UNIFIED CONCEPT OF FREEBOARD IN HYDRAULIC DESIGN AND IN FLOOD MAPPING

Swiss Commission for Flood Protection (KOHS)

E-mail: kohs@swv.ch

Abstract

In Switzerland, different approaches are used to calculate the freeboard and its consideration in hydraulic design and in flood mapping. Engineers must rely on their experience and on state-of the art rules, as no unified concept at the national or regional level has been established. The desire for a unified and systematic concept of the freeboard is widely shared by professional engineers in the whole country.

The Swiss Commission for Flood Protection (KOHS) has leaded a discussion in different workshops with experts from scientific institutions, from regional and federal water authorities and from engineering companies. A literature review identified the approach in neighbouring countries (Austria, Germany, Italy). Interviews with Swiss experts showed no homogenous and consistent practice in the determination of freeboard and on how it is taken into account in hydraulic design and flood mapping.

Two concepts are competing with different requirements in terms of calculation, complexity and level of detail.

Concept A : freeboard as a variable resulting from an error propagation calculation depending on uncertainties in the river bed level and in the water depth, or on uncertainties due to backwater or wave effects, and to floating materials.

Concept B: freeboard as a constant value depending on the type of water course and correcting factors according to the hydraulic situation (dams, bridges, etc.).

Advantages and consequences of both concepts have been discussed, and the consideration of freeboard in flood mapping has raised a highly challenging discussion.

Although it is unanimously accepted that freeboard does not account for hydrologic or constructive uncertainties, freeboard can take a wide range of value in hydraulic design. In flood mapping, there is no agreement on whether freeboard should be accounted for, and, if it should, what are the assumptions for its calculation.

With its recommendation on freeboard, the KOHS wishes that the freeboard will be taken into account in hydraulic design on a unified and coherent basis in Switzerland.

Introduction

The freeboard gives the distance between the water level and the top edge of the dam, resp. the lowest point of a bridge. For the definition of the freeboard, different approaches have been implemented, for example fixed values or functions of the flow velocity. In Switzerland no concept has come through, and the definition of the freeboard is left to the project designers, resp. a specialized hydraulic engineer.

The definition and the implementation of the freeboard in hydraulic design and in flood mapping have significant consequences on the costs and the safety of hydraulic structures and on the evaluation of possible hazards.

KOHS has set up a working group with the objective to establish and recommend a unified concept for freeboard. The working group has interviewed many professionals from flood protection authorities at the regional and national level, from leading engineering companies and scientists from technological institutes. Five projects were analysed as practical examples for calculation and consideration of freeboard in hydraulic design. An international comparison of recommended practice was conducted. Although there is an agreement on the fundamentals of freeboard, its implementations greatly vary according to the situation, the protection objectives, the damage potential, etc.

Freeboard: basic principles

Different approaches have been identified for the determination of the freeboard:

- F_e = fixed values
- F_e = function of the velocity component (v^2/g)
- F_e = probabilistic values

The determination of the freeboard in these approaches takes into account different processes:

- Wind
- Clogging with wood, ice, etc.
- Waves and unstationary conditions
- Variable bed height
- Objective of protection and potential damages

Most institutions recommend that the freeboard should depend on hydrologic and constructive uncertainties.

Necessary freeboard: load, effects and capacity

In a workshop, experts agreed on a simple definition: “the necessary freeboard defines the flow capacity of a channel for a given geometry”. If the freeboard is below the necessary value, the flow capacity of the channel is no more guaranteed. The necessary freeboard describes the uncertainties in the calculation of a water level for a given flow. It does not account for hydrological uncertainties due to the estimation of the flow corresponding to a given probability. The necessary freeboard is not a safety coefficient reflecting higher needs of safety for higher potential damages and higher risks.

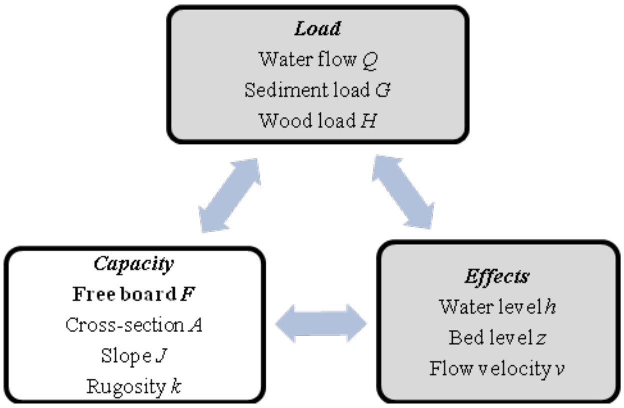

Figure 1: Relation between load, capacity and effects

Freeboard: two concepts

In the discussion during the workshops, the experts agreed on two main different concepts for the calculation of the freeboard. The first concept relies on an error propagation equation raking into account the main uncertain hydraulic factors. The second concept relies on a table which gives freeboard level values according to watercourse and/or situation characteristics.

The calculated necessary freeboard is rounded to the upper decimetre value. The necessary freeboard can vary between a minimal value F_{min} of 0,3 m and a maximal value F_{max} of 1,5 m.

Concept A: freeboard as a variable

$$F_{min} \leq F_e = \sqrt{F_z^2 + F_h^2 + F_v^2 + F_{\Delta h}^2} \leq F_{max} \tag{1}$$

F_{min} = minimal value of the freeboard
F_e = necessary freeboard
F_z = uncertainty about the stream bed level
F_h = uncertainty about the water level
F_v = uncertainty for wave formation or for backwater effects
F_t = uncertainty due to the presence of bridge
F_{max} = minimal value of the freeboard

The uncertainty about the stream bed level F_z can be assessed by numerical sensitivity analysis. Sediment deposition during a flood should be considered separately and is not included in the freeboard. Although there is not much experience about the possible value of F_z , values of 0,2 m for main rivers and 1,0 m for torrents should be considered.

The estimation of the water level h is subject to many uncertainties. A numerical experiment was conducted on 17 hydraulic cross sections to estimate with a first-order analysis the uncertainty about depth depending on all other parameters of the Strickler equation: river bed geometry, rugosity, and slope. The analysis showed that the depth h is a good predictor of the flow depth uncertainty F_h:

$$F_h = 0.06 + 0.06 \cdot \mathrm{h} \tag{2}$$

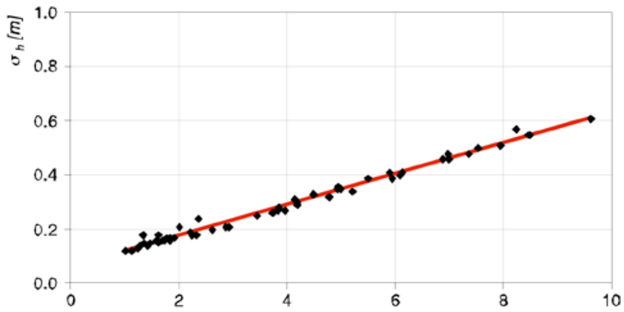

Figure 2: Water level mean error σ_h in relation with water level h [m], estimated at 17 cross sections

The freeboard component for wave formation or for backwater effects can have a maximal value of $v^2/2g$, where v is the mean flow velocity or flow velocity on the side to consider curve effects.

The freeboard must be increased for bridges, especially for river reach with a scouring hazard. F_t varies for 0,3 m to 1,0 m according to the river and the bridge specificities.

Not all components of the freeboard have to be taken into account for the estimation of the necessary freeboard, criteria for their use is given in table 1.

Table 1: Criteria for the use of the freeboard component

Freeboard component	Criteria for use
F_z	Rivers with moving bed
F_h	All rivers
F_v	• Bridges with scouring hazard • Dykes • Torrent cone • Torrent with paved bed
F_t	• Bridges with scouring hazard

Concept B: freeboard as a fixed value

In concept B, the freeboard dimension has a fixed base value depending on the river type (see table 2).

Table 2: Necessary freeboard F_e categories

River type	Freeboard for small rivers	Freeboard for large rivers
Torrents	1,0 m	1,2 m
Mountain rivers	0,8 m	1,0 m
Floodplain rivers	0,8 m	0,8 m
Streams	0,5 m	-

The above river categories have been defined in Bezzola and Hegg (2008), where detailed criteria are given. The differentiation between small river and large river depends on the catchment size, the water flow and the river morphology.

The base value F_e has to be corrected (increased respectively decreased) according to the river reach situation. The presence of dykes, of bridges, of a torrent cone or a paved bed implies to increase the freeboard. If the channel has a foreland the freeboard can be reduced.

Discussion on the use of the freeboard

The freeboard is used for hydraulic design and for hazard mapping. The implementation of the freeboard in the hydraulic design follow a systematic approach based on the choice of a design flow, the definition of the hydraulic structure and the identification of the characteristics of the river reach. This application of the freeboard did not lead to a discussion in the expert group.

The implication of the freeboard in hazard mapping was much more debated. An approach has been proposed within the framework of a weak point analysis (see figure 3).

For some experts if a hydraulic analysis shows that the necessary freeboard is not met for a given scenario, the following questions have to be examined:

- Where can water, for a given flow, run out of the river channel?
- How can water run out of the channel (overflow, dam break, scouring, and backwater)?
- How much water does run out?

This implies that if a hydraulic calculation shows that the necessary freeboard is not met then the hazard of inundation must be assessed.

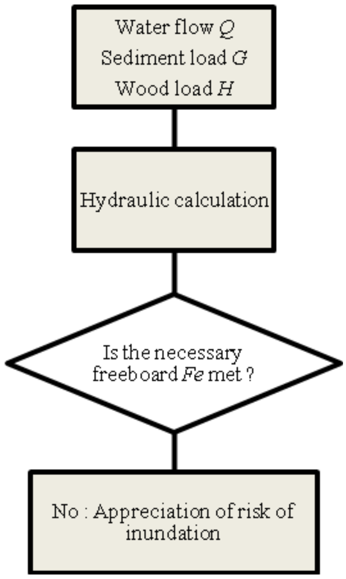

Figure 3: Framework for the assessment of weak point

The channel situation is central that assessment. For incised channels, the process of inundation is simpler to asses and is generally less dynamic than by embanked channels. In that case the level of inundation is given by the freeboard taking into account the uncertainty about the stream bed level *z* and the water level *h* (see figure 4).

Figure 4: Freeboard and level of inundation for incised channels

Embankment of river implies that the water level lies artificially much higher than the flood plain. If the necessary freeboard F_e is not met, the hazard of overflow must be assessed and possibly the hazard of a dam break (see figure 5). This implies that the water level of an inundation must be assessed through a hydraulic and geotechnical analysis of dam break processes.

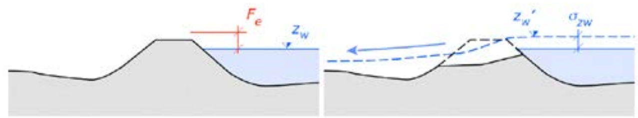

Figure 5: Freeboard and level of inundation for embanked channels

If the freeboard is not met at the cross section of a bridge, the cross section area must be reduced and the consequences for the water level must be analyzed. If clogging occurs, a severe reduction of the cross section must be assessed (see figure 6).

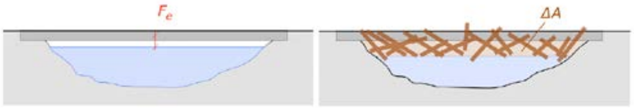

Figure 6: Freeboard and cross section at bridges

The approach using a weak point analysis if the freeboard is not met has been criticised by some experts, when it is used in flood mapping. These critics can be expressed as follow:

1. There was no unified concept as most of the flood maps were elaborated in Switzerland. More than 50% percent of the maps do not take into account the freeboard and should be therefore worked out again.
2. During a flood event, the fact that the freeboard is not met does not imply that dykes or embankments would be overtopped. Very often the freeboard works as a safety margin during a flood event, and the actual water level lies below the embankment level even for water flow slightly higher than the design flow. Switzerland has suffered many flood events in the last 3 decades, and there was no systematic overtopping of the embankments when the freeboard was not met.
3. The weak point analysis could lead to an overestimation of flooding hazard. On many water courses in Switzerland, the freeboard is not met for the desired design flood (in most cases the 100 years return period flood) and the proposed approach would indicate flooding areas along these water courses and be reported in flood maps. Land use restrictions can be imposed by flood maps through building codes, and therefore, in some cases, the fact that the freeboard is not met would have an exaggerated impact on land use.

These critics are levelled at the consequences for the flood maps of the failure to respect the freeboard and not at the definition or at the calculation of the freeboard itself. Most experts agree that the freeboard has to be checked in a hazard assessment or in a risk analysis. There are strong differences when it comes to the implementation in flood maps, due to their impact on land use. It is felt by some that the failure to respect the freeboard cannot justify land use restrictions. On the other hand, other experts think that when the freeboard is not met, the probability of flooding is very high especially for embanked channels. Moreover when the freeboard is not met, a rehabilitation of the hydraulic structure must be undertaken. In Switzerland the rehabilitation of flood protection structures must meet some economical and technical criteria. How can rehabilitation be justified when no impacts appear on the flood maps? These questions are now discussed in the elaboration process of the final version of the paper on a unified concept for the freeboard.

The decision on whether concept A or B should be implemented is to be met until June 2012. KOHS can also decide to implement both concepts but in different cases.

Conclusions

KOHS has worked out a unified concept for the definition and the use of the freeboard in the design of hydraulic structures and in flood mapping. A literature review has shown that there is a great diversity of approach and definition and no concept is widely accepted and implemented.

Two concepts have been elaborated and proposed for expert discussion. The implementation of the freeboard in flood mapping is intensely debated, due to its practical and important implication for land use planning and for the funding of hydraulic structure rehabilitation.

The elaboration of a unified concept for freeboard is still undergoing a consultation of experts from many different (local, regional and national) authorities, engineering companies and universities.

Acknowledgements

Lukas Hunzinger, Martin Jäggi, Jürg Speerli, Heinz Weiss, Benno Zarn and Jean-Pierre Jordan were active members of the KOHS working group on freeboard. This paper is based on the working paper of the working group and was summarised by Olivier Overney.

References

Bezzola G.R., Hegg C. (ed.) (2008). *Ereignisanalyse Hochwasser 2005, Teil 1 –Prozesse, Schäden und erste Einordnung*. Bundesamt für Umwelt BAFU,Eidgenössische Forschungsanstalt WSL. Umwelt-Wissen Nr. 0707. 215 S.

KOHS (2010): *Literaturrecherche Freibord*. HSR Hochschule für Technik Rapperswil– Institut für Bau und Umwelt.

KOHS Arbeitsgruppe Freibord (2010). *Fehlerschätzung am berechneten Wasserspiegel*. Unpublished working paper.

KOHS Arbeitsgruppe (2011) *Positionspapier Freibord – Konzept*. Unpublished working paper