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SURF ZONE HYDRODYNAMICS AND ITS UTILIZATION IN BIOTECHNICAL STABILIZATION OF WATER RESERVOIR BANKS

Petr Pelikán[1], Pavla Pilařová[1], Jana Marková[1], Lenka Gernešová[1]

[1] Department of Landscape Management, Mendel University in Brno, 613 00 Brno, Czech Republic

Abstract

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The water reservoir banks are eroded mainly by two factors. The first one is wave action (i.e. wave abrasion) affecting the bank in direction from the reservoir. The second one is the influence of water flowing downward over the bank surface in direction from land into the reservoir (e.g. rainfall). The determination of regular altitudinal emplacement of proper designed particular biotechnical stabilization elements is the most important factor on which the right functionality of whole construction depends. Surf zone hydrodynamics solves the wave and water level changes inside the region extending from the wave breaking point to the limit of wave up-rush. The paper is focused on the utilization of piece of knowledge from a part of sea coast hydrodynamics and new approach in its application in the conditions of inland water bodies when designing the biotechnical stabilization elements along the shorelines. The "reinforced grass carpets" as a type of biotechnical method of bank stabilization are presented in the paper; whether the growth of grass root system is dependent on presence or absence of geomats in the soil structure and proceeding of their establishment on the shorelines.

Keywords: bank erosion, biotechnical stabilization, geosynthetics, surf zone, wave run-up

INTRODUCTION

The rapid growth of building-up of large water reservoirs in 20th century caused spreading of the water wave mechanics research to the inland water bodies. The attention was paid to the influence of waterwork on its vicinity, wave regime respectively, due to the shoreline deterioration, predominantly caused by wind waves. Dams and levees are usually protected well by proper technical stabilization methods from their construction. Conversely the shorelines around backwater zone are often unstabilized due to potential high expenses on the stabilization elements. If there is combination of some adverse factors (e.g. conditions for long wind run over water-table – fetch, steep slope banks from material poorly resistant to the wave effects, etc.), the optimal conditions occur for wave abrasion progress. Abrasion causes the deterioration of the banks with consequent shoreline retreat and sedimentation of scoured material in the reservoir.

The aim of paper is the determination of active zone bank profile due to the proposed wave height and the example of biotechnical measure design along the shores, which are frequently footworn by people and strained by wave action and water flowing downward over the bank surface in direction from land into the reservoir.

Knowledge of the processes within the surf zone is prerequisite for proper bank stabilization especially in the way when appropriate biotechnical stabilization is to be used. The Brno reservoir was selected for the project of biotechnical bank stabilization based on the research of the surf zone hydrodynamics. The proposed biotechnical method of bank stabilization is the "reinforced grass carpet" which use advantages in interaction of vegetation and construction materials (in this case grasses and erosion control mats) (Fig. 1). Erosion control mats can be used on all kinds of slopes. Their open net structure allows the topsoil to easily pass into the composite where it is then held in place and it makes constant contact with the underlying soil. This offers protection even before any vegetation has been established.

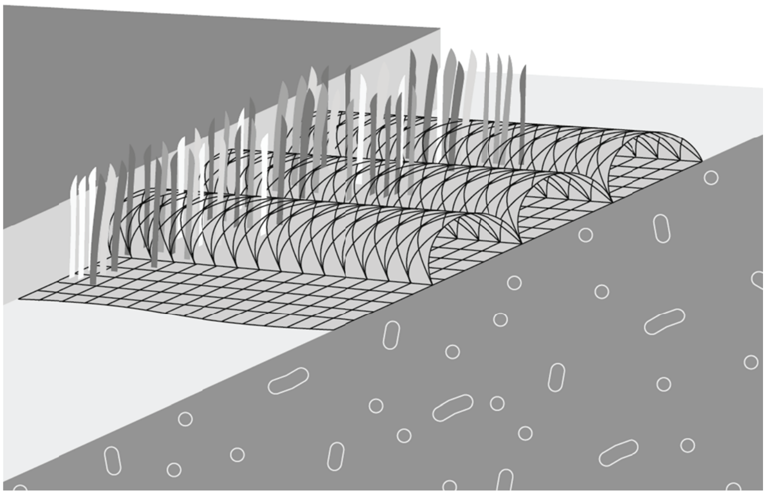
MATERIALS AND METHODS

The problem of bank deterioration on water reservoirs has been solved by many scientists (Kačugin, 1964; Kratochvíl, 1970; Linhart, 1957; Pyškin, 1963; Šlezingr, 2012). Each of them specified the sum of factors with negative influence on the shoreline but the most important is wave action.

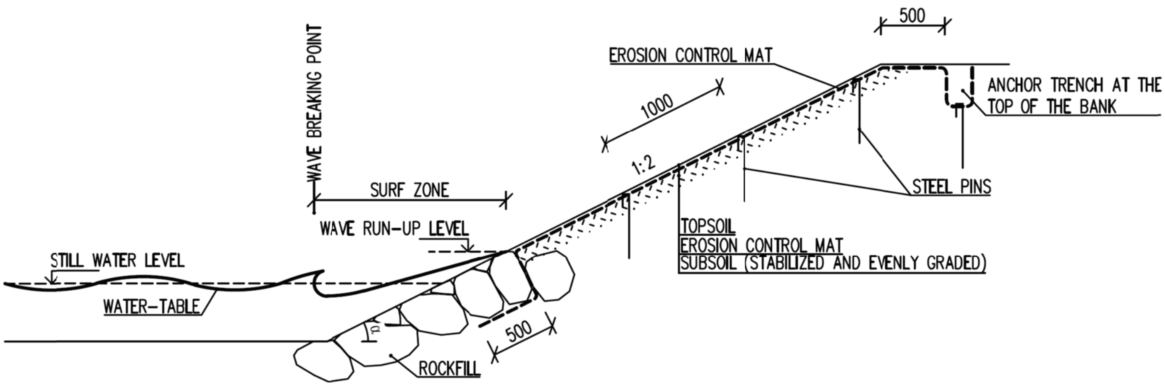
Waves approaching the coast increase in steepness as water depth decreases. When the wave steepness reaches a limiting value, the wave breaks, dissipating energy and including nearshore currents and in increase in mean water level. Waves break in the water depth approximately equal to the wave height. The surf zone is the region extending from the wave breaking point to the limit of wave up-rush. Within the surf zone, wave breaking is the dominant hydrodynamic process.

The "reinforced grass carpet" is a biotechnical method of bank stabilization resulting from the interaction between erosion control mats (a three-dimensional geosynthetics) and root system of grasses. The first step of experimental procedures was to find out whether the growth of grass root system is dependent on presence or absence of erosion control mats in the soil structure. This part of research was accomplished in laboratory conditions because achieving data homogeneity (comparable data) for the following statistic analysis. Three easily available types of erosion control mats (Enkamat 7010, Enkamat 7020 and Trinter) and three types of grass seeds (Perenial Reygrass (*Lolium perenne*), Common Meadow-Grass (*Poa pratensis*), Tall Fescue (*Festuca arundinacea)*) which are most commonly used for erosion control grass mix were selected and tested. For data evaluation were used WinRHIZO (image analyses system provides a quick determination of various root morphological parameters) and Analysis Of Variance (ANOVA).

The following experimental procedure will be the establishing of proper bank stabilization measures in selected sites (Osada, Sokolské koupaliště) of the Brno reservoir. The banks in selected sites have a slope ratio of 1V : 2H. The active



1: *Interaction between the erosion control mat (Trinter) and vegetation (geomat.cz)*



2: *Surf zone hydrodynamics and biotechnical stabilization technology* zone of bank profile should be protected with riprap or other durable, structural treatments. The rest of the water reservoir bank (minimum length two meters) will be stabilized by the "reinforced grass carpets" (see Fig. 2). The procedure of the establishment of the "reinforced grass carpet" is as follows:

1. stabilizing the bank subsoil and evenly grade surface,
2. securing the erosion control mat at the top of the bank into an anchor trench and fixing it using steel pins,
3. filling the erosion control mat with topsoil,
4. seeding onto the filled erosion control mat.

The composition of the erosion control grass mix has to suit the site conditions. It is recommended to use grass mix with higher number of grass species for enhancing rapid establishment of natural vegetation.

RESULTS AND DISCUSSION

The determination of the limit level on the reservoir bank up to which we can consider negative influence of wind waves is the fundamental problem of successful design of stabilization components. Former researches focused on abrasion process and shoreline stabilization performed on Brno and Vranov waterworks were based on the method for determination of potential altitude of the toe of the abrasion cavern (Šlezingr, 2004). The final potential altitude of the toe V_a (m a.s.l.) is given by the sum of the most frequent still water level altitude SWL (m a.s.l.), half characteristic wave height $H_0/2$ (m), mean water surface elevation about the still water level η (m) and elevation of water level drifted by wind in reservoir ΔD (m):

$$V_a = SWL + \frac{H_0}{2} + \eta + \Delta D \ \text{[m a.s.l.]}.$$

The determination of characteristic wave height (H) and wave length (L) can be realized by various methods (ČSN 75 0255, USACE, 2002–2011). Characteristic wave is defined as the mean wave of one third of the highest waves (wave with 13% probability of occurrence) due to the Rayleigh distribution.

When the wind blows in the approximately same direction over the water-table, the water is gently cumulated near opposite reservoir shoreline. Determination of the water-table superelevation caused by wind drift in reservoir ΔD (m) depends on wind velocity measured in the level of 10 m above water-table w_{10}^2 (m·s⁻¹), mean depth of water reservoir in the direction of wind blow $d_{\varnothing}$ (m) and fetch – the length of wind run over water-table F (m):

$$\Delta D = k_w \frac{w_{10}^2 F}{g d\phi} \cos\delta \ \text{[m]}.$$

In the equation, k_w is empirically determined dimensionless coefficient dependent on wind velocity with values $2.1 \cdot 10^{-6}$–$3.0 \cdot 10^{-6}$, g denotes gravitational constant (9.81 $m \cdot s^{-2}$) and δ represents the angle between the wind direction and longitudinal axis of the water reservoir (ČSN 75 0255, Lukáč, Abyffy, 1980). The water drift is often negligible because the resulting water-table superelevation reaches values in order from milimeters to centimeters.

Observations showed that the calculations through the use of equation 1 give underestimated results in the cases of steeper bank slopes and the toes of abrasion caverns are situated higher in reality. Thus the correction factor could be used for the particular locality on the basis of survey (Šlezingr *et al.*, 2012). However the recent research is focused on the complex solution of this problem and determination the general form of calculation which would fit into any case. Equation for determination V_a consider untransformed characteristic wave height in deep water conditions, further η = 0 due to the small amplitude theory (USACE, 2002–2011; WMO, 1998). These presumptions are valid in deep water conditions but their use near the shoreline seems to be misleading due to the wave breaking, refraction and overall water level changes within the surf zone.

The proposed calculation procedure better reflects the hydrodynamic events which take place near the shoreline. The determination of breaker type is the first step. Breaker type refers to the form of the wave breaking which may be classified in four types as spilling, plunging, collapsing and surging. Breaker type may be correlated to the surf similarity parameter ξ – Iribarren number modified by Walton [11], which is defined as:

$$\xi_0 = \sin\alpha \left(\frac{H_0}{L_0}\right)^{-\frac{1}{2}} \ [\text{-}].$$

In the equation, α = bank slope (°), H = wave height (m), L = wave length (m) and subscript $_{-0}$ denotes the deepwater condition. In spilling breakers ($\xi < 0.5$, high-steepness waves on gently sloping banks), the wave crest becomes unstable and cascades down the shoreward face of the wave producing a foamy water surface. In plunging breakers ($0.5 < \xi < 3.0$, intermediately steep waves on steeper banks), the crest curls over the shoreward face of the wave and falls into the base of the wave, resulting in a high splash. In collapsing breakers ($3.0 < \xi < 3.5$, low steepness waves on steep banks) the crest remains unbroken while the lower part of the shoreward face steepens and then falls, producing an irregular turbulent water surface. In surging breakers ($\xi > 3.5$, low steepness waves on steep banks), the crest remains unbroken and the front face of the wave advances up the bank with minor breaking. The most intense local fluid motions are produced by a plunging breaker. As it breaks, the crest acts as a free-falling jet that may scour a trough into the bottom. Thus, we are able to predict extreme situations due to the bank deterioration based on the breaker type, proposed wind speed and wave height and length respectively, for any locality on the water reservoir.

The half characteristic wave height ($H_0/2$) and mean water surface elevation about the still water level (η) are newly replaced by wave run-up on the water reservoir bank. Run-up is defined as maximum elevation of wave up-rush above still water level. Wave up-rush consists of two components: superelevation of the mean water level due to wave action (setup) and fluctuations about the mean (swash). So, wave run-up calculation also results from the wave height in deep water condition but it better respects wave changes in surf zone. Further, run-up could be considered as local maximum of η. The upper limit of run-up is the important parameter determining the active zone of the bank profile.

Run-up of breaking waves was empirically determined as a function of bank slope, incident wave height (H) and wave steepness on laboratory data for $0.1 < \xi < 2.3$ (Hunt, 1959):

$$R = H_0 \xi_0 \text{ [m]}.$$

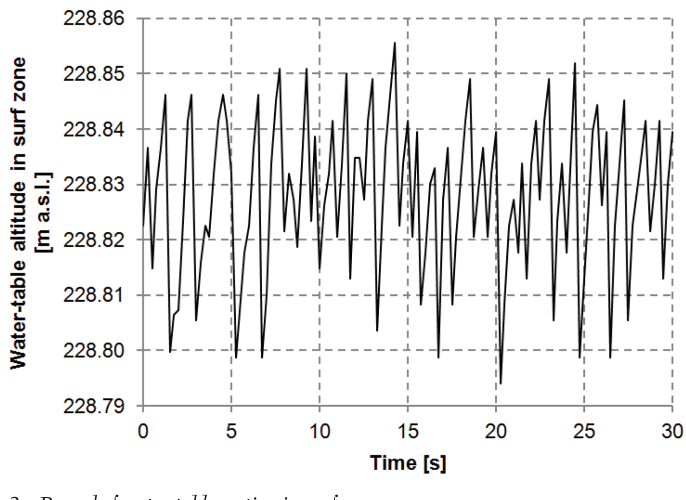
There is the proposal of new form of the calculation for the determination of active zone of bank profile affected by wind waves on water reservoirs due to the application of piece of knowledge from surf zone hydrodynamics:

$$V_a = SWL + R + \Delta D \text{ [m a.s.l.]}.$$

The field measurement was realized for the verification of discussed presumptions. Experimental locality was situated on Brno water reservoir in the conditions of sandy beaches. Main input data included the measured values of actual still water level (passed by Brno dam dispatching centre), wind direction and speed (w_{10}), fetch length (F) and bank slope (expressed as cotg α). On the basis of measured inputs were modeled water-table superelevation caused by wind drift (ΔD), characteristic wave height (H_0), wave length (L_0), wave period (T_0) and surf similarity parameter (ξ_0) for deep water conditions.

A levelling staff was laid in the parallel with shoreline and the video recording of water-table motion in surf zone was provided (Fig. 3).

Consequently the record was analyzed and the particular values of water-table elevation were registered in frequency of 4 Hz (i.e. 1 value per 0.25 second). In the graph, points of local maxima of the curve were considered as wave run-up. Thus the data were filtered and the values related to run-ups were statistically processed due to the purposes of the active zone of the bank profile determination. The results of the experiment are summarized in Tab. I. The results show the accordance of measured and modeled values of characteristic



3: *Record of water-table motion in surf zone*

I: *Results of field measurement and modeled values of wave run-up*

Wave run-up: measured							
SWL	**F**	**$d_ø$**	**δ**	**cotg α**	**w_{10}**	**R**	**V_a**
228.800 m a.s.l.	762 m	10 m	36°	10.5	9.6 m·s⁻¹	0.050 m	228.850 m a.s.l.
Wave run-up: modeled							
k_w	**ΔD**	**H_0**	**L_0**	**T_0**	**ξ_0**	**R**	**V_a**
$2.10 \cdot 10^{-6}$	0.0012 m	0.132 m	1.781 m	1.068 s	0.348	0.046 m	228.847 m a.s.l.

wave run-up and altitude of upper limit of the active zone of bank profile.

The first results from laboratory experiment indicate that the growth of grass root system is not dependent on presence or absence of erosion control mats in the soil structure. The sampling of the grass roots was more difficult from the experimental fields with presence of erosion control mat. It means that thanks to the erosion control mat the grass roots have higher pull-out resistance.

The facts of the preliminary survey field have approved that the local geomorphologic features do not contribute to internal erosion of the bank (piping or sapping). The selected areas around the Brno reservoir are southwest-facing sites. They are more affected than the other-facing sites (beyond south-facing sites) by the temperature of the site (hotter temperature condition) and evapotranspiration (higher than in other direction except south-facing sites). For these reasons will be selected three different types of erosion control grass mix. The results from the biotechnical bank stabilization will be known during year 2014.

CONCLUSIONS

There is no doubt that the bank erosion is a natural process and project of pristine bank protection does not exist if we want to accomplish bank stability and erosion protection in conjunction with ecological concepts and aesthetic appeal. It is necessary to have knowledge of wave hydrodynamics in the surf zone for suggestion of the most suitable bank proportion whether we are in the phase of new water reservoir creation or in step of rehabilitation of current bank failure.

For the present, theoretical approaches for calculating water level behavior within surf zone and wave run-up are applicable with difficulties for coastal design. Problems include nonlinear wave transformation, wave reflection, bathymetry, porosity, roughness, permeability and groundwater elevation.

The important decision lies in the formulation of the protection degree of shoreline – setting up of the design wave height and design wind speed respectively. The dams and levees are protected from the waves with 1% probability of occurrence and the backwater zone is usually protected from characteristic wave with 13% probability of occurrence due to high expenses spent on stabilization measures.

The sites selected for the project of bank stabilization (Osada, Sokolské koupaliště) are mainly threatened by bank erosion which is caused by hydrodynamic processes of wave breaking within the surf zone on the one hand and by the human activities (hiking, cycling, boating, swimming, fishing, etc.) on the other hand. The method of the proposed biotechnical bank stabilization (see Fig. 2) protects the region from the wave breaking point to the limit of wave run-up with placed rockfill and the rest of the water reservoir bank (minimum length two meters) with the “reinforced grass carpets”. It is necessary to build up overlap of hard structural treatments (in this case the placed rockfill) due to accurate establishment of “reinforced grass carpet”.

The erosion control mats which were selected for the biotechnical bank stabilization are made of thick polyamide filaments fused where they cross (Enkamat 7010 and Enkamat 7020) or polypropylene net and HDPE net heat bonded to form a corrugated structure (Trinter) (geomat.cz, geosyntetika.cz). Thanks to this composition these erosion control mats are lightweight, flexible and strength and could establish permanent protection against soil erosion by protecting development of strong vegetation.

Due to site conditions (high level of pressure by human activities) is fundamental presence of the permanent erosion control mats for biotechnical bank stabilization because only biological (natural) methods of bank stabilization or biotechnical method with using biodegradable products (coir mats, etc.) cannot guarantee required bank erosion protection.

The erosion control grass mix must to have low maintenance requirements. Have to resist drought, storm water, cold, heat and be able to exist pretty much without regular care in mostly lower fertility soil. On the other hand the selected grass species must to ensure a rapid germinating and establishing for quick surface cover and soil stability.

SUMMARY

The water reservoir banks are eroded mainly by two factors. The first one is wave action (i.e. wave abrasion) affecting the bank in direction from the reservoir. The second one is the influence of water flowing downward over the bank surface in direction from land into the reservoir (e.g. rainfall). The determination of regular altitudinal emplacement of proper designed particular biotechnical stabilization elements is the most important factor on which the right functionality of whole construction depends.

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The "reinforced grass carpets" as a type of biotechnical method of bank stabilization are presented in the paper. Three easily available types of erosion control mats (Enkamat 7010, Enkamat 7020 and Trinter) and three types of grass seeds (Perenial Reygrass (*Lolium perenne*), Common Meadow-Grass (*Poa pratensis*), Tall Fescue (*Festuca arundinacea))* were selected and tested. For data evaluation were used WinRHIZO (image analyses system provides a quick determination of various root morphological parameters) and Analysis Of Variance (ANOVA).

REFERENCES

GEOMAT s. r. o. c2006. *Geomat.cz*. Available online: http://www.geomat.cz/.

GEOSYNTETIKA s. r. o. c2007–2008. *Geosyntetikia.cz*. Available online: http://www.geosyntetika.cz/.

HUNT, I. A. 1959. Design of Seawalls and Breakwaters. *Journal of the Waterways and Harbors Division*, 85(WW3): 123–152.

KAČUGIN, E. G. 1961. Nekotorye zakonomernosti processov pererabotki beregov vodochranilišč, *Voprosy ustojč. sklonov 35*. Moskva, AN SSSR.

KRATOCHVÍL, S. 1970. Stanovení parametrů větrových vln gravitačních vln v hlubokých přehradních nádržích a jezerech. *Vodohospodárský časopis*, XVIII(3).

LINHART, J. 1957. *Voda a život II*: Ustupování břehů nádrží. Praha.

LUKÁČ, M., ABAFFY, D. 1980. *Vlnenie na nádržiach, jeho účinky a protiabrázne opatrenia*. Bratislava: Ministerstvo lesného a vodného hospodárstva SSR.

PYŠKIN, B. A. 1963. *Voprosy dinamiki beregov vodochranilišč*. Kiev, AN SSSR.

ŠLEZINGR, M. 2004. *Břehová abraze*. Brno: CERM.

ŠLEZINGR, M., FIALOVÁ, J. 2012. An Examination of Proposals for Bank Stabilization: the Case of the Brno Water Reservoir (Czech Republic). *Moravian Geographical Reports,* 20(2): 47–57.

ŠLEZINGR, M., PILAŘOVÁ, P., PELIKÁN, P., ZELEŇÁKOVÁ, M. 2012. Verification and proposal of the modification of "The method for the establishment of the erosion terminant". *Acta Univ. Agric. Silvic. Mendelianae Brun.,* LX(6): 303–308.

U.S. ARMY CORPS OF ENGINEERS. 2002–2011. Coastal Engineering Manual. *Engineer Manual*, I–VI: 1110-2-1100.

ÚNMZ. 1987. *Calculation of wave effects on waterworks*. ČSN 75 0255.

WALTON, T. L., Jr. 1992. Interim Guidance for Prediction of Wave Run-up on Beaches. *Ocean Engineering*, 19(2): 199–207.

WMO. 1998. *Guide to Wave Analysis and Forecasting.* 2nd edition. Geneva: WMO No. 702

Contact information

Petr Pelikán: pelikanp@seznam.cz
Pavla Pilařová: xpilaro1@node.mendelu.cz
Jana Marková: jana.markova@mendelu.cz
Lenka Gernešová: xgerneso@node.mendelu.cz