Geosynthetics as eco-friendly defence against erosion in arctic regions

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ABSTRACT
In arctic area, such as on Svalbard near the North Pole, suitable good quality geological material for building protective shorelines and harbours infrastructures is often scarce. Traditional embankment solutions have short lifetime, are too expensive or do not comply with strict environmental regulations. An environmentally friendly embankment solution in arctic conditions, with geosynthetics bags and tubes filled with local soil, was developed and tested along a 100 metre coastline. Conventional and innovative monitoring systems were installed to register changes. Results after three years of installation from this embankment showed positive results to be used for a spin off project with goal to stop erosion on a quay foundation in the local harbour.

RÉSUMÉ
En zone arctique, comme au Svalbard proche du pôle Nord, les géomatériaux de bonne qualité pour construire des ouvrages de protection côtiers sont souvent rares. Les solutions traditionnelles de remblais ont une durée de vie courte, sont coûteuses et ne répondent plus aux réglementations environnementales strictes. Une solution respectueuse de l'environnement en conditions arctiques, utilisant des sacs et des tubes remplis de sol du site, a été développée et validée sur une longueur de côte de 100 mètres. Des systèmes d'auscultation conventionnels et innovants ont été installés pour mesurer les changements. Les résultats après 3 années de service sont très positifs et ont permis la réalisation d'un projet de stabilisation contre l'érosion d'un mur de quai du port local.

1 INTRODUCTION

Shorelines and harbours are traditionally protected from sea erosion by rocks, or soil filled geosynthetics bags and tubes. In the northern regions, where good quality material is often scarce, the prohibitive economic and environmental cost of importing suitable construction material has led to a demand for solutions where local soil, with low mechanical properties, can be used. This paper is based on experience from research projects on Svalbard near the North Pole. In this area, suitable geological material for building protective infrastructures is not readily available. Also traditional embankment solutions have a short lifetime, are too expensive or do not comply with strict environmental regulations.

The partners of the European EUREKA project Σ! 3702 GISSAC (Geosynthetics for Innovative Sustainable Solutions in Arctic Climate) aimed to develop an environmentally friendly embankment solution in arctic conditions, with geosynthetic bags and tubes filled with local soil. It started in 2006, and is funded by grants from Foundation Franco-Norvégienne, the French Agence Nationale pour la Recherche (ANR), Statoil and the partners of the project: Main challenges for such a construction are low temperatures combined with strong wind/waves, and sea ice impact on structures.

The paper describes public results from research carried out on an embankment section in Svalbard protected by geosynthetic bags. One of the challenges is regarding instrumentation and monitoring systems: to register changes, both visual and electronic methods where used. The main factors to monitor were stresses related to ice impact, sea currents and temperature. Together with conventional monitoring systems a new generation of intelligent geotextile sensors using fibre optic technology was installed and tested. Additionally the paper will deal with results from an erosion protection project by use of geosynthetics on a quay in the same area.

The paper describes the public part of the results.

2 METHODOLOGY OF THE PROGRAM

2.1 Program methodology

Constructing environmentally friendly shore structures in cold regions using geosynthetic bags filled with locally available geological material, three main problems have to be analyzed.

The first issue is to assess the macroscopic behavior of the bags in arctic conditions, their resistance to ice loads, and the optimized design of the bags in terms of weight, size, layout and anchorage.

The second issue is about the behavior of the surface of the bags, define the optimum type of polymer and type of structure (e.g. woven - nonwoven – composite) to fulfill the requirements regarding actions such as freeze/thaw cycles in contact with poor quality soils, abrasion by the ice, the long term durability of the geosynthetics in arctic conditions.

The third is related to the method of design and the construction method.

To cover all the above questions, three main approaches have been chosen for the project realization: theoretical studies, laboratory models and a full size realization in Svea. A PhD-thesis by Caline (2010) covers the construction of the test structure, and the observation and analysis of the ice conditions in Sveasundet (Figure 1). The laboratory experimental work performed at LRPC covers the study of the behavior of geosynthetics in simplified arctic simulated conditions. This is described in section 5.

Figure 1. Map over the Svea area : the experimental site in Barryneset and the harbour in Kapp Amsterdam. (Courtesy SNSG).

2.2 The full size experimentation site in Svea

The test structure is a breakwater protected at its surface by more than 150 bags, realized from seven different geosynthetics. The embankment has been observed during a period of three years, allowing three sampling periods. During these samplings, 46 bags have been analyzed and tested for the two first years. The "UV frames" covered by geotextiles placed close to the embankment have allowed additional evaluation of the behavior of these geotextiles under arctic climate, especially on potential degradation from UV-radiation.

The bags are placed at the end of the breakwater parallel to the fjord axe and most of the bags on the west corner in the direction of the sea (Figure 2 and 3).

The activity at the test site has allowed studying:

• bag filling and bag installation;

• ice actions under several situation: freeze-up, stationary ice and break-up (as the conditions of ice are site specific, the results shall be extrapolated with care):

• wave actions (site specific):

• durability to UV exposure (also site specific).

The test site at Svea, provided for research purposes by SNSG, is ideal for several reasons. There is sea ice every winter and, several workshops and heavy construction machinery available. The test site itself, Barryneset, is a headland between Braganzavågen and Sveabukta, on the north side of Sveasundet (Figure 1).

The climate in Svea is high-Arctic. The snow cover is usually thin due to little precipitation and strong winds.

The maximum yearly ice thickness in Sveasundet between 1998 and 2006 varied between 0.72 and 1.28 m.

The sea usually freezes over between November and January, reaches its maximum thickness in mid-May and breaks up between the middle of June and the middle of July. A substantial amount of ice is generated in the shallow waters of Braganzavågen and transported into the fjord with the tidal current. In general, the seabed consists of a 1.5 to 3.5 m soft layer on top of a hard layer (Caline, 2010).

A 50 meter long breakwater was built during the summer of 2006. The inclination of the embankment is 1:3.5 (Figures 3 and 4). Its top is 3.2 above datum and 5 m wide. The masses were extracted from the mountainsides surrounding Svea.

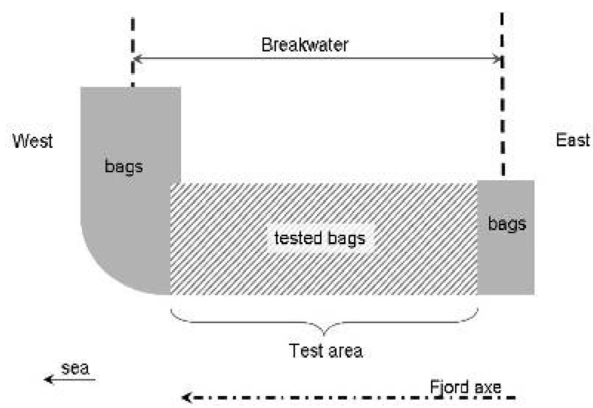

Figure 2. Design of test bags location.

2.3 The geobags

The geobags were mainly pre-fabricated at the TenCate factory. Several types of textile envelopes were used (Table 1). The choice of has been realised based on the experience of TenCate in bags design for erosion protection in coastal protection. In addition, considering the potential actions of ice, specific composite structures have been designed including an internal layer made of nonwoven fabric and an external geonet layer. Four main types have been tested: needle punched nonwoven,

woven, woven with loops and composite needle punched nonwoven covered with different geonets.

The geobags shape and size design has been realised based on the experience of geobags design in coastal protection (Figure 5). A previous research realised in a wave flume confirms that the geobags filled with soil can successfully be used to replace armour-blocs in erosion control (Vassal, 2003). The volume of one bag is about 0.6 m3 and the mass 1000 kg when filled to 80% with materials of 1900 kg/m3 density (Figure 5).

Figure 3. Aerial view of the breakwater.

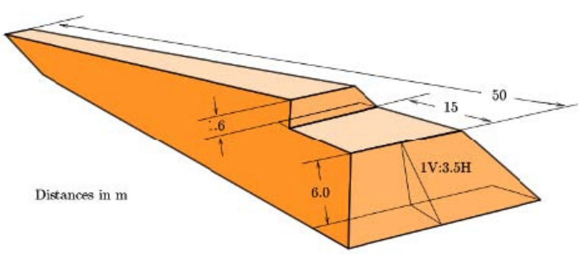

Figure 4. Sketch of the breakwater (Caline, 2010).

Table 1. Characteristics of tested geobags envelopes.

Envelopes	P50U	P80U	F80	F8a	F8b	GL	RL
Int. envelope[1]	NP	NP	NP	NP	NP	W	W
Ext. envelope[1]	No	No	No	Ka	Kb	No	No
Thickness mm	4.2	6.0	6.5	6.5	6.5	NA	10
Tensile MD kN/m	30	45	35	35	35	210	40
Opening s. µm	80	80	80	80	80	NA	1000
Permeability mm/s	15	10	30	30	30	NA	NA
Unit weight g/m²	525	800	800	800	800	875	480

[1]NP : Needle-punched nonwoven; W: Woven: Ka or Kb : Knitted net
MD : Machine direction

Filling equipment was designed for the project, consisting of a funnel and a box, which was attached to the arm of an excavator (Figure 6). The bags were filled with local masses. 70% of the masses had a diameter smaller than 19 mm. The construction took place in August 2006. The filling and installation of a bag took approximately 10 minutes and required two excavator operators and two bag operators. 150 bags were constructed in total (Figure 7).

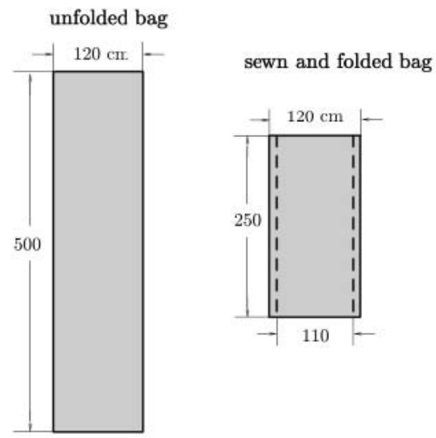

Figure 5. Sketch of the geobags used at Barryneset.

Figure 6. Elevated funnel used to fill the bags on site.

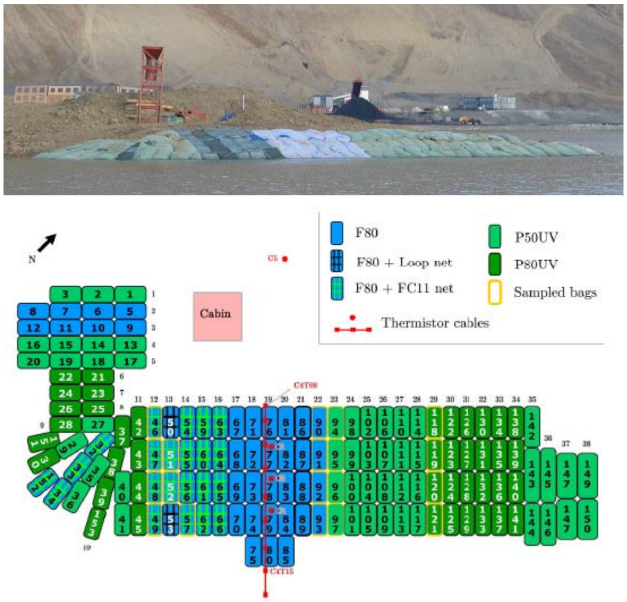

Figure 7. View and map of breakwater after construction (September 2006).

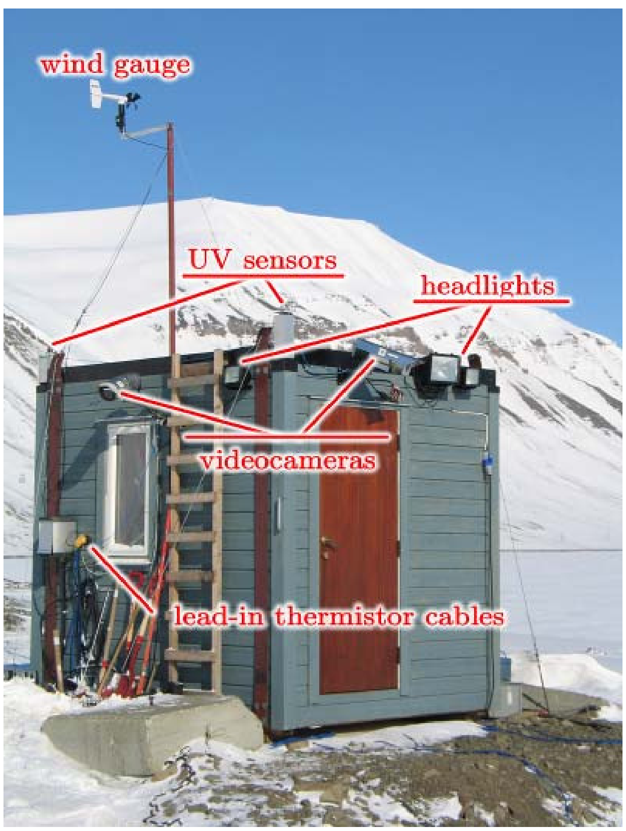

Figure 8. Weather station and instrumentation hut (September 2006).

Figure 9. Time lapse camera on Liljevalchfjellet above Svea taking pictures of the sea ice in Sveasundet, May 22nd 2007. The experimental breakwater in the red circle (Caline, 2010)

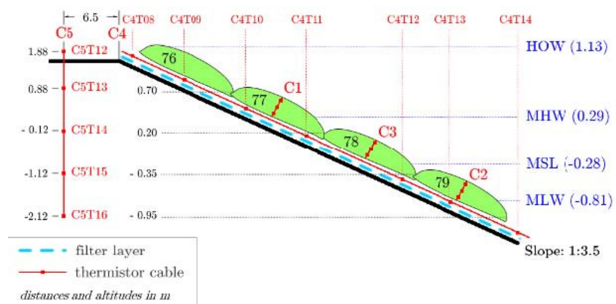

Figure 10. Profile of the breakwater slope covered with bags

Figure 11. The TenCate GeoDetect® textile fiber optics sensor

Figure 12. Location of the textile fiber optics sensor (red shape).

Figure 13. The connection cable from the textile fiber optic sensoring strip below the geobags.

2.4 The conventional instrumentation

Monitoring equipment including a tide and wave gauge, thermistor strings, a weather station and cameras were installed (Figures 8, 9 and 10).

2.5 The fiber optics textile composite sensor

The TenCate GeoDetect® S-FBG solution embodies a strip of geocomposite fabric, fiber optics, software and instrumentation to provide an innovative solution for the multi-functional requirements of a geotechnical application (Figure 11). It uses Fiber Bragg Gratings (FBG) technology to measure strain in soil structures as low as 0.02% with a spatial resolution of 1 m.

The strip was laid below the bags of the West corner (Figure 12). The strain measured between the installation in September 2006 and spring 2007 ranged between 0 to 0.1%, concluding to no significant movement of the bags, nor settlement of the slope. The connection cable (Figure 13) was cut by an engine. It is planned to repair it and run new measurements in summer 2010.

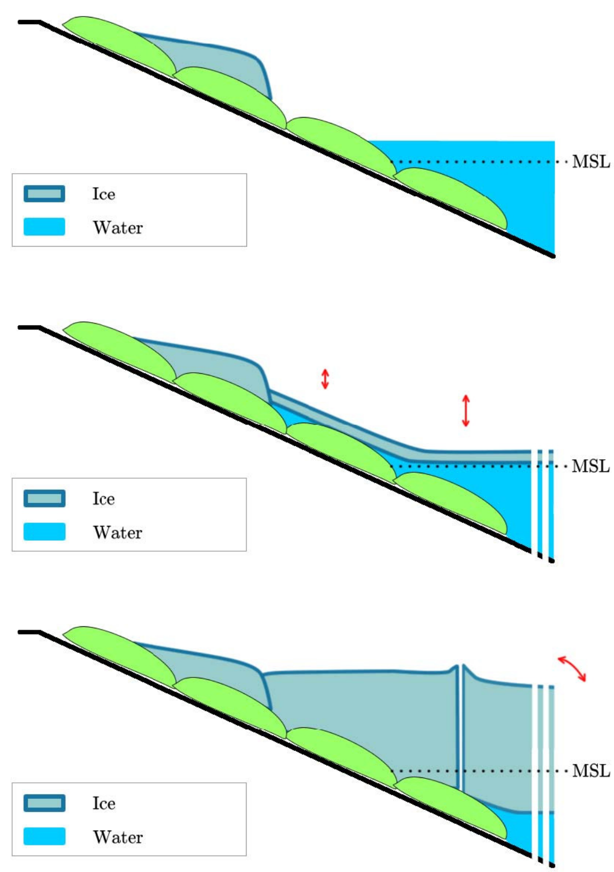

Figure 14. Profile of the bags during the ice cover period at resp. freeze-up, low tide and high tide from top to bottom (Caline, 2010)

2.6 Sampling and testing procedure

Observations and sampling has been realised in three successive years (2007, 2008 and 2009) with the same methodology for each bag:

- Visual observation and pictures, eventual damage recorded. Levelling of the structure.
- Sampling of the envelopes of some geobags for further testing.
- Sampling of the soil in the bags in 2007.

In year 2007 the bags sampled have been emptied and replaced by new geobags made of woven envelopes.

3 ICE ACTIONS

The ice loads may be characterized as mild. The biggest ice loads occurred during the break-up, when the structure was subjected to ice cake impacts and ice pile-ups. The sea usually freezes over between November and January, reaches its maximum thickness in mid-May and breaks up between the middle of June and the middle of July.

During the freeze-up, as temperatures get below 0 ±C, ice starts forming on the fjord. It drifts back and forth with the tidal current. On the shore an ice cap forms. Loads were mostly limited to abrasion from drifting pancakes. As they drift along the breakwater, the ice cakes erode against the bags, creating a white ice powder and brushing the bag fibres. Above the mean high water level (MHW), no brushing occurs since the bags are protected by the ice foot.

During the ice cover period, due to the vertical tidal movement, tide cracks form parallel to the shore. The most shoreward tide crack runs above the last row of bags. The ice is rotating around the crack with the tide and by doing so, deforming the underlying bags: masses are displaced from below the crack to the top and bottom Loads were small due to the absence of significant horizontal movement of the coastal ice

As solar radiations increase, the snow melts away and the ice cover melts. The broken ice drifts back and forth with the tide. The break-up lasts for about 10 days. The ice foot gradually melts away, increasingly exposing the bags to dynamic loads from drifting cakes. At the end of the break-up, several pile-ups may occur in the east. One bag, bag 150, was cut open during a pile-up. By that time, the ice was not more than 30 cm thick and quite soft. Hence, the pile-ups are not extensive enough to displace the bags. Other observations were that the upper rows melted first, while 2.5 m remained fixed to the bags. The ice panels are rotating with tide and then leaving. Some places the net were trapped in the ice. Some floating panels push and go back, ice cakes were pushed on top of the ice foot and some large cakes were pushed up on the shore.

4 HYDRAULIC ACTIONS

Because Sveabukta is at approximately 90º ± to the rest of Van Mijenfjorden, the waves are essentially wind generated. The fetch from the Braganzavågen direction is of the order of 1 km. Waves generated in Braganzavågen need therefore not be considered during design. The waves did not cause any movement of the bags. Figure 10 presents the bags with the different water levels.

5 OBSERVATIONS ON THE GEOBAGS

5.1 Visual & surface observations

The main types of visual damages have been classified based on observations. Some of the bags have been sampled from the site for testing. In some cases removed bags have been replaced with new bags. Four main criteria were chosen to assess the condition of the geobags. The first three criteria have been rated on a 0-3 scale, where 0 is the best. The last criterion, functionality, has been graded adequate or inadequate. There are obviously some ice actions on the bags that wear the material. The geosynthetic envelope of the bags is fairly thick, and rupture of bags because of abrasion or scouring would take a long time. But a bag with worn textile is more susceptible to rupture due to some sort of action on the bag. This criteria is a measure how worn the geosynthetic textile is in general. It is a visual survey and may differ greatly from more thorough testing, like tensile strength. As the bags did not cover the whole breakwater, loose rocks were displaced in the east corner during a pile-up. Apparently, one rock was caught between the ice and bag 150. It probably caused increased damage of the bag. To allow distinguishing the degradation linked to UV exposure from the one linked to installation of bags and ice actions, separate UV exposure frames have been installed.

On nonwoven products it appears that some filaments are loose but still connected to the surface. If the tears and the cuts linked to the position of the excavator are excluded, some small punching has been observed. They are mainly due to large stones inside the bags and their number is quite limited. Holes have been observed: one the first year, none in 2008 and several in 2009. They are mainly located on the side of the test area, on the west side of the structure. They seem to be linked to the combination of big stones in the bags and the action of large ice block during the breakup phase. Quite many of the bags have small punctures from stones in the soil filled into the bags, and some of the punctures are from scouring. The medium and large holes are most likely only done by ride up of ice.

Between 2006 and 2007, the degradation is relatively limited in term of gravity, with only one large hole and some abrasion in the two lowest rows of the bags. The large part of abrasion appears on the two lowest rows of bags at the level defined as the freeze-up area. The hole occurs in the east area, which had not been considered as being very sensitive (compared to the west area) at the time of the design. The bags situated on the west part of the structure have also some visual abrasion, but no serious degradation.

Between 2007 and 2008, it appears that during this year no serious increase in damage was observed, mainly increase of loose fibers but no new hole. Some serious damages have been observed on one special woven composite envelope, showing it is not suitable to this type of application without proper protection. Other woven envelopes behave well.

Between 2008 and 2009, Figure16 presents the evolution of the damages observed on the bags during 1 year in relation with the different ice actions. The arrows show the way followed by the ice blocks pushed over the bags during the break-up phase, either from the East or from the West.

As a summary, the impact of the breakup were much more severe on the bags in 2009 than for the two previous years :

- 1 bag has been lost as it was without side-bags which were sampled the year before and gives more side impact from the ice blocks pushed over the bags from the East (or less probably from the West) (Figure 15);
- 5 bags have been severely damaged (large holes); they are all situated in the side areas (East & West) and

not in the test area; this confirms the large effect of the breakup.

- the bags in the test area have also been damaged by small punctures but which don't seem being critical for the stability. It has to be noted that due to the tide conditions the lower line of bags could not be observed during the sampling 2009.

As a total over three years, seven out of 150 have been severely damaged (less than 5%) which is a very good ratio.

5.2 Effect of freeze-thaw cycles on the envelopes

In order to have a first approach of the behavior of geotextiles in extreme conditions tensile tests have been carried out on two geotextiles submitted to freeze-thaw cycles. One of the geotextiles has been tested at controlled negative temperatures. If the small number of tests and cycles does not allow concluding definitely, these results do not show any alteration or significant change of tensile properties of the geotextiles submitted to freeze-thaw cycles between 0°C and –19°C. The variations remain inside the normal ± 10% variation range due, both to the variability of the product and to the small number of specimens used. The tensile characteristics of the geotextiles do not seem to be affected by negative temperatures as long as the products are not exposed to stress. On the other hand, under negative temperatures and for wet specimens these characteristics are significantly modified (increase of strength) but no brittle failure has been observed during the tests.

These first conclusions should be confirmed by complementary tests by increasing the duration of the freeze-thaw cycle and/or the range of the temperatures and by increasing the number of cycles.

5.3 Ageing the geobags textile envelopes

In July 2007 samples have been taken on bags installed on site one year before (2006). The upper side of the bags, exposed to weathering, waves and ice actions, have been cut in order to get the largest possible surface and in particular the lower part of the bags. The following tests have been carried out on the samples: tensile (EN ISO 10319), static puncture with a pyramidal plunger (NF G 38019), permeability (EN ISO 11058) and mass per unit area (adapted from EN ISO 9864). The remaining tensile strength (RTS) calculated by comparison with the control specimen is nearly 87% (mean value) and varies from 100% to 71%. Effect of the geotextile structure was observed in term of filament size and needling. These results demonstrate that after a year in service and exposure to weathering, action of waves and ice, the geotextiles do not show up significant changes of their strength properties, excepted for only 3 bags. Elongation is perceptibly modified (mean value: 80% of the normal elongation) with values reduced to 60%. This has already been observed on needle-punched geotextiles polluted with soil. The puncture values confirm that the mechanical properties of the geotextiles are not deeply modified.

On bags sampled in 2008, only tensile tests and mass per unit area tests have been carried out. And with the same conclusions as in 2007 : the RTS is globally 86% (compared to 87% in 2007). These results clearly demonstrate that there is no significant evolution between 2007 and 2008, after the bags are exposed one or two years. Tests on non-woven envelopes submitted to UV (weathering) do not show significant change of properties (RTS higher than 90%). Therefore, it can be hypothesized that the filling and the installation of the bags is partly (or mainly) the cause of the relative loss of tensile properties rather than to the exposure to weathering and action of waves and ice. This should be confirmed by new samples after three years.

Figure 15. Visual inspection in 2009. Contact of the ice on the west corner One hole on bag 26, second on the left.

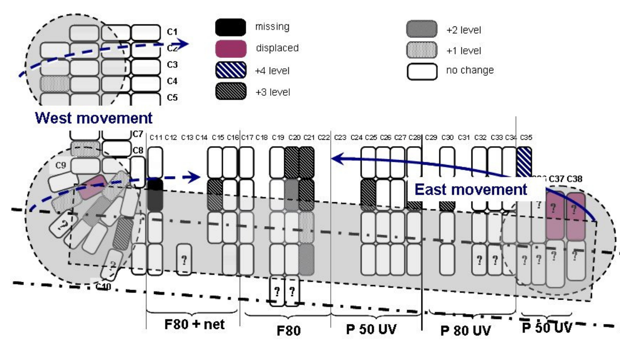

Figure 16. Evolution of the damages observed on the bags during 1 year (summer 2008 to summer 2009) in relation with the different ice actions either from East or from West.)

6 ECONOMICAL AND ENVIRONMENTAL IMPACT

The geobags solution is a real economical alternative to traditional rocks. For example, geobags were used to reinforce an existing quay previously protected with large rocks against scour erosion at the Kapp Amsterdam harbor in Svea, a few kilometers from the Barryneset experimental site (Figure 1). It consists in a slope stabilization built with 10 levels of geobags (Figure 17). Two years after installation, the results are very promising and will be published in other papers.

Environmental impact of the geobag solution can be compared positively versus the classical armour rock solution used in other areas of Svea. The low weight and low volume of the prefabricated bags compared to the armour rock, makes the transports environmental impact clearly in favour of the geosynthetic solution. Filling and installation of bags are in the same order of magnitude as the extraction, displacements and installation of the armour rocks. By experience, SNSG needs to replace regularly every year a great number of rocks, This has to be compared (1) to the need of replacement of <5% of the bags over the 3 years (Svea ice conditions), and (2) no need of replacement in Kapp Amsterdam after 2 years. Finally, the easy sampling and replacement of the sampled bags, shows that the structure may be easily repaired and whenever needed easily dismantled without damages to environment.

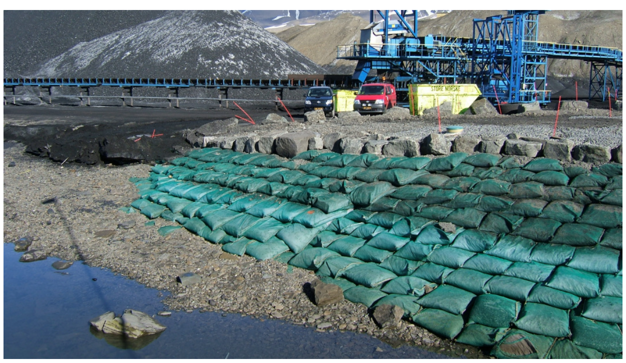

Figure 17. The Kapp Amsterdam quay wall stabilised with the geobags

7 CONCLUSION

The work realized during the GISSAC-project provides some guidelines and recommendations for the use of geosynthetic bags as erosion control in arctic areas where the climatic and ice conditions are similar to the ones in Svea. The technique based on the use of local available soils to fill the bags fulfils the requirements of an efficient erosion protection structure, considering that some simple recommendations are followed.

The classical techniques for design of armour rocks may be successfully used for geosynthetics bags. For the same weight the geosynthetic bags show generally a slightly increased stability due to their flexibility compared to rock armours.

Design of geosynthetics versus UV exposure is not a critical issue compared to other areas of the world. The low UV intensity in addition with the low temperatures, allow a classical design of the geosynthetics by the producers to fulfill the sustainability requirements versus this external action.

Even if the stationary stage of ice seems not to have any influence on the geosynthetics, the design versus the freeze-up and the break-up are important. In case of similar ice actions and breakwater structure as in the Svea experimentation, some design suggestions may be proposed. For the freeze-up period, the non-woven bags covered with an adequate protective geonet or geogrid offer the necessary resistance to abrasion from the floating ice “cakes”. For the breakup period, it appears that some damage has to be expected, depending on the severity of the ice actions. The maintenance to be planed stays at a reasonable level (< 5% of the bags to be replaced over a period of 3 years). This behavior may be successfully improved by appropriate design of the geobags and of the structure.

Based on the experience acquired, bag filling and installation can successfully be realized in arctic conditions similar to the Svea experimental site. Optimization will be usefully adjusted depending on the local contractor resources and materials. Adequate design of the geosynthetic versus damage during the installation and especially the filling is an important issue; also this is not specific to arctic conditions. Regular survey of the bags has to be planned at least during and/or after the breakup periods. Depending on the observed damages replacement of some bags may be necessary. In similar ice and site conditions as in Svea breakwater, the maintenance costs stay at a very reasonable level which makes the solution quite efficient.

ACKNOWLEDGEMENTS

The writers would like to acknowledge FFN, Eureka, and ANR for their support to this study.

REFERENCES

Caline F. 2010. Study of stationary costal ice around an inner-fjord breakwater in Svalbard. PhD thesis, NTNU/UNIS, 222 p.

Vassal P. 2003. Étude du comportement des tubes géotextiles, Mémoire de 3ème année ISITV, Toulon, 98 p.