design of TBPs according to the experiences of the WG 128 members. The lower the impact, the more "green" solutions are possible. Thus, the measures are categorized into those related to weak, average and strong impacts.

Each Fact File contains the designation and the affiliation to different measure types, as pre-embankment or direct measures or those using living and dead plants only (bioengineering measures) or bio-technical engineering measures and so on. Then, the boundary conditions and objectives of the measures are described. Next, construction details and the time course of realisation is reported, followed by the discussion of the achieved functionality in view of the boundary conditions and objectives. At last, the lessons learned, improvements, and advices for applications under different conditions are discussed.

The different measures can be seen again in the aforementioned Figures. It is obvious that most of the measures are realized in Channels with small, up to average water level changes. The problem with TBPs for free flowing rivers is, that long periods of draught or floods hinder the usage of plants as the only protection elements, which means that realized measures are often combined with technical components. One reason is that very high water level changes are generally not really natural, hence there is almost no experience available from real nature to be transferred to appropriate bank protections.

The third category of measures is described very comprehensively in form of Case Studies (CSs), containing the following points: Designation, objectives, brief description, realization in site, relevant local boundary conditions, evaluation, overall result and imprint. They are as the FFs categorized according to the magnitude of water level fluctuations.

For waterways with low water level fluctuations (canals, strongly canalized rivers and still water), two CSs are presented from the Brussels-Schelt canal: Shallow water zone behind a parallel dam and behind a sheet pile wall. The examples demonstrate impressively that the most important ecological deficits in canals arise from lacking shallow water zones. These are thus compensated by artificial ones, which are – as the impacts are large – sheltered by wave breakers. The challenge is to “balance” the necessary protection against ship impact with the need of water exchange between the channel and the shallows.

There is one example concerning moderate water level fluctuations between MW and the highest shipping level, as it is often the case in impounded rivers. It describes a *planned* measure, not a realized one, but it was derived on basis of a test area (measure 3.2.3.1 in Fig. 4) with similar boundary conditions and on numerous investigations. The measure creates a large shallow water zone behind a sheet pile wall. The most important design feature is that it offers adjustable top and under water openings (“fish windows”), because experiences showed that the vegetation in the artificially created shallows (planted and natural succession) has to be “controlled” in some way, whereby the openings have to be small in the initial phase and can be larger in the mature state.

Three Case Studies concern large water level fluctuations in free flowing rivers. They are situated in a German test section of TBPs on the Rhine River near Worms town and have been monitored up to now for more than 10 years. The first Case Study describes a vegetated riprap protection with a low-level dam ahead of the bank slope for improving fish ecology, the second measure protects the bank with vegetated gabions (reed gabions) and the third with living brush mattresses. The latter form the AC-example used everywhere in the report for explaining the various approaches.

Fig. 4. Visualisation of all measures described comprehensively in Part 2 of the WG 128 report: FFs for low water level changes (ΔW) and average ship-induced impact up to high ΔW and average ship-induced impacts.

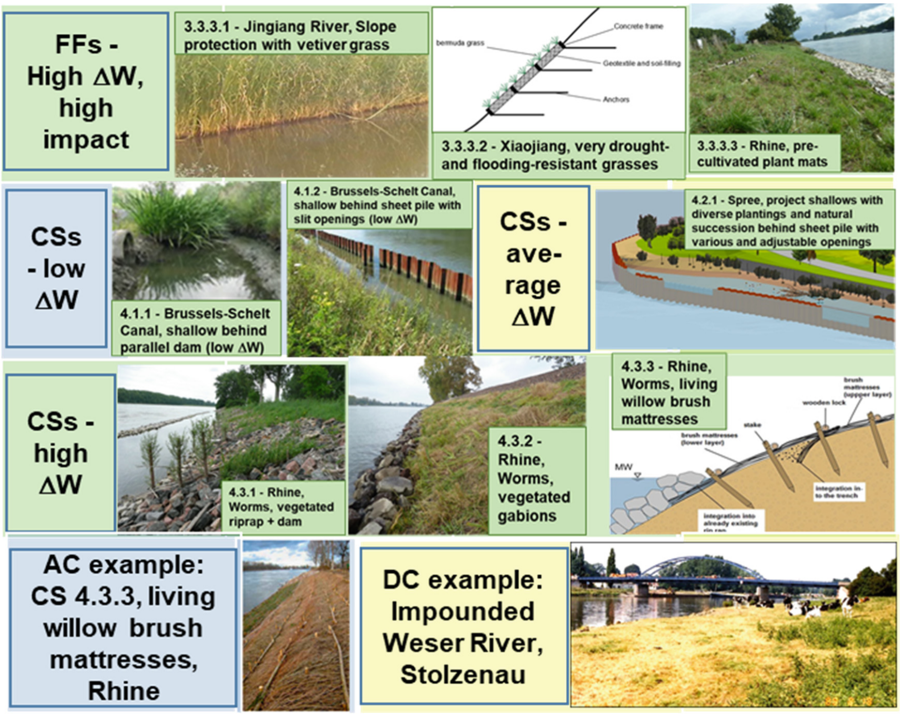

Fig. 5. Visualisation of all measures described comprehensively in the WG 128 report: Fact Files for high water level changes (ΔW) and high ship-induced impact, Case Studies and examples for applying the report.

5 Summary and Conclusions

The report of WG 128 is in its final stage at the time of writing this paper. It follows the reviewing phase, first by the members of the WG, then by INCOM. It is assumed that the report can be published by the end of 2022. After the publication, tutorials may start, which are very important, as the application of all the tools need some explanations and guidance by the authors.

The PIANC WG 128 has collected, comprehensively described and evaluated a lot of TBPs usable for different types of inland waterways with focus of those applicable under humid climate. To facilitate the selection of appropriate measures, the latter are grouped into different categories of water level changes and the magnitude of ship-induced impacts. These categorizations can be used in a first step to select generally applicable measures.

The report offers not only a collection of measures, but also several approaches to select appropriate measures on a rational, quantitative basis, based on a scoring system, whereby the scores of all the collected measures are provided from the experts in the WG. The selection tools use comparisons of boundary conditions of the Design Case and those of realized measures (ACs), called Feasibility Check as well as the balance of demands versus properties of the measures, which is called Suitability Check. These "Checks" are provided both for technical and ecological issues and concerning technical issues for the measures "as they are", but also "as they could be", e.g. up to which extent the measures may be appropriate even for worse boundary conditions. The ACs may be those from the collection, but also measure-combinations.

The pre-selection tools tackle selected technical and ecological criteria, but for the final selection all the relevant design criteria are considered, including social and legal design aspects, whereby these approaches are supported in numerous ways by EXCEL sheets. These concern various pre-selection tools up to the application of multi-criteria-analysis tools on the basis of a special Analytic Hierarchy Process.

Also two other, very stringent design tools, those derived and extended from the German Code of Practice DWA-M 519 and from the UK Waterway Management Guide (1999) were presented. They are recommended as two alternatives to the pre-selection tools.

The report offers finally process recommendations supporting the whole design process. This, especially for planners. But also decision-makers in waterway authorities or contract-makers, which need less comprehensive information and may be satisfied with the results from pre-selection. Therefore, the report allows a selective reading and application to satisfy all the usual users of the PIANC guidelines, which reach from technically interested laymen up to planners in engineering bureaus.

It is clear even to the authors, that the report will not solve all design problems and it may be necessary from case to case to perform additional studies. But it is obvious that the report provides a very useful and supportive tool for applying more nature-friendly bank protections by providing numerous design hints for solving the complex design problems associated with TBPs.

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