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COASTAL PROTECTION AGAINST WIND-WAVE INDUCED EROSION USING SOFT AND POROUS STRUCTURES: A CASE STUDY AT LAKE BIEL, SWITZERLAND

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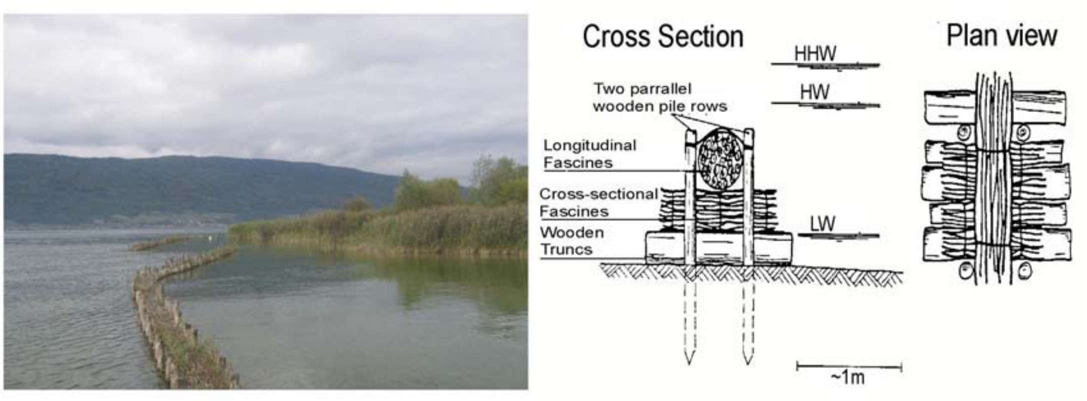
Abstract: At the southern shore of Lake Biel in Mörigen, Switzerland, the sandy beach covered with reed plantations suffers strong erosion although a protection project was realized in the late 20th century. The design of this protection project included the construction of segmented porous structures (brushwood fences) parallel to the shoreline. Their purpose was to damp the incoming energy of wind-generated waves and to protect the shoreline against additional erosion. In order to enhance the shoreline protection, an additional study, based on in situ analysis of wind, waves and bathymetric evolution and numerical modeling of wave field and nearshore wave generated current responsible of sediment transport on the other hand, was carried out. The results revealed that by an adaptation of the existing system an enhancement can be achieved in order to thwart any further erosion and to promote sediment deposition at the leeside of the fences.

INTRODUCTION

Brushwood fences (see Fig. 1a-b) are most commonly used in lakes to provide reliable, soft, and cheap shore protection (Sayah et al. 2004). They are especially effective in shallow regions where hydrodynamic forces, generated by wind and currents, are not very significant. The fences are mainly composed of two elements (see Fig. 1b). The first one, related to the structural stability, is composed of two parallel rows of wooden piles (average spacing of piles equals 0.6 m). Between the two rows, wooden branches, often called “fascines”, are inserted in a cylindrical bundled manner. This porous middle element is responsible for the dissipation of incident waves. The average porosity of fascines varies between 10% and 80%.

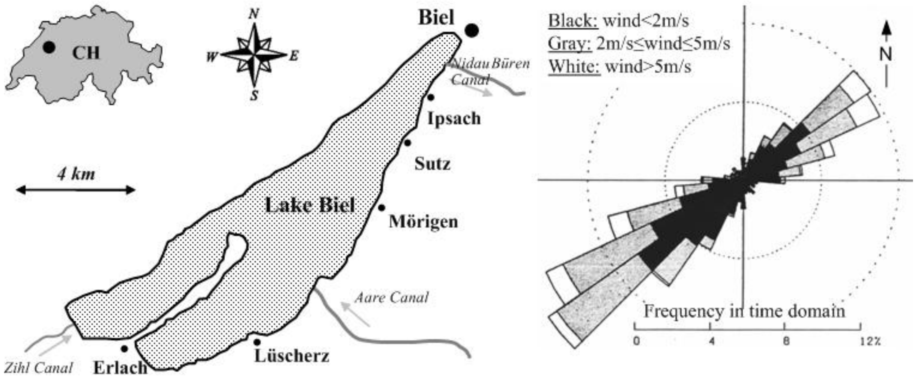


(a) (b)

Fig. 1. (a) Brushwood fences in Lake Biel (Switzerland) used to protect reed plantation; (b) Typical design concept of the brushwood fences

The site selected for the case study where multiple brushwood fences are constructed is located at the South-Eastern shore of Lake Biel (see Fig. 2) at almost 6 km South of Biel city. The location is called Mörigen. The selection of this site was based on three main reasons:

1. Many field surveys were carried out in this site: wind, waves, and bathymetric measurements
2. This site is located almost at the middle of the shore side of Lake Biel where erosion is most active
3. More than ten brushwood fences segments are located at this site used for wave damping



(a) (b)

Fig. 2. (a) Lake Biel in Switzerland and localities where in situ measurements are undertaken; (b) Wind rose based on statistical analysis at Payerne wind station situated at 30km south-west of Lake Biel (MeteoSuisse 1990)

The segmented brushwood fences in Mörigen are shown in Fig. 3. Each extremity of a single structure was located using GPS technique that provided the Swiss coordinates X and Y. The altitude Z for each segment was measured locally. In addition to the positions of brushwood fences, wind velocities over water are measured at almost 2 m above the water level together with wave characteristics and the transmission coefficient of one single segment of brushwood fences at the upper part.

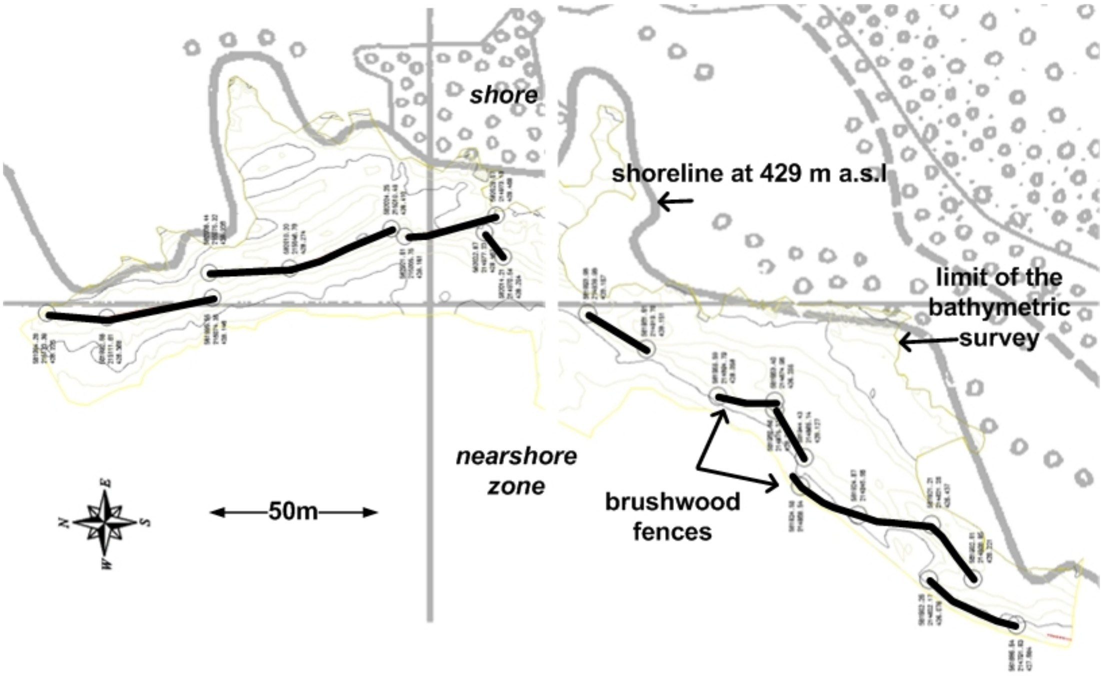


Fig. 3. Segmented brushwood fences at Mörigen in Lake Biel

FIELD MEASUREMENTS OF WIND AT MORIGEN

In situ wind measurements at Lake Biel have been realized in several other localities. However, the measurements of wind at the site of Mörigen selected for the present case study, show substantial results concerning wind velocities for the two major regimes over Lake Biel (see Fig. 1b). Instant over water wind velocities U_W and directions are measured during 6 months period (from first of October 2004 until the end of March 2005) with a Young anemometer Velocities and directions are averaged at 10 minutes intervals. Furthermore, the wind is measured at Payerne ANETZ wind station (wind over land) for the same period of time (wind rose of the fixed wind station is at Fig. 1b).

The comparison of over water and over land wind speeds and events shows relevant similarities. The events are selected when wind speed is significantly higher than 2.5 m/s and lasting at least 1 hour. The events at Payerne occur at the same period and almost for the same direction trends as at Mörigen. However, the measured wind speeds are at both station shows little discrepancy.

Fig. 4 highlights the effect of wind speed variation due to transition from land to water. The data shown corresponds to wind speeds for the South-western wind events during the period [Dec. 2004 - Mar 2005]. It includes measurement during more than 10 wind events. Thus, wind speed tends to increase after a transition from a land surface. However, due to the behavior of water roughness as a function of wind speed, the ratio of over water wind speed at a fixed level to over land wind speeds (U_W/U_L) is not constant, but varies nonlinearly. Fig. 4 provides the trend for the form of such variation. The exact magnitude and characteristics of the transition depend on the roughness properties of the terrain and vegetation on one hand, and on the stability of the air flow on the other hand. Resio and Vincent (1982) presented a simple approximation of this wind speed variation based on a logarithmic fitting curve to the asymptotic over land and over water wind speed values.

Furthermore, trends in Fig. 4 indicate, as expected, that wind speeds over water follow a power law. The ratio (U_W/U_L) tends to infinity when U_L tends to zero and to almost 1 when U_L tends to infinity. The latter fitting depends mostly on the location of on water measurement station and on the wind regime. For "mean" wind speeds (roughly varies between 6 and 10 m/s in Switzerland), corresponding to recurrent wind events, such fitting provides a rough ratio of (U_W/U_L) equal to 1.35. Thus, wind over water is 35% stronger than wind over land for average wind events. This rough estimation strongly depends on the nature of vegetation beside the lake and the local topographic conditions. Therefore it could be not used for general applications.

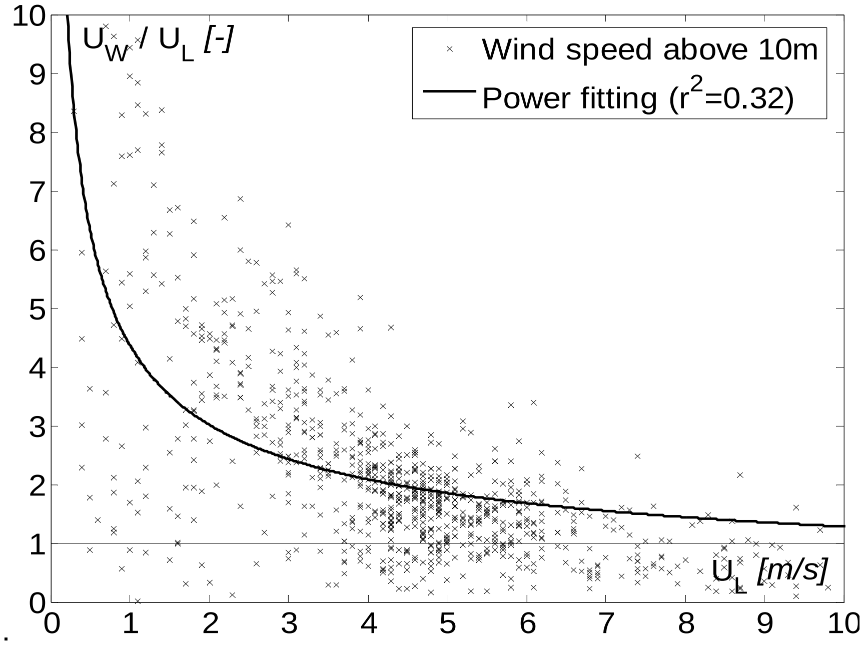


Fig. 4. Ratio of wind speed over water U_W at Mörigen to wind speed over land U_L at Neuchâtel according to U_L for a wind sector [210°-240°] during [Dec. 2004 - Mar 2005]

IN SITU WAVE TRANSMISSION

The field measurements of waves were carried out at the upper part of the brushwood fences field in Mörigen. Waves were measured before and behind a typical segment of brushwood fences during the same period as the wind measurements. The waves selected for the analysis correspond to significant waves heights H_s greater than 0.15 m. Results of K_T according to the dimensionless freeboard R_c/H_s are provided in Fig. 5. During field measurements, the lake water level was always lower than the top of the brushwood fences. Therefore, the structure was always emerging and the transmission coefficient calculated is considered as average. The mean K_T value could be estimated during such conditions is equal to $K_{T,mean}=0.32$.

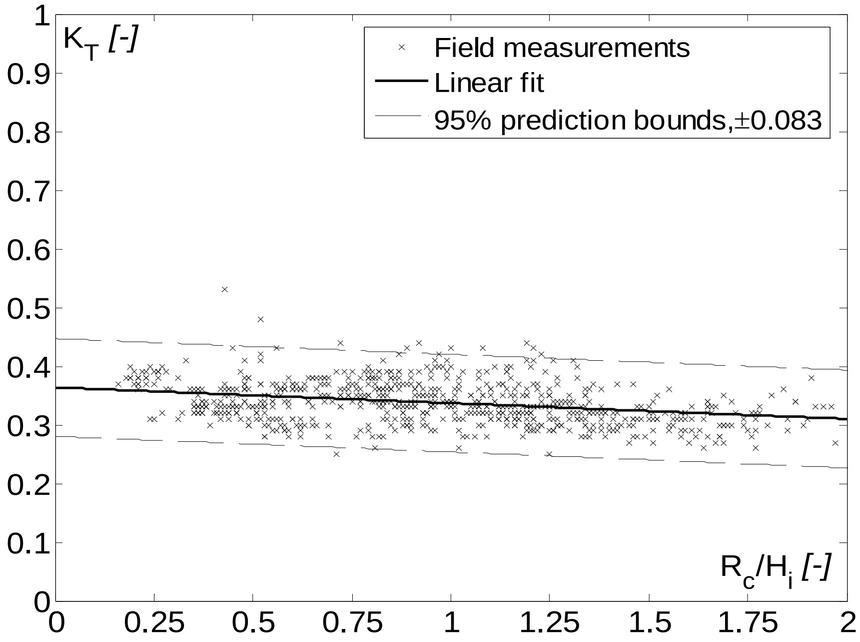


Fig. 5. Transmission coefficient K_T of typical brushwood fences at Mörigen according the relative freeboard R_c/H_s for a structure height h=1.12 m

ANEMOMETRIC AND LIMNIMETRIC BOUNDARY CONDITIONS

For the present case study, it is proposed to calculate incoming wave in the region of Mörigen using the numerical analysis by Swan model (Booij et al. 1996) .Since the duration of wave measurements in the nearshore region of Mörigen is too short, a long term analysis of incoming waves could not be carried out. Therefore, it was proposed to calculated wind-waves based of the statistics of wind measured off shore (at Payerne) after applying on wind velocities the correction coefficient as described before in order to obtain calibrated data.

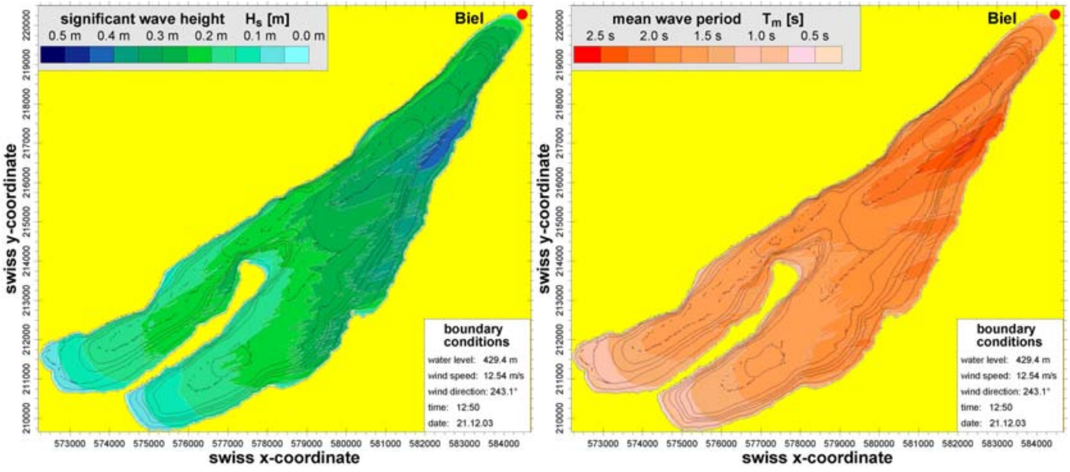
Three main wind regimes are considered for Mörigen as following:

1. South-Western wind (sector [210°-240°]) "Le Vent": fetch=7000 m
2. North-Eastern wind (sector [30°-60°]) "La Bise": fetch=4500 m
3. North-Western wind (sector [300°-330°]) "Le Joran": fetch=3500 m

By using the long term statistical analysis for the three regimes, a calculation of wind velocities for every wind sector and return period could be made. Afterwards, the calculation of waves is carried out in Swan, using as input wind velocities and directions. Since waves are refracting near Mörigen, incoming wave directions are different than wind directions. Therefore special attention should be given to wave direction used afterwards when calculating wave field in the brushwood fences location.

By calculating wave heights, periods and directions in Swan, it is possible to introduce these values as boundary conditions for the modeling of the wave field at Mörigen. Fig. 6 provides an example of wave characteristics for the stronger and more frequent wind regime (le Vent). The wind duration does not play a major role since the condition for the selection of wind velocities is defined when the duration is long enough to produce a fetch limited condition (Kamphuis 2000) Furthermore, the wind speed depends mainly on the selected return period T_r.

The return periods of waves are the same as the return periods of winds. Only three return periods are selected as follows: T_r= 1, 5, and 20 years. For each return period, three water levels of the Lake Biel are selected: MHWL= 429.60 m, MWL=429.20 and MLWL=428.8 m.



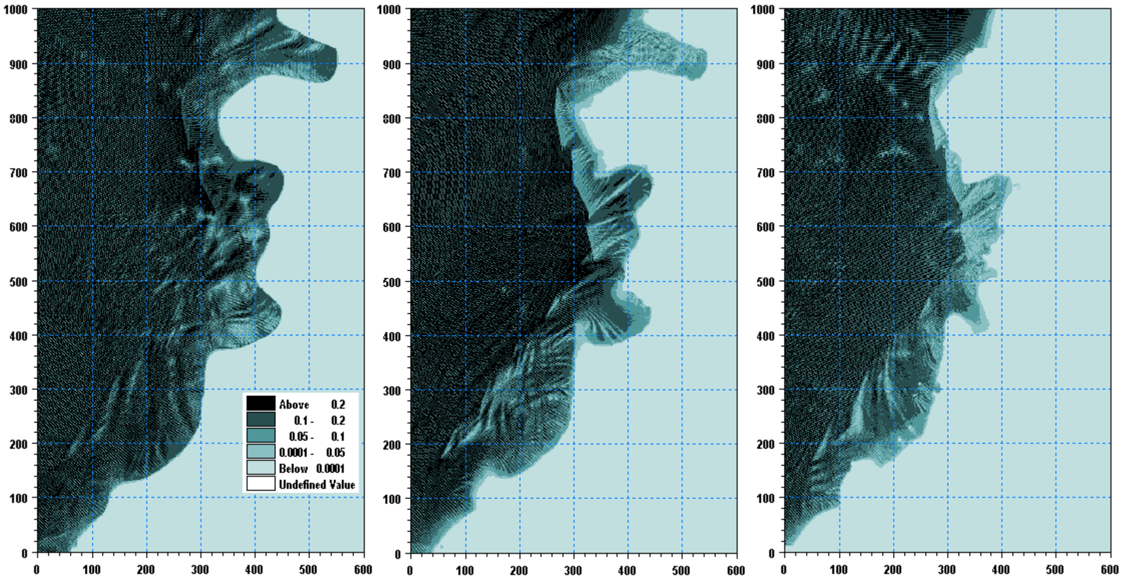
(a) (b)

Fig. 6. Wave field in Lake Biel during a South-Eastern wind regime for the MHWL: (a) significant wave heights; (b) mean wave periods

EFFECT OF THE LAKE WATER LEVEL VARIATION

This section highlights the effect of the present nearshore brushwood fences field at Mörigen on the incoming waves when the lake water level changes. They are based on numerical modeling carried out by an elliptic mild slope solver as described by Madsen and Larsen (1987). It was proposed to calculate first the wave field without introducing any structures. In a next step, the wave field is calculated with the presence of the protection system as described before. This allows an accurate description of the effect of the protection system on the nearshore hydrodynamics and constitutes the basis of any protection enhancement proposals.

The variation of the water level influences significantly the shoreline position (see Fig. 7). Therefore, for the MHWL the shoreline moves in the landward direction and for MLWL, it moves in the seaward direction. At some shallow places, for a water level variation of 0.80 m, the shoreline displacement could reach 25 m. Furthermore, for shallower regions the shoreline displacement is almost 75 m. Such high values bring out the effect of the distance of brushwood fences from the shoreline. This distance should be long enough in order to enable a good performance of the structure during low water regimes. The results show that this criterion is practically fulfilled in almost all the cases. Even for the MLWL, all brushwood fences structures are still in water and able to damp efficiently the incoming waves.



(a) (b) (c)

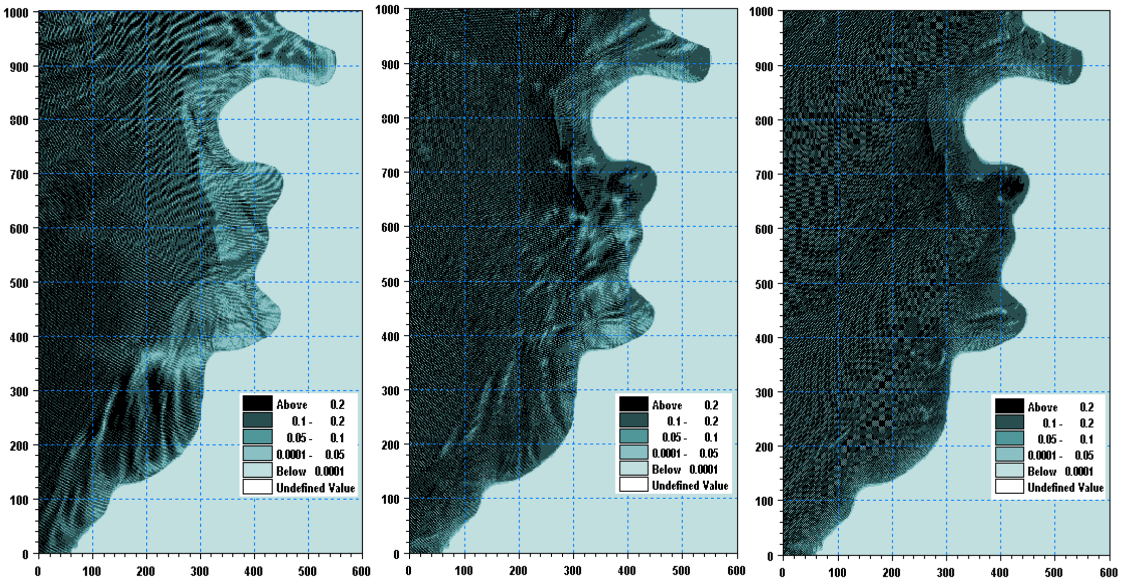
Fig. 7. Wave heights at Mörigen during a Western wind regime with the presence of the protection structures and T_r= 5 years (a) MHWL (B) MWL (c) MLWL

Additionally, the wave damping effect decreases significantly for all the modeled wind regimes when the water level is high. Therefore, when comparing in wave heights behind the brushwood fences field for the three modeled water levels of the lake, it is apparent that during a MHWL period, the incoming waves are almost equal before and behind the protection structures. It has to be noted that during this water level regime, the structures are totally submerged.

For the MWL, waves in the protected area at the leeside of the brushwood fences are much smaller than waves corresponding to the MHWL. However, when compared to waves during the MLWL, they do not appear to be much higher, although the water level variation is the same. This is probably due to the fact that for both water level regimes, the structure in emerging. For this condition, its efficiency is almost constant. Concerning the wave field width at the leeside of the protection structure, the results show that for MWL, the protected region is much wider than the one corresponding to MLWL.

EFFECT OF THE WIND REGIME VARIATION

The wind regime has a clear effect on the nearshore wave field at Mörigen. When comparing results in Fig. 8 it appears that waves tend to be higher for the South-Western regime. This could be clearly seen for the return period T_r= 5 years. Such high waves are essentially due to the fact that the fetch of this wind regime is almost twice as large as the fetches of the two other main wind regimes. Moreover, wind speeds for South-Western wind are the highest.



(a) (b) (c)

Fig. 8. Wave heights at Mörigen during a three different wind regimes with the presence of the protection structures at the MHWL and T_r= 5 years (a) South-Western (b) Western (c) North-Eastern

With the presence of the brushwood fences (see Fig. 8), wind regimes influences significantly the wave field at the leeside of the protection structures. Therefore, when comparing wave fields for MHWL, it appears clearly that for both North-Eastern and Western wind regimes, waves reach more easily the shore by diffraction through the wide gaps in the brushwood fences field. However, during a South-Western wind regime, although waves are higher, it seems that the present geometrical disposition of the structures protects the shoreline very efficiently.

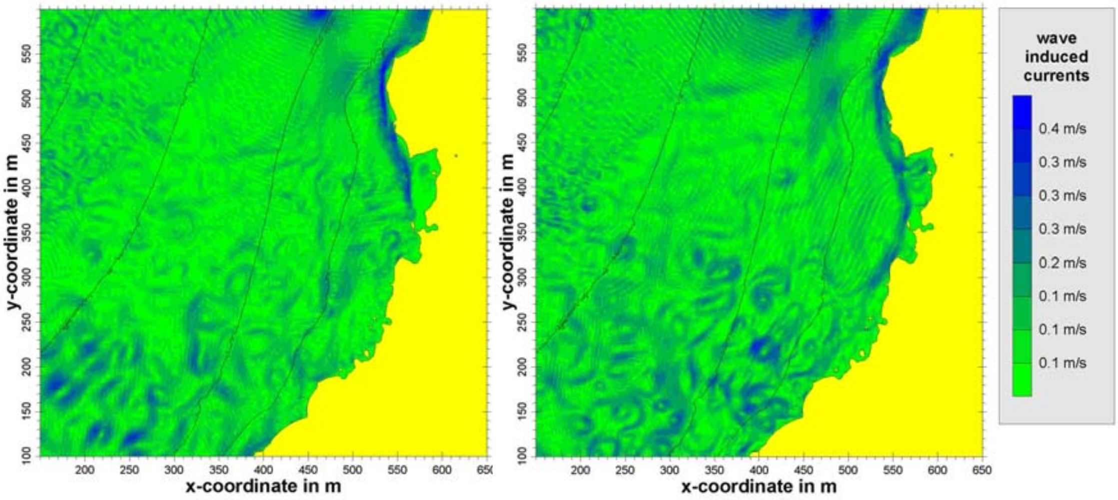
Furthermore, the efficacy of the brushwood fences geometrical disposition during a South-Western wind regime is clearly shown for the MHWL. When comparing the wave field in Fig. 8, it appears that the average wave heights in the lee of the structures are almost twice smaller for the South-Western wind.

NEARSHORE CURRENT GENERATION

For the most significant cases, radiation stresses (Copeland 1985) were calculated in order to generate current maps in the nearshore region of Mörigen. This has been carried out using a hydrodynamic model.

The main conclusions of current simulations were as follows (see Fig. 9):

1. The nearshore wave generated bed currents are significantly reduced for the MHWL. However, for the MLWL, strong currents are more frequent and could easily reach values up to 0.5 m/s.
2. Without the presence of the protection structures, the currents could be easily "canalized" parallel to the shore. Their presence enhances current disturbance and damping.



(a) (b) (c)

Fig. 9. Wave generated currents based on the calculation of the radiation stresses for the MWL and T_r= 5 years (a) with the protection system (b) without the protection system

CONCLUSIONS AND RECOMMENDATIONS

The brushwood fences field at Mörigen in Lake Biel has been modeled using the elliptic mild slope equation. The wave field at the leeside of the fences is obtained for the three main lake water levels, and for the three main wind regimes. The statistical analysis of in-situ over-land wind measurements permitted the identification of three main wind directions, North-East, North-West and South-West. After adjustment of wind velocities based on the ratio of over-water and over-land wind speeds (equal to 1.35), waves statistics for each regime were determined using the numerical model of the entire lake based on Swan application. In average, for a wind return period of T_r= 20 years, corresponding to an average wind velocity of 12 m/s , the waves at Mörigen are almost 0.4 m height and 2.2 s period. The introduction of the transmission values of the brushwood fences and bottom characteristics into the numerical model of the nearshore region of Mörigen are provided through in-situ measurements and depend on water level variation.

For each wind regime, eighteen cases have been investigated. In order to evaluate the effectiveness of the brushwood fences field related mainly to their geometrical distributions, nine cases are considered without the presence of the structures and nine cases with the presence of the structures. They correspond to the three selected return periods, T_r= 1, 5 and 20 years, for each, three selected water levels, MHWL,MWL and MLWL are considered.

The comparison of the results permitted the following conclusions:

1. When the water level of the lake is MHWL, the effectiveness of the brushwood fences field is very low. The transmission of the incoming waves is almost 100%
2. Although during the South-Western wind regime, incoming waves reaches their highest values, they are efficiently damped by the particularly adapted geometrical configuration of the brushwood fences field. For the two other wind regimes, waves are able to reach the shore through wide gaps between the fences

The present study demonstrated the effectiveness of the use of elliptic mild slope equation to model real cases, where porous structures are built. The input of the results obtained by the Swan model for wind-wave data appeared to be very relevant and adequate. Further detailed numerical analysis of currents and bedload sediment transport is crucial, and should reveal significant nearshore phenomenon that contributes to a better understanding of the hydrodynamics of the brushwood fences field in order to suggest resolute enhancement of the protection system.

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