Pollution Control of a Norwegian Fjord by Use of Geotextiles

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ABSTRACT: In the 1970-ies Soerfjorden on the west coast of Norway was ranked as the third most polluted fjord in the world. The pollution were mainly heavy metals as zink, copper, lead, mercury and cadmium. The sea-bottom was covered of layers of residue from more than 70 years of discharge from the melting-industry. It was not allowed to eat fish caught in the inner parts of the fjord.

In 1986 NORZINK AS, one of the main industrial companies in the area, launched a project for clean-up of the fjord. Based on concepts developed by INSTANES A/S , a consulting engineering company in Norway, an unique project was realized and built during 1991-92. The project were based on capping the most polluted area called the Eitrheim Bay with a composite geotextile and securing the shore area with gabions. In addition a sheet-pile wall were established in the inner part of the Eitrheim Bay for tide and surcharge water control. The total area of capping were 100.000 m², and the capping extended down to a sea-depth of -10 metres.

1. INTRODUCTION.

During the 1970-ies it was established that the beautiful fjord Soerfjorden on the west-coast of Norway was one of the most polluted fjords in the world. As shown in Table 1 there were few comparisons to Soerfjorden.

Table 1. Maximum metal consentrations in sediments from different sites (Førstner & Wittmann, 1979). Values given in ppm.

Site	Ag	Cd	Cr	Cu	Hg	Pb	Zn
Average shale	0.1	0.3	90	45	0.4	20	95
Soerfjorden[f] (Norway)	**190**	**850**	-	**12,000**	**853**	**30,500**	**118,000**
Rio Tinto Estuary[a] (Spain)	-	4,1	-	1,400	-	1,600	3,100
Restronguet Estuary[b] (United Kingdom)	7	12	1,060	4,500	-	1,620	3,000
Acushnet Estuary[c] (New Bedford Hr)	40	76	3,200	7,500	3,8	560	2,300
Corpus Christi Bay[d] (United States)	-	130	-	-	-	-	11,000
Derwent Estuary[e] (Tasmania/Australia)	-	862	258	-	1,130	1,000	10,000

[a]Stenner & Nickless, 1975. [b]Thornton et al., 1975 [c]Summerhayes et al., 1977. [d]Holmes et al., 1974. [e]Bloom & Ayling, 1977. [f]Skei et al., 1972/79.

The average discharge from Norzink AS alone during the years from 1928 to 1984 were some 60,000 m³ of residue pr. year. From 1928 to 1954 this discharge went into the shallow Eitrheim Bay. The residue filled the inner parts of the bay completely to a height of +15 metres. During the 1960-ies the residue was recovered for recycling purposes. The bay was left with a residue cover on the seabed and shore areas from +2 to -10 metres. In addition other factories in the vicinity contributed to the overall pollution in the Soerfjord. The total leakage from the seabed sediments in the inner parts of the Soerfjord (an area of 2.6 km²) were in 1986 calculated to 21,000 kg/year of zink (Zn), 1,800 kg/year of led (Pb), 270 kg/year of copper (Cu), 140 kg/year of camium (Cd) and 0.5 kg/year of mercury (Hg).

In the same investigation it was calculated that approx. 80% of the heavy metal leakage were located in the Eitrheim Bay. This was due to the shallow shores in this bay, and the consentration of resiude exposed to sea erosion combined with a high level of heavy metals in the pore water in the area.

Table 2. Consentration of metals in pore water from 0 to 20 mm sediment depth compared to consentrations 200-300 mm over the sediments. (NIVA, 1986) Values given in

µg/l.

Site	Cu		Pb		Zn		Cd	
	PW	OS	PW	OS	PW	OS	PW	OS
Inner basin of Soerfjorden	2.25	1.73	2.00	13.0	33.0	101.7	0.09	1.47
The Eitrheim Bay	5.50	1.53	3.00	10.2	154.0	257.7	0.06	1.57
The Eitheim Cape	19.0	1.57	6.25	3.23	500.0	908.0	14.0	1.32

PW=Pore water OS=Over sediment

2.0 THE EITRHEIM BAY

The Eitrheim Bay is a long narrow bay approx. 500 m long and 220 m wide. See Figure 1. The depth varies from 0 to 10 metres. The sea bottom is a postglacial deposite consisting of a 40 metres thick clay layer. The clay have a very low shear resistans varying from s_u=5 kN/m² to 10 kN/m². Water content is w=35%.

The sea bottom is covered of a top layer of residue varying in thickness from 100 mm in the outer parts of the bay to 2200 mm in the inner parts. The natural water content of the residue is w=98-100%.

The very soft top layer overlaying the weak clay made it necessary to do elaborate geotechnical calculations conserning slope stability, and enforce strict filling procedures during construction.

3.0 PROPOSED SOLUTIONS

In march 1988 INSTANES delivered a feasability study of possible solutions to remove the pollution effects from the Eitrheim Bay. Three possible solutions were presented:

Alternative 1.
Capping down to -10 m sea depth with surface water control. Calculated cost 3 mill US dollar.

Alternative 2.
Capping down to -10 m sea depth with surface water control and tide control by means of a sheet pile wall. Calculated cost 5.5 mill US dollar.

Alternative 3.
A sealing of the Eitrheim Bay by means of a cellular cofferdam wall in the outer part of the Eitrheim Bay. Calculated cost 8 mill US dollar.

In 1990 alternative 2 was chosen, and the detail engineering fase was started. The alternative is shown in Figure 1.

4.0 THE CHOSEN ALTERNATIVE

Alternative 2 is based on four main elements:

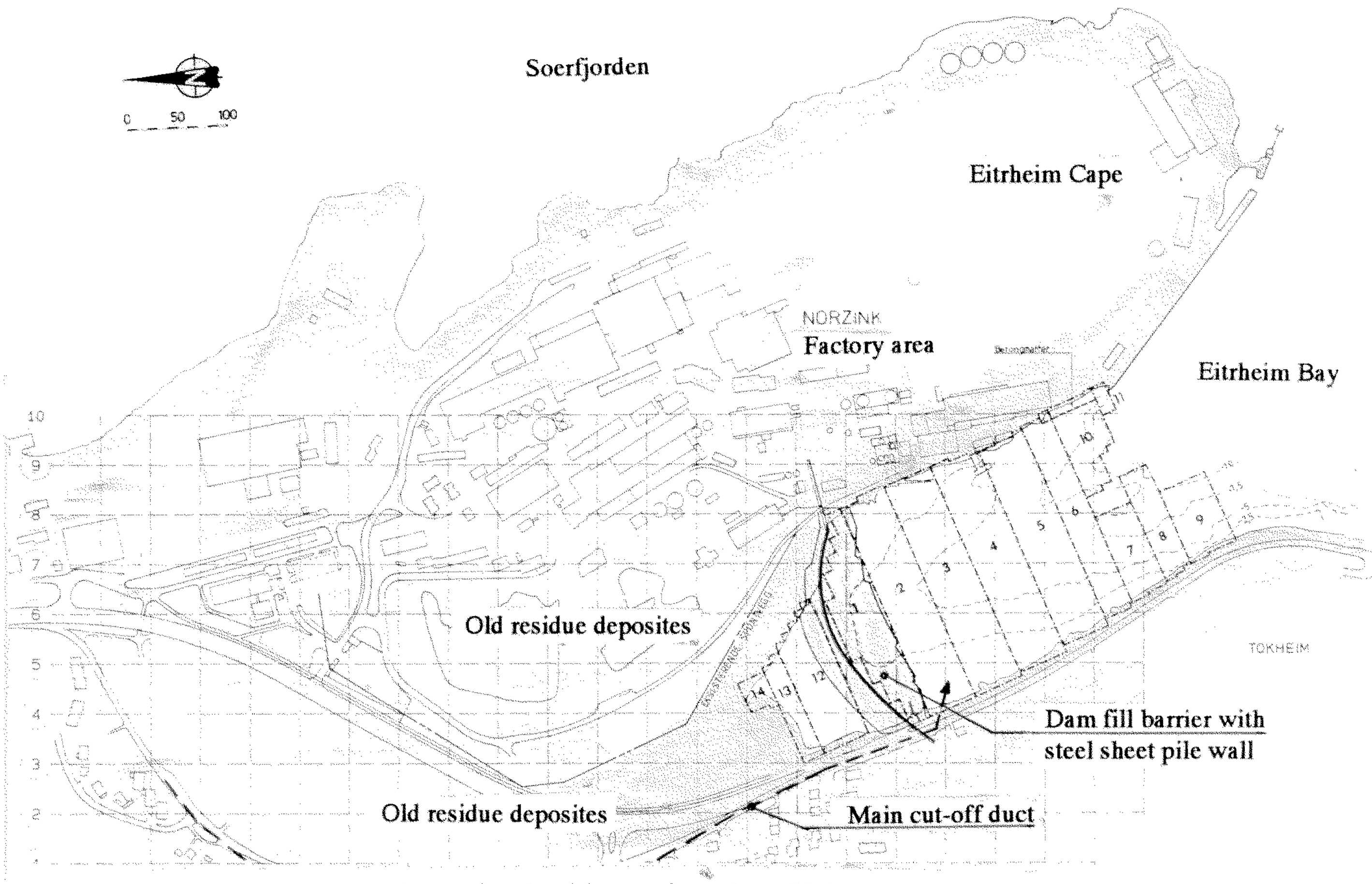

Figure 1. The Eitrheim Bay. Alternative 2 with capping, dam fill barrier and surface water cut-off duct

a. A geotextile capping with sand coverage covering the whole bay from +2 to -10 metres.
b. A sheet pile barrier situated approx. 150 metres offshore the inner parts of Eitrheim Bay.
c. A surface water duct in the inner parts of the Eitheim Bay cutting off surface water floating through the old residue pits.
d. A shore protection with gabions

4.1 THE CAPPING WITH GEOTEXTILES

During spring 1990 INSTANES A/S investigated several solutions for capping of the sea bottom. Membranes and different types of geotextiles were evaluated.

Membranes were ruled out at an early stage because of problems with gas developing from organic deposites on the sea bottom. The conlusions from the investigations were:

a. The geotextile had to be a nonwoven fabric made from polyester with a $O_{90,w} < 0,1$ mm.
b. Elongation at break should not exceed 10%
c. An ultimate breaking strength of minimum 50 kN/m at 10% elongation
d. It had to be possible to sew the geotextile to form big sheets of minimum 220 x 56 metres.
e. The geotextile should be heavier than water.

The conlusions were based on the soil parametres for the residue, calculated construction forces due to wind and currents, construction methods and the weigth of the sand overlay over the geotextiles.

It was not possible to find a nonwoven geotextile that met all the requirements given. We than searched for a composite geotextile consisting of a high modulus polyester reinforcing mat interwoven with a nonwoven fabric. This type of geotextile were not common, but during discussions with the Norwegian branch of the company HOECHST we were introdused to HUESKER synthetic GmbH and a new type of geotextile called COMTRAC®. This geotextile consisted of a nonwoven geotextile of the type TREVIRA® Spunbond type 11/180 g/m² and a high modulus woven polyester geotextile TREVIRA® Hochfest with a longitudinal strength of 50 kN/m an a transverse strenght of 100 kN/m.

As shown in figure 1 we based the design on 14 main sheets overlaying the sea-bottom. The biggest sheets (1 to 5) were made up by 10 pieces of 5,2 metres wide and 220 metres long sheets of Comtrac®. The main sheets were prepared in the factory as four sheets, sewn together with a polyester sewing yarn Nm3 (333 Tex). The main sheets were shipped to the site in four parts, and then sewn together at the construction site to make up one main sheet. The sewing on site were performed with hand held sewing machines provided by Huesker. The yarn used for the hand held machines were an Aramide Nm2 (500 Tex) to ensure a minimum of 50% strength performance of the transverse seams. The main sheet would in this way have a minimum strength of 50 kN/m in both directions after sewing.

The different main sheets were placed on the seabed with a minimum overlay in the longitudinal direction of 2,5 metres to allow for settlements and possible construction error. Sewing was only performed within each main sheet, and the main sheets were not sewn together. In the area of the sheet pile barrier it was left an opening between sheet 1 and 12 to secure easy installation of the sheet piles.

The placement of the sheets were performed by means of a 64 metres long steel pipe floating in the water. The geotextile was rolled up on the pipe after sewing. The pipe were connected to steel wires streched over the bay to fasilitate accurate placement of the geotextile. Then the geotextile was rolled out over the bay and sank to the bottom in an controlled way.

On the steep shores in the outher parts of the Eitheim Bay we used an INCOMAT® Filterpoint mat of 100 mm thickness from Huesker. This geotextile consists of two very strong polyester fabric plies connected to each other in the filterpoints. The geotxtiles were placed on the sea bottom by divers, and filled with high-strength concrete pumped into holes in the fabric. The shore protection went from +2 to -10 metres at the most. Average depth of the shore protection were -3 metres. In addition these geotextiles were used under pipe outlets and inlets on the sea bottom and at the quay area to prohibit erosion from slipstream. Total area of Incomat placed in the Eitrheim Bay were 2 800 m².

In the inner parts of the Eitrheim Bay shore protection were performed with TENSAR® geogrids made from HDPE formed as mats (gabiones) filled with rock pebbles . The gabiones were 6x2 metres and 300 mm thick. They were placed on the sea shore by use of a construction crane thus avoiding pollution from the deposites in the shore area. The gabiones locked the geotextiles in the shore area, and protected the main sheets against erosion caused by currents, humans, animals etc. In addition they formed the base for a new pollution free shore. Total area of Tensar gabiones were 2 900 m².

After the geotextiles and the gabiones were in place the total area of geotextiles were covered with a 300-600 mm thick layer of sand. This sand function as a ballast on the geotextile preventing movements caused by currents and wawes. In addition the sand maintain the hydraulic equilibrium in the underlaying residue thus preventing leakage of heavy metals into the seawater. The sand also form a natural seabed for organisms as seaweeds and mussels.

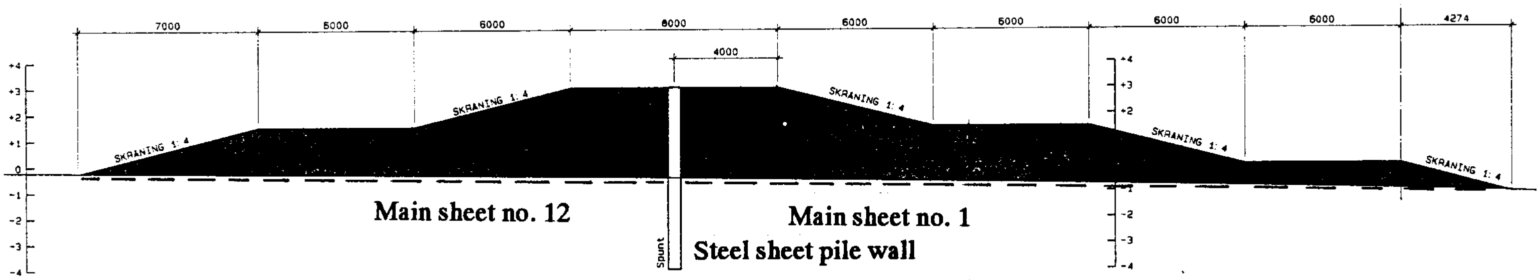

Figure 2. Section of dam fill barrier with steel sheet pile wall for tidal control

4.2 THE SHEET PILE BARRIER

The barrier consist of a 40,000 m³ fill made of blasted rock with a core of chalk residue from a nearby factory and gravel. This core fasilitaded easy installation of the steel sheet piles. Although steel sheet piles were used in this project also a sheet pile wall made from HDPE-panels of the type GEOLOCK was evaluated for the project. But fear for problems with installation due to rock blocks in the clay tilted the choice toward steel. The barrier were buildt after the main geotextile sheets number 12, 1 and 2 were in place on the seabed. Due to the very complex geotechnical conditions in the Eitrheim Bay, with very weak clay deposites overlayed with an even more unstable residue deposite, elaborate fill procedures were enforced on the contractor.

Although every precaution were taken the soil collapsed during construction of the rock barrier due to filling with too steep slopes and to thick fill layers. The collaps were local, but an area of approx. 2,000 m² were effected and turned in to floating clay without any shear resistance.

The area was covered with high modulus woven polyester of the type TELE® 150/150 with a tensile strength of 150 kN/m in both directions. The geotextile was sewed on the construction site, and pulled in place by hand. Than the geotextile was secured on two sides with rock fill before a light weigth bulldozer carefully showeled crushed rock onto the geotextile in a carefully planned manner.The barrier was than completed successfully.

Surface water on the inside of the barrier were pumped over the barrier from a pump station. The water is controlled for pollution from heavy metals.

Fresh unpolluted surface water is cut off by a main cut off duct with dimensions up to D=1600 mm capable of handling 2,500 l/sek. The fresh water is discharged outside the barrier as shown in figure 1.

The tender documents for both the geotextile tender and the construction tender had high demands on accuracy, quality and performance. All quality control etc. were to be performed according to the quality standard ISO 9001. In addition there were high demands to the contractors performance on health, safety and environmental considerations.

Construction started in march 1992, and were finished in november 1992. Coverage of the sea-bottom with geotextiles took approx. six weeks.

5.0 CONCLUSION

The main purpose of the clean-up was to reduce heavy metal leakage from the sediments in the Eitrheim Bay by 90 %. In spring 1994 the reduction is 96% as shown in table 3.

Table 3. Consentration of metals in the seawater in the Eitrheim Bay before and after the clean-up. (NORZINK, 1994) Values given in kg/24 hours.

Quarter of year	Zn			Cd		
	B	A	Red %	B	A	Red %
1. 1993	82	41.6	**49**	3	1.8	**40**
2. 1993	82	3.5	**96**	3	0.14	**95**
3. 1993	82	2.25	**97**	3	0.07	**98**
4. 1993	82	5.1	**94**	3	0.2	**93**
1. 1994	82	3.4	**96**	3	0.13	**96**

B=Before clean-up A=After clean-up
Red=Reduction in %

The conlusion of the project is that with careful planning it is possible to use geotextiles as means to establish a new sea bottom. The cover of geotextiles and sand maintain hydrostatic equilibrium thus preventing heavy metals to leak into the surrounding seawater. The barrier prevents tidal erosion on the old residue deposites thus eliminating leakage from these areras.

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