Future Challenges for Waterway Hydraulic Structures

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1 Introduction

Looking into the future, (massive) hydraulic structures face a not inconsiderable number of challenges that need to be overcome. Almost like a bracket, climate change encompasses several issues, of which, in addition to adaptation to climate change and climate change mitigation, examples of newly constructed hydraulic structures, existing hydraulic structures and construction methods for hydraulic structures are mentioned in more detail. Due to the short time available, the topics can only be briefly touched upon. It can be assumed that several contributions to PIANC SmartRivers 2022 will already address individual of these topics. Otherwise, future exchanges on the most pressing issues will be sought.

2 Climate Change

The consequences of climate change are increasingly being felt. In particular, the world faces more extreme weather events, like heat waves, forest fires and droughts, heavier precipitation and an increased risk of flooding and erosion, Fig. 1. The impacts of climate change will further grow in the coming decades and will threat human lives and nature. Impacts affect water management and hydraulic engineering.

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Fig. 1. Flood affecting urban areas

The challenge of climate change makes adaptation to climate change necessary on the one hand and efforts to protect the climate (climate change mitigation) on the other.

2.1 Climate Change Adaption

In order to prepare water bodies and structures planned or located in them for climate change, climate change surcharges can be helpful, which mean a surcharge on the runoff. In Germany, either flat-rate surcharges (e.g. 20%) or surcharges differentiated

T [years]	Climatic factors				
	1	2	3	4	5
2	1,25	1,50	1,75	1,50	1,75
5	1,24	1,45	1,65	1,45	1,67
10	1,23	1,40	1,55	1,43	1,60
20	1,21	1,33	1,42	1,40	1,50
50	1,18	1,23	1,25	1,31	1,35
100	1,15	1,15	1,15	1,25	1,25
200	1,12	1,08	1,07	1,18	1,15
500	1,06	1,03	1,00	1,08	1,05
1000	1,00	1,00	1,00	1,00	1,00

Fig. 2. Climate factors for 5 regions of Baden-Württemberg to be considered for discharges of different annuality (source: LUBW 2015)

by river basin and annuality are known (LAWA 2017), Fig. 2. For the sea level rise on the German North Sea coast, a water level rise of about 0.7 m is to be foreseen for an observation period from now on over the next approx. 100 years. This rise has to be taken into account for constructional facilities.

In the future, building structures must be able to withstand higher temperatures in summer. These temperatures mean higher thermal gradients and consequently greater constraints in the structure. Standardization activities and implementation of the standardization request on adaptation to climate change has been intiated by CEN under the mandate M/526 (CEN 2021).

The management of water, whether low water or high water, can be done by dams or weirs. Depending on the river regime, this requirement may or may not be reconciled with inland navigation. Navigation itself can adapt to climate change, e.g. by developing and maintaining shallow draft vessels for low water periods.

2.2 Climate Change Mitigation

Climate change is attributed to the increase in greenhouse gases. Of the total emissions of the construction industry, about a quarter and thus about 10% of the global CO_2 emissions are attributable to the construction of buildings (Global Allience 2020). It is therefore necessary to record the CO_2 emissions caused by projects in the form of CO_2 equivalents (corresponding to GWP = Global Warming Potential) and to reduce them, cf. in particular Sect. 3. Hydraulic engineering should contribute to the reduction of harmful greenhouse gases through low-emission building materials and construction methods and continue to build durable structures. However, the preservation and extension of the service life of existing (hydraulic) structures also makes a significant contribution to climate change mitigation, cf. Sect. 4.

As an energy-efficient - and moreover safe - mode of transport, inland shipping can contribute to reducing greenhouse gases and thus to climate protection simply by taking over transports. This also includes further optimization and improvement of propulsion technology, alternative drives, ship controls and automation in ship operation. In Germany at least, the potential for transporting goods by waterway could be exploited to a much greater extent.

3 New Structures

3.1 Building Materials

The building materials concrete and steel are predominant in structural hydraulic engineering. Table 1 shows the CO_2 equivalents of the construction materials predominant in hydraulic engineering.

Table 1. Values from (BMI 2022)

Material	Unit	CO_2-equivalents in [kg]
Concrete C30/37	m^3	299
Reinforcement steel	t	684
Construction steel	t	1.127
Wood	m^3	89

In the production of concrete, the main component, clinker, is emission-intensive. Approx. One third of the CO_2 emissions result from the operation of the kiln and approx. Two thirds from the chemical reaction to deacidify the limestone to quicklime (Feldmann et al. 2022). Reducing the proportion of clinker and increasing the proportion of natural additives, such as ground limestone or calcined clays, would be possible solutions. Steel production is also very CO_2-intensive in the production of pig iron and further in the processing into crude steel. Recycling steel scrap into secondary steel can reduce CO_2 emissions by more than half (Arcelor Mittal 2021). However, due to limited supply and strong demand, only around 20% of global steel production can be covered by steel scrap.

In this context, it is important to use the materials optimally within the framework of structural design and to consider the life cycle in order to be able to make comparative considerations and decisions. Thus, the durability of the building materials or even the construction methods also plays a role (Westendarp and Kunz 2020). Durability would also have to be evaluated in the development of new materials. While experience often proves the long-term durability of known materials, suitable performance tests are often lacking for new materials.

3.2 Construction Methods

Alternative construction methods may be considered for some hydraulic structures. For example, a concrete lock could be evaluated over a sheet pile sluice, where the sheet pile steel chamber would generally be constructed with anchorages, if the foundation soil is suitable. A combined construction method for locks would be possible if the excavation pit enclosure were solidly constructed (diaphragm wall construction) and integrated into the final lock construction. Another promising approach is the construction of lock chambers with precast elements (Lühr et al. 2020), Fig. 3, which the BAW is dealing with in a research project (Hasselder 2021).

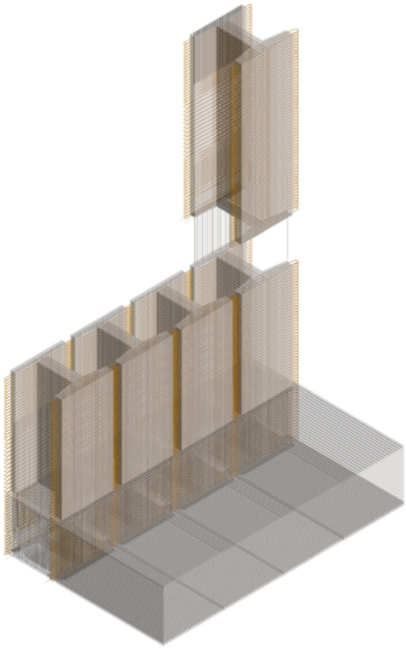

Fig. 3. Cut-out of a lock chamber wall planned with prefabricated cellular concrete elements (Source BAW)

In addition to an optimization of the concrete cross-section, recycled materials could provide for an appropriate dead weight in the cavities in a cellular construction, whereby other construction material properties could be in the lower limit range.

Due to the high corrosion susceptibility of steel weir gates, the BAW is currently investigating the use of inflatable elastomer structures. Inflatable structures have already been in use internationally for decades, but not on shipping lanes and not for dam heights up to approx. 5 m (PIANC 2018). A Eurocode-compliant verification procedure for weir gates of this type planned for German inland waterways has already been developed (BAW 2019), guidelines for hydraulic dimensioning, material requirements and material testing are in preparation. Although the inflatable weir membrane has a shorter service life of approx. 30 years compared to a steel closure, it does not require corrosion protection and replacement is easier.

3.3 Sustainability Assessment

In the future, for new structures CO_2 emissions must be limited and resource consumption reduced. A comprehensive concept is offered by a sustainability assessment, which, however, includes even more far-reaching aspects than the reduction of greenhouse gases, Fig. 4. In principle, it encompasses the 5 criteria of ecological quality, economic quality, sociocultural quality, technical quality and process quality (BMI 2019). Sustainability assessments have already been developed and applied in building construction, but not yet in hydraulic engineering. A partial section considers ecological balancing by means of life cycle assessment (LCA) to quantify the environmental impact (Haller et al. 2022). BAW has recently started a research project "Sustainability assessment for new construction and rehabilitation of massive transport water structures under consideration of established and alternative building materials and construction methods". The project aims to develop a sustainability assessment system for the construction and rehabilitation of massive hydraulic structures. The use of new alternative building materials and construction methods is to be taken into account in the sustainability assessment.

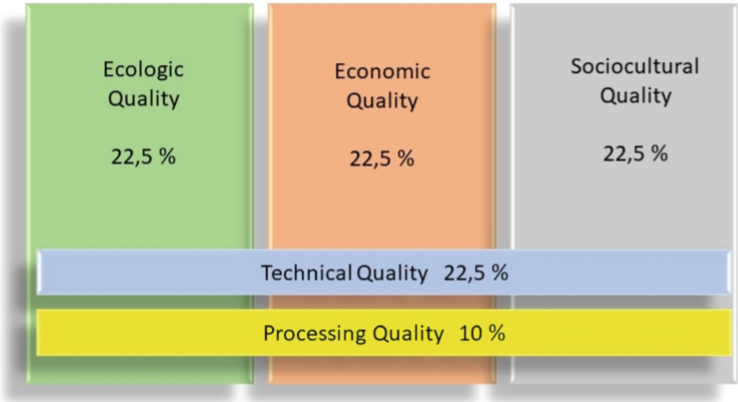

Fig. 4. Five criteria for assessing sustainability and their weighting in [%] (Source: based on (BMI 2019))

However, the most effective measure for reducing CO_2 emissions and resource consumption is to avoid new constructions. This makes the preservation of existing building fabric enormously more important, cf. Sect. 4.

4 Existing Structures

4.1 Static Verification

Hydraulic structures are long usable infrastructure assets that have been designed for a long service life since time immemorial. Age statistics in Germany with approx. 30% of hydraulic structures that have exceeded a service life of 100 years to be applied today should rather fill with pride than indicate the obsolescence of the structures, Fig. 5. Nevertheless, structural verifications are necessary for existing hydraulic structures, because some structures show damage, others have changed their boundary conditions in the course of time, and others were built according to earlier standards, in whose verifications changes and further developments were made (conceptual ageing).

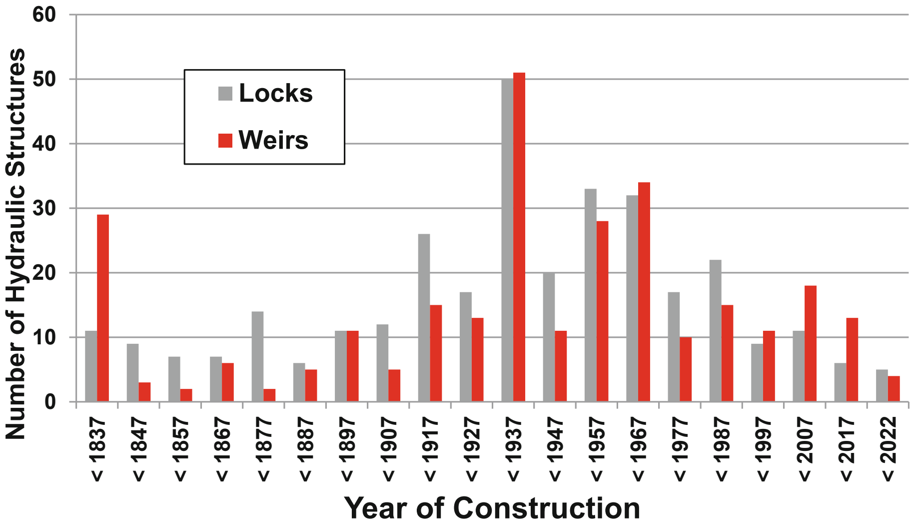

Fig. 5. Age distribution of German locks and weirs within the waterway system (Source: BAW)

In many cases, normative safety can no longer be verified with the relevant standards. From the discrepancy that structures can no longer be verified numerically, i.e. they are "unsafe", and the fact that they have been operated inconspicuously for decades in some cases, a frame-work was developed to get to the bottom of this discrepancy and to clarify the facts leading to the uncertainty. Basis is the verification guideline (BAW 2016). The outcome may lead to an adjustment or change of procedures and standards.

The framework for a more realistic assessment provides for the following three categories:

1. observations, experimental tests and monitoring,
2. revision of actions and verification formats in current standards,
3. considerations of the safety concept and reliability.

For category 1, the application of test loads that exceed normal actions and a subsequent post-calibration can be mentioned. Further a minimum safety level could be calculated, from which a remaining service life can be determined. Within category 2, the application of tensile strength in massive concrete cross-sections is investigated, which is not yet permitted in the current codes. Tensile strength helps to reduce the effect of crack water pressure and to make the verifications more reliably. Within category 3 a reliability level BETA for existing hydraulic structures may be defined different from that for buildings. A risk-based methodology may be used for verifications and for decision making for necessary upgrading measures.

The safe and economical preservation of structures, especially those with a high cement content, by means of adapted verification procedures preserves the "gray energy" contained in the structures and thus prominently serves climate change mitigation. Gray energy is the energy that must be expended for the manufacture, transportation, construction, operation, and demolition of the structure and its components. For a new building, gray energy accounts for over 50% of the energy consumption in the life cycle of the structure, with gray energy representing around 80% of CO_2 emissions.

4.2 Maintenance

In addition to the verification, however, the preservation of existing structures on site, and especially maintenance, is also important. Timely maintenance can effectively prevent exponentially increasing damage, and its cost-effectiveness has been proven. Corrosion is known to be the dominant damage mechanism in hydraulic steel structures. In the field of hydraulic steel structures, the BAW was concerned with repair products for corrosion protection that can be implemented at short notice, so-called SmartRepair (BAW 2020). Products whose rapid on-site application is possible repair damage for a short time so that the progress of corrosion can be halted. BAW is also currently researching maintenance options for the concrete of massive hydraulic structures (BAW 2021).

5 Outlook

In this article, current and near future challenges for hydraulic structures were presented, partly from a German point of view. These are essentially the adaptation to climate change for hydraulic structures and inland navigation, climate change mitigation in the construction of new hydraulic structures and here the assessment of the sustainability of building materials and construction methods. Furthermore the preservation of hydraulic structures through adapted verification formats and above all as an effective contribution to climate change mitigation has been adressed. Some aspects may already be covered by contributions in SmartRivers 2022, others still require discussion and further development. The author would be pleased about a feedback or contact from the circle of the participants by e-mail to one or the other aspect. A further bilateral or international discussion is not excluded.

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