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Development and Testing of Water-Filled Tube Systems for Flood Protection Measures

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Summary: This paper provides information on mobile flood protection systems in general and on water-filled tube systems for flood control in particular. Results of field tests and laboratory tests of prototypes developed in the research project HWS-MOBILE are described and recommendations for the use of water-filled tube systems are given.

1 INTRODUCTION

Floods are one of the most frequent natural hazards worldwide. According to the NatCatSERVICE database of the reinsurance group Munich Re approximately 38% of the total number of natural catastrophes since 1980 are a consequence of hydrological events like river floods, flash floods, storm surges as well as resulting landslides[1]. The flooding caused by the Hurricane Katrina can be assumed as the flooding with the highest economical losses for more than 100 years amounting to US$ 81 billion at the US coast[2, 3]. The second most expensive flooding took place in China in 1998 with more than US$ 30 billion at the rivers Yangtse and Songhua. In Europe, the flooding at the rivers Elbe and Danube in 2002 caused damages of US$ 21 billion[4].

Such major events cause public attention; however, a fact frequently overlooked is that small local events cause approximately 50 % of total flood damage[5]. To avoid fatalities and damage it is necessary to select the appropriate measure of flood control for a specific site. Even with technical measures it is not possible to eliminate the risk but it is obvious that taking precautions pays off.

Beneath dykes and floodwalls, mobile constructions are a solution for flood protection especially in densely populated areas where no space for permanent structures is available. In addition, permanent structures may obstruct heavily the view onto the water body. In these cases, mobile flood protection measures may be a solution to fit both requirements: protection in case of flooding and open access to the floodplain over the remaining time. Furthermore, mobile protective systems can be used as emergency tool against flooding in unprotected low-lying areas and for heightening of permanent flood protection structures in extreme events.

Mobile flood protection systems differ in material, construction, permanent facilities, and available protection height. In the following, planning criteria of mobile flood protection and a systematization of different mobile protection systems are given. Project results of the research project HWS-MOBILE on the development and testing of water-filled tube constructions for the use in flood protection are shown in detail resulting in recommendations for the use of such construction in emergency flood control. The project HWS-MOBILE was conducted in 2009 to 2011 by the Leuphana University Lüneburg together with the Hochschule München and the business companies Optimal Planen GmbH Menden and Karsten Daedler e.K. Trittau.

2 PLANNING CRITERIA FOR MOBILE FLOOD PROTECTION

Considering the use of mobile flood protection systems, in particular safety-related aspects have to be accounted for. The mode of operation, construction and the applicable materials are dependent on available early warning time, static and dynamic loads from water level, waves, ice pressure and flotsam impact as well as physical stresses due to weathering effects and required protection height.

Beside the general stability with regard to static and geotechnical aspects, the risk of failure of mobile protection systems is mainly dependent on the possibility of a safe assembly of the system. Important parameters are available early warning time, number of skilled helpers mobilized in a short time as well as manageability of protective components even under bad weather conditions.

A strict assembly schedule is mandatory based on locally defined threshold values of forecasted water levels defining action steps. The assembly schedule of mobile flood protection must not leave to the discretionary power of the decision maker. All in all, a low failure risk of mobile flood protection can only be guaranteed, if technical components as well as administrative conditions are suitable designed.

Generally, the structural failure of mobile flood protection systems can be distinguished into five types:

- Sliding (also rolling)
- Tilting
- Failure of stability (due to poor layout, capacity overload, or vandalism)
- Leakage without overall failure
- Geotechnical failure

If the static friction between system and underground is not sufficient due to minor friction coefficient or small normal force in interaction with buoyancy, the system may slide in case of acting lateral loads from water levels, waves, currents, and wind. A special case of sliding is the lateral rolling of cylindrical constructions.

A system is in a stable position as far as its centre of gravity is lying normal above the contact patch. If the centre of gravity is normal above the tilting line, the position is unstable and the system may topple over due to smallest interferences if no additional fastening is existing. The steady position of a body is impacted by the geometry of the body itself as well as lateral forces due to wind (static / dynamic), hydrostatic water loads, and hydrodynamic loads from wind, waves, and currents.

The inner stability can fail in case of capacity overload and/or incorrect installation. Especially high puncture loads, e.g. due to flotsam impact, can lead to failure. Furthermore, mobile systems can fail due to vandalism, which can be encountered only by safeguarding of the system.

Leakages can occur especially at the underground contact area and lateral connection surfaces resulting from design aspects or incorrect installation. Minor leakages are normally acceptable whereas larger leakages with higher current velocities may soak the underground leading to wash out of soil particles at the contact patch and consequently to stability problems.

Geotechnical failure occurs if the system possesses no stable foundation, unstable slopes exist in the protection line or the safety against hydraulic base failure or erosion is not guaranteed.

3 SYSTEMATISATION OF MOBILE FLOOD PROTECTION SYSTEMS

Available mobile flood protection systems differ in material, construction, permanent facilities, and available protection height. In the following, a systematization of different mobile protection systems is given.

Mobile flood protection systems can be divided in stationary and non-stationary mobile systems, see Figure 1. Stationary mobile systems may be partly or completely preinstalled whereas non-stationary systems are fully mobile and can be installed on different locations. The systems may be sub-divided in wall, container, mass, and flap systems. Further information on the different mobile flood protection systems is given in [6].

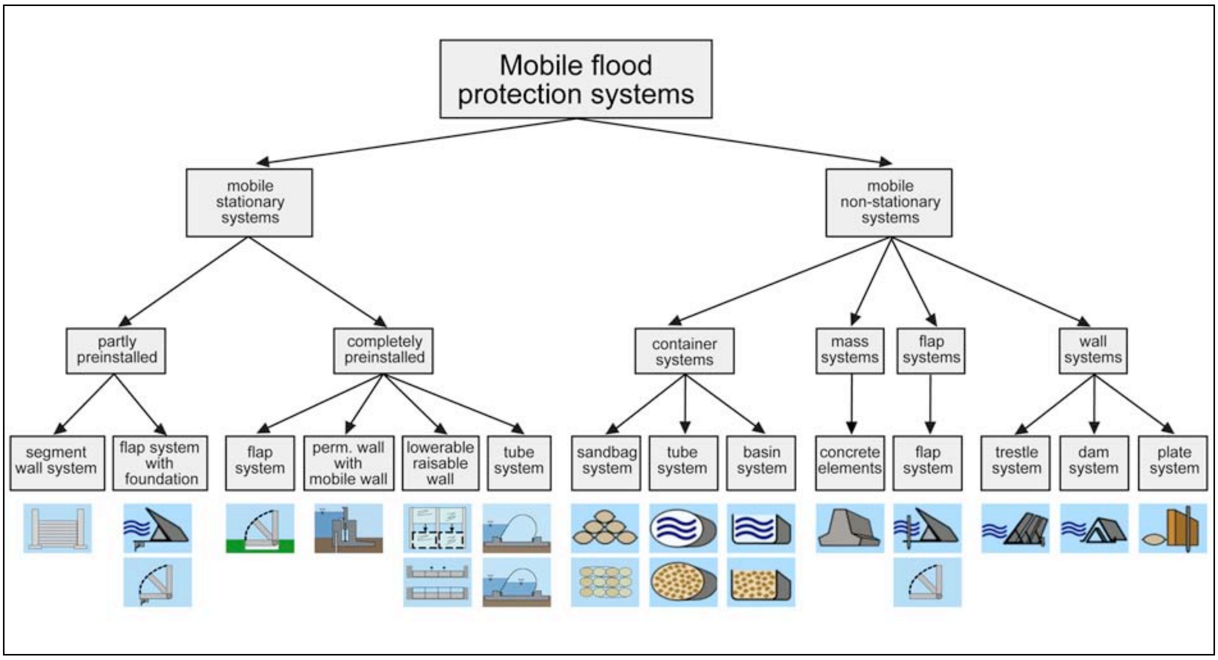

Figure 1: Classification of mobile flood protection systems[6]

4 WATER-FILLED TUBE CONSTRUCTIONS

Like other mobile flood protection devices water-filled tube constructions can be distinguished in stationary and non-stationary systems.

4.1 Stationary water-filled tube constructions

Stationary, i.e. permanently installed tube systems, consist of a foundation made of concrete, a hull made of synthetic or rubber as well as the filling material water. For filling of elements pumps are in use, whereas a redundancy of filling technique is obligatory. In case of flood protective use of the system must be protected in idle time by a cover.

Permanently installed water-filled tube systems are mainly used as weirs in rivers (Figure 2). Up to now, no longer system lengths are realized in flood protection. Permanent installed tubes offer the opportunity of easy installation but investment costs for foundation, construction and coverage are high.

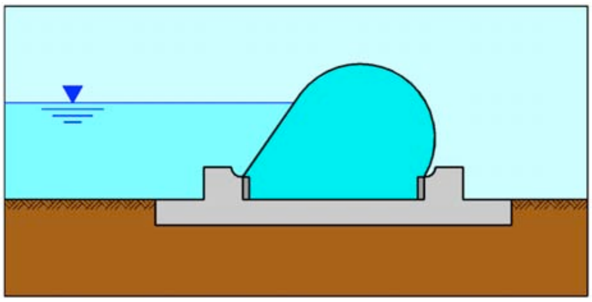

Figure 2: Construction principle of a permanent installed tube system (left) and an example of a water-filled weir in Marklendorf at the river Aller, Germany[7] (right)

4.1 Non-stationary water-filled tube constructions

Non-stationary water-filled tubes are made of synthetics like a reinforced plastic liner and are filled with water. In most cases, an initial filling with air is required for alignment. For filling, special equipment is needed like compressors and pumps. Normally, no additional anchorage like mounting bars and end constructions are necessary and the fixation of the construction is done only by its mass effect. The use of ground spikes is often not possible as the ground might be asphalted or the soil might be water-saturated and is consequently too weak for the use of spikes.

Also a non-destructive installation at walls or buildings is advantageous and can often be realized by these flexible constructions, which are able to follow existing structures.

Nevertheless, it is important to avoid any gaps between flood protection tube and structure as these will result in water leakage and, depending on the erosion stability of the ground, wash out of soils and therefore instability of the overall system. The emergency use of protection measures always requires some scope for improvisation and it is advisable to keep at hand materials like rubber mats and filled sandbags to construct waterproofed wall connections.

Because of their flexibility, tube systems are able to follow an uneven ground, but problems occur if smaller gaps and joins exist as e.g. in case of paved surfaces. These potential water passages cannot be sealed by the structure itself. Laboratory tests executed within the research project HWS-MOBILE show that the use of foam rubber mats 6 cm thick (only charged by dead load) underneath the structure shows good sealing results.

Further substructures are normally not required, but the ground must:

- be stable to bear structural and hydraulic loads,
- offer a sufficient static friction between the system ground / tube or the system ground / foam rubber mat / tube to enable a stable position of the flood protection device and
- not show any sharp edges (in case a foam rubber mat is used underneath eventually existing sharp edges will not damage the tube material)

Difficulties may arise in the fixation of water filled tubes. Especially in case of dynamical loads, e.g. wave loads, cylindrical elements may roll aside and change their position uncontrollably. This can be avoided by e.g. the use of two cylindrical inner tubes and one cylindrical outer tube (Figure 3). Due to the friction between the two inner tubes as well as between the inner and the outer tubes the movement of the construction can be minimized.

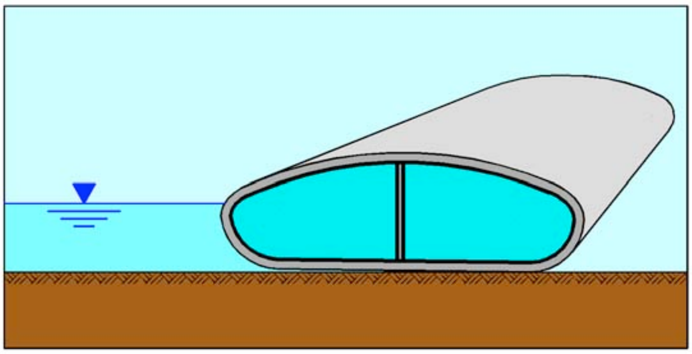

Figure 3: Exemplified non-stationary tube system with two inner and one outer tube

Position control can also be achieved by a special shaping with internal reinforcements applied to the tube construction or the coupling of two tubes. The prototypes shown in Figure 4 and Figure 5 have been developed within the project HWS-MOBILE and have been produced by the involved companies Karsten Daedler e.K. Trittau and Optimal Planen GmbH Menden.

The length of the single element of water-filled tube systems varies from 5 to 60 m. By coupling the elements any system length can be achieved. The element joints must be largely water proofed, which can be achieved easily if the construction is designed that way that the single elements are pressed together by their own weight during water-filling.

Figure 4: Tube system prototype with inner reinforcements made by the company Karsten Daedler in Trittau, Germany (photo: M.W. Jürgens)

Figure 5: Tube system prototype made of two jointed cylindrical tubes made by the company Optimal in Menden, Germany (photo: M.W. Jürgens)

Large radius curves are easy to realize with water-filled tube systems. For smaller curve radiuses special angle or corner elements are required, see Figure 6.

The use of water filled containers saves material and personnel and enables a quick installation. Drawbacks are that the density of the filling material is identical with the density of the source of loading and buoyancy. Also horizontal shifting is a problem in case of high water levels bearing the potential of sudden failure. Laboratory tests on an even concrete ground with different water-filled tube prototypes (Figure 7 and Figure 8) show that a horizontal shifting of the structure occurs system-dependent already at a flood water level of 70% of the filling water level. In the laboratory tests the highest achieved flood water / filling water ratio was 97% applying a foam rubber mat underneath the tube structure to increase the water tightness and the static friction.

Figure 6: Corner element of the prototype Optimal in a laboratory test of the research project HWS-MOBILE (photo: B. Koppe)

Figure 7: Laboratory test of the prototype Daedler within the research project HWS-MOBILE (photo: B. Koppe)

Several producers of mobile flood control systems (e.g. [8, 9, 10]) recommend the installation of plastic sheets on the waterside of the construction to decrease the hydraulic pressure underneath the system. This shall lead to a decrease of leakage and to an increase of the overall system stability. From theory, this assumption can only be valid if the plastic sheet offers 100% water tightness or if the underground is highly permeable to dissipate any available hydraulic gradient below the plastic sheet. In praxis, these conditions are not existent and a waterside placed plastic sheet will not increase the functionality of a flood protection system. This could be validated by executed laboratory tests within the project

HWS-MOBILE as leakage and stability measurements show no improvements by placement of a plastic sheet at the waterside of the structure (Figure 9).

Figure 8: Laboratory test of the prototype Optimal within the research project HWS-MOBILE (photo: B. Koppe)

Figure 9: Laboratory test of the prototype Daedler with a waterside placed plastic sheet on an impermeable ground within the research project HWS-MOBILE (photo: B. Koppe)

Beneath static loads also dynamic loads from waves, currents and flotsam impact have to be considered in flood control. Because of low dead load and related buoyancy problem, water-filled constructions are not applicable in regions with higher quasi-regular dynamic loads like waves. In contrast, flexible water-filled tube construction are able to sustain flotsam impact very well. The constructions have been able to stand flotsam weights of 1 ton and impact velocities of up to 2 m/s within laboratory tests conducted in the project HWS-MOBILE (Figure 10).

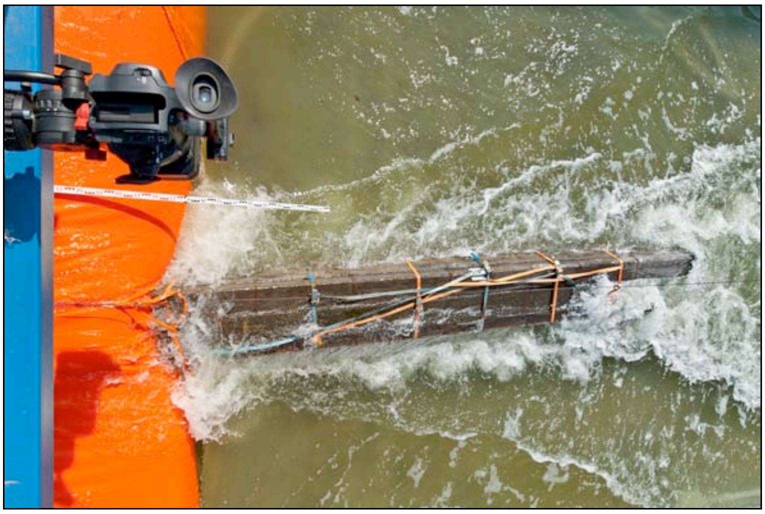

Figure 10: Flotsam impact test at water-filled tube prototype Optimal within the research project HWS-MOBILE (photo: B. Koppe)

Also the use of water-filled tubes during frost periods shows no difficulties. Freezing tests in the severe winters 2009/2010 and 2010/2011 within the research project HWS-MOBILE show that even after freezing periods of weeks to months no structural or material damages occurred at water-filled tube systems (Figure 11). The only problem is that water filled constructions cannot be drained during frost but must be remained installed up to the beginning of the thaw period.

Figure 11: Water-filled, sandbag loaded prototype Optimal after a several months lasting freezing period in January 2011, research project HWS-Mobile (photo: B. Koppe)

5 CONCLUSIONS

A variety of mobile flood protection systems are on the market fulfilling different security and manageability levels. Therefore, it is necessary to analyze properly the requirements and site conditions in every specific application.

Within the research project HWS-MOBILE water-filled tube systems have been developed and tested, both in field and in laboratory tests. It can be stated that the developed prototypes are able to withstand a hydraulic load of 70 to 97% of the filling water level, depending on the construction. As testing underground an even concrete surface was chosen with low static friction coefficient.

Furthermore, a loading by flotsam impact with a flotsam weight of 1 ton and an impact velocity of 2 m/s showed no structural or functional damages. In contrast, in field tests quasi-regular wave loads in conjunction with higher static water loads lead to sudden failure. These tests have been conducted at the shore of the river Elbe where mainly ship-induced wave loads have been applied.

Additionally, the theoretical assumption that water-filled tubes equipped with plastic sheets at the waterside of the construction show no better performances than plain water-filled tubes has been validated in laboratory tests.

It can be concluded from the experiences made in the research project HWS-MOBILE that properly designed water-filled tube systems can serve as an appropriate tool for emergency flood control up to a flooding height of 0.60 m[1] as the constructions offer the following advantages:

- Low consumption of resources
- Short installation time
- Small number of personnel required
- Deployable at different undergrounds without any destructive installations

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