SUBMERGING HIGH RESISTANT GEOMEMBRANES AS CONTAINMENT BARRIER CLOSURE DAMS BAKU - AZERBAIJAN

R.H. (Rijk) Gerritsen
Witteveen+Bos Engineering Consultants, The Netherlands (rijk.gerritsen@witteveenbos.com)

E. (Etibar) Abbasov
Tamizshahar, Azerbaijan

D.H. (Dick) van Regteren
Genap geomembrane systems, The Netherlands (d.vanregteren@genap.nl)

B. (Bill) Shehane, P.E.
Seaman Corporation, USA (BShehane@seamancorp.com)

ABSTRACT: This article will explain the experiences by submerging a high resistant geomembrane at a large closure dam as containment barrier. Geosynthetics were used to cover the new constructed closure dam in the Boyuk Shor Lake in order to prevent new oil pollution entering the remediated lake. A lot of project challenges had to be taken into account, knowing the transport of materials and equipment, working method, suitability of the subsoil, weather circumstances, etc. The objective was to install a high resistant geomembrane (XR-5) as an artificial barrier against oil and severe pollutions entering the remediated lake from outside. To ensure the durability the geomembrane was protected by a non-woven geotextile at both sides of the geomembrane (subsoil and top). By means of winches and cables all geosynthetics were put in place, submerged and installed under water. In May 2015 the project was successfully finished in total building period of less than two years. This paper describes the approach within the constraints of all challenging circumstances.

Keywords: Geomembrane, Geosynthetic barriers, Underwater installation, Submerging, Environment, Hydraulic engineering, Innovations and New Developments.

1 INTRODUCTION

The Ministry of Economy and Industry of the Republic of Azerbaijan is making a major effort aimed at the remediation and rehabilitation of the lakes around Baku. These lakes adjacent to the capital of the Republic of Azerbaijan are ecologically and environmentally heavily impaired due to oil industry activities. In autumn 2013 efforts were focused on the remediation of the Boyuk Shor Lake. The remediation aims at development of social and economic potential of this part of the city in the vicinity of the lake. One of the key components of the project was a dam designed by Witteveen+Bos Engineering Consultants closing off the 250 ha of Boyuk Shor from the remaining part of the lake, knowing approximately 800 hectares. The project resulted in the isolation by several dams and cleaning up of the lake bottom by dredging, environmental safe storage of the sediments, construction of a park and boulevard. The project started in June 2014 and in May 2015 the project was finished and presented to the President of the Republic of Azerbaijan and the lake shore was decor for the first European Games held in June 2015.

2 HISTORICAL SETTING

Baku, the capital city of Azerbaijan, is situated on the Absheron Peninsula, which protrudes eastward into the western waters of the Caspian Sea. The city is surrounded by water from all sides: on the south by Baku Bay (part of the Caspian Sea) and on land by a ring of nine lakes (see figure 1). These lakes vary in origins, composition, level of human and industrial influence and by consequence in ecological state and are the subject of the Absheron Lakes Rehabilitation Project.

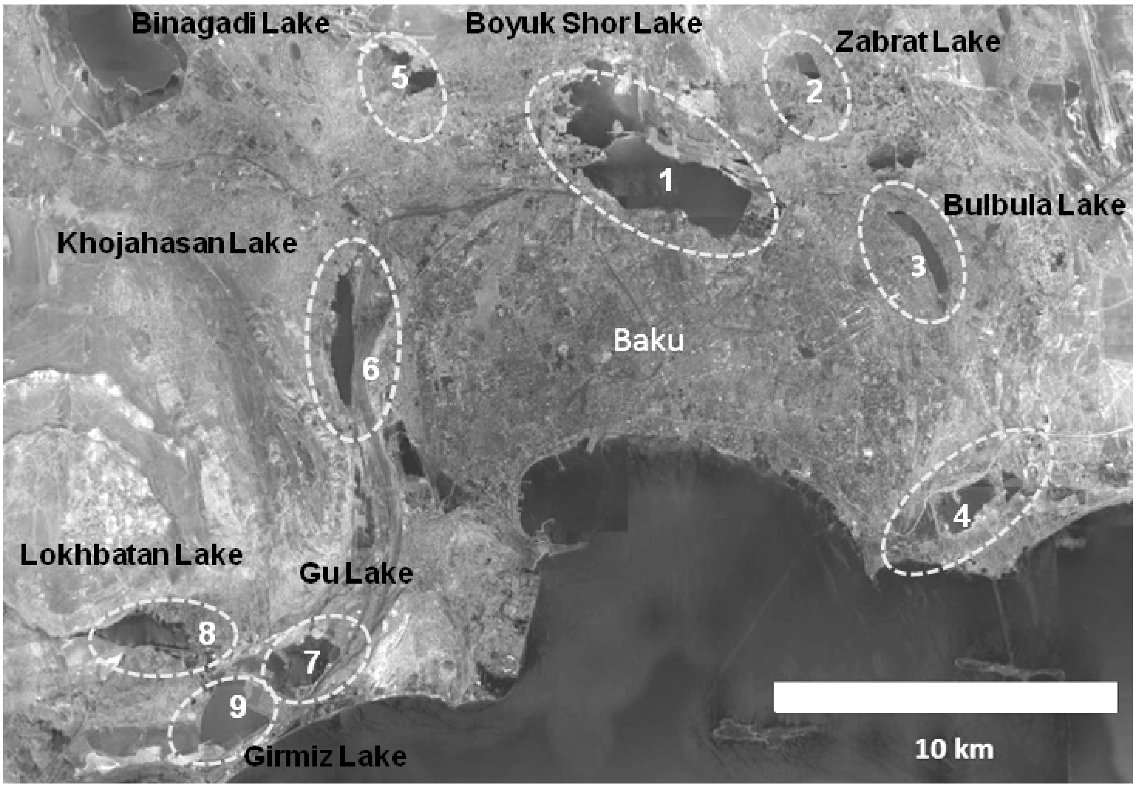


Figure 1. Aerial photograph with nine lakes adjacent to the capital city Baku

The Baku area has been associated with oil and fire since ages. Azerbaijan is known as ‘Land of Fire’ due to the historic occurrence of so called ‘eternal flames’: spontaneous and continuous eruptions of natural gas stemming from shallow pockets in the local geology. Fire worshipping has been part of the historic culture and indeed eternal flames nowadays still erupt at various locations around Absheron. These extraordinary phenomena are resulting from the presence of (very) shallow hydrocarbon deposits. As a result, oil has a naturally ubiquitous presence in the environment around Baku. Large scale exploration of oil started in the later decades of the nineteenth century. In the booming periods, Baku had a very high growth rate, with industrialists investing heavily in the development of the oil fields and the city. Also in more recent times, the oilfields are a source of Azerbaijan growing wealth: the country produced upward 1 million barrels per day.

Azerbaijan has gained its independence after the dissolution of the Soviet Union. Last decades Azerbaijan has pushed through various investments (amongst others in the energy sector) and economic reforms. Since then, the country has experienced a strong economic growth. Following the economic development of the region, the city is letting go of its traditional ‘bay facing’ orientation and looks to expand in all directions. It thus gets confronted with the dire environmental conditions of its surroundings, following from legacy as well as ongoing environmental issues. Hence the city faces the challenge of getting to grips with the severely deteriorated condition of the lakes *(Van de Enden, 2015).*

3 LAKE RESTORATION

As the city expands, the lands and lakes gain a potential value: where previously the lakes weren't cared for, they now are identified as a potential asset to the city and places where people like to live and relax. By presidential decree dating from 2013, the Ministry of Economy and Industry of the Republic of Azerbaijan made a major effort aiming the remediation and rehabilitation of the lakes. The Ministry initiated several projects to improve the situation. In the run-up to the first European Olympic Games, held in Baku summer of 2015, the first tangible results were delivered within two year time.

Boyuk Shor Lake is the second largest lake in Azerbaijan. It is oval shaped, 1060 ha surface area with an average depth of 3.5 meters. It is fed primarily from groundwater and adjacent runoff. The lake has been heavily polluted from adjacent oil production and municipal/construction wastes on the Northern shore primarily. In table 1 typical physic-chemical conditions in Lake Boyuk Shor as investigated are shown.

Parameter	**Medium**					
	Water		**Sludge**		**Sediment**	
TPH sum (C10-C40)	150 - 500	µg/l	0 - 120,000	mg/kg dm	100 - 25,000	mg/kg dm
benzene	0 - 0.2	µg/l	0 - 2	mg/kg dm	0 - 2	mg/kg dm
toluene	0 - 0.5	µg/l	0 - 6.5	mg/kg dm	0 - 6	mg/kg dm
m,p,o-xylene	0 - 0.4	µg/l	0 - 25	mg/kg dm	0 - 15	mg/kg dm
sum EPA 16 PAH	0 - 7	µg/l	0 - 32	mg/kg dm		
NH4	0.1 - 0.2	mg/l	0 - 120	mg/kg dm		
pH	6.5 - 9.5					
chloride	10,000 - 40,000	mg/l				
salinity (TDS)	20,000 - 75,000	mg/l				

Table 1. Physical-chemical conditions in Boyuk Shor

By 2004, the pollution of the lake, in conjunction with its central location (Figure 2) reached a new awareness as Baku was selected to be the host of the 2015 European Games. Further, the main venue site with a very large sport stadium was built at the eastern shore of Boyukshor Lake. As such, the lake was continuously given priority during the study, with the basic design for remediation starting even before the economic assessment for lake restoration was finished. Quite early during the project it became evident that - given the time constraints - it would not be feasible to remediate the complete lake. A section of approximately 250 hectares of the lake was selected for remediation by using large closure dams, cleanup activities of the shore lines and redesigning the boulevard (see figure 2 and 3).

Figure 2. Boulevard shoreline Boyuk Shor Lake original situation (Witteveen+Bos, 2012)

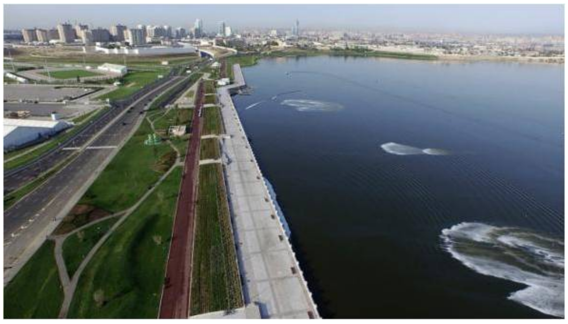


Figure 3. Boulevard top view shoreline Boyuk Shor Lake (Ministry of Economy and Industry of the Republic of Azerbaijan 2015)

4 DESIGN STAGE

Site restoration required that portions of the lake be isolated for rehabilitation, allowing the 300 ha closest to the proposed Olympic Stadium. Two closure dames were to be constructed (see figure 4 and 5):

- North Dam: 1850 m along northern shore (most contaminated area parallel to industrial areas)
- Road Dam: 1570 m connecting north and south shores and assigned as future 6-lane highway connector.

Figure 4. Design projection of the Road and North Dam Boyukshor Lake (Witteveen+Bos)

Figure 5. Animation Boyukshor Lake dam location

The purpose of both dams was separating clean versus contaminated lake water. The dams would serve as closure embankments. Based on extensive design assessments, regarding the geometry, geotechnical stability and material use, designs were made by Witteveen+Bos Engineering Consultants. Typical cross sections of the design are given in figure 6 (Road closure Dam) and 7 (North Dam). The dams were constructed of quarry run rock based on local availability. The dams were to be constructed by end-dumped quarry run that was graded into place.

Figure 6. Typical cross section design Road closure Dam (Witteveen+Bos, Van de Enden, 2014)

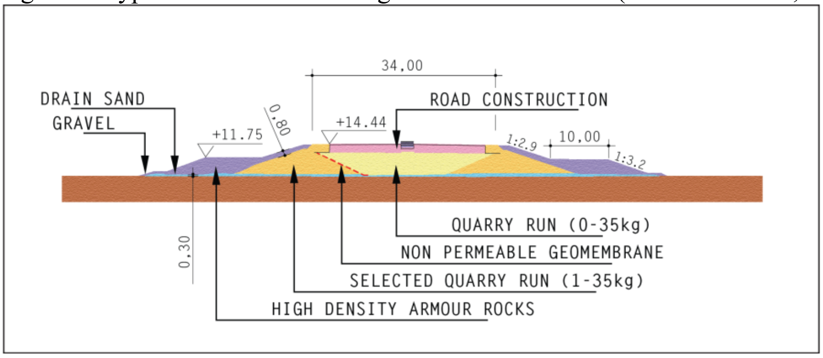
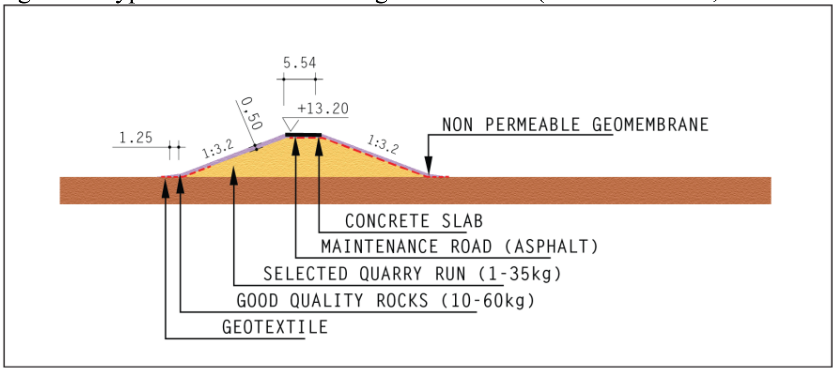


Figure 7. Typical cross section design North Dam (Witteveen+Bos, Van de Enden, 2014)



4.1 *Geomembrane properties*

Knowing the site circumstances with closure dams in the water, the containment barriers had to be installed below the water table. A trade off was made of different geosynthetic materials and working sequences. In consultation with the contractor, client and engineering consultant it was chosen to realize the non-permeable barrier by submerging a high chemical and oil resistant geomembrane in large panels. Prevailing arguments were the risks and impossibility to dewater the full construction site, the existence of high polluted water with sediments, and the very tight planning of construction works (about 6 months for geomembrane installation). Knowing the circumstances in place the geomembrane had to be heavier than water, be resistant to hydrocarbons/oil pollutions, be able to withstand sustained loaded on the seams in an exposed condition, be able to be seamed into large panels and be flexible. The selected product was a high resistant reinforced geomembrane (EIA). The material characteristics of the geomembrane are listed in table 2. Knowing the pollution rate the chemical resistance of the geomembranes was of major importance. A comparison of chemical resistance with a general scaling is given in table 3 based on test-results and literature.

Description	**Test method**	**Unit**	**Specification**
Material Type	ASTM D 751	-	Reinforced EIA (Ethylene Inter-polymer Alloy)
Base fabric type	ASTM D 751		Polyester
Weight	ASTM D 751	gram/m^2	1288 ± 2
Thickness (nominal, minimum)	ASTM D 751	mm	1.0
Roll width (mother rolls)	ASTM D 751	meter	2,54

Breaking yield strength	ASTM D 751 Grab Tensile	Newton meter	> 2,448 / 2,448
Tear strength	ASTM D 751 Trap Tear	Newton	> 175 / 245
Puncture resistance	ASTM D 4833	Newton	> 1,200

Table 2. Material characteristics XR-5 geomembrane

Product	XR-5®	HDPE	PVC	Hypalon	Polypropylene
Kerosene	A	B	C	C	C
Diesel Fuel	A	A	C	C	C
Acids (General)	A	A	A	B	A
Naphtha	A	A	C	B	C
Jet Fuels	A	A	C	B	C
Saltwater 160° F	A	A	C	B	A
Crude Oil	A	B	C	B	C
Gasoline	B	B	C	C	C
A = Excellent					
B = Moderate					
C = Poor					
NF = Not Found in Published Chart					

Table 3. Comparative chemical resistance geomembranes

As requirement in the design non-woven geotextiles were instructed to protect the geomembranes for damage by puncturing by quarry run backfill or handling (mechanical damage by personnel or heavy equipment). Material characteristics of these non-woven geotextiles are given in table 4.

Description	**Test**	**Unit**	**Specification**
Material	-	-	Polypropylene
Mass	EN ISO 9864	g/m2	≥ 1000
Thickness at 2 kPa	EN ISO 9863-1	Mm	≥ 7.0
Static puncture	EN ISO 12236	kN	≥ 9,0
Cone drop resistance (hole diameter)	EN ISO 13433	Mm	≤ 6,0

Table 4. Material characteristics non-woven protective geotextile

5 CONSTRUCTION STAGE

5.1 *Transport and preparation*

Full rolls of high resistant geomembrane , manufactured in the USA were shipped directly to Baku. In Baku the installation and prefabrication company Genap used a local building as pre-fabrication plant. The so called mother rolls of the geomembranes were prefabricated to obtain large sheets to the desired dimensions of embankment slopes. The prefabrication was done in a local project facility plant using rolling and unrolling equipment including cutting and welding devices. In the prefabrication hall welding was done by the hot wedge method (machines with one hot wedge). From the plant panels with a surface of approximately 1400 m^2 were prefabricated (length 70 meter versus about 20 meters width), packaged and transported to the closure dam for submerging on site. At the front of each panel Genap welded a floating air tube. This air tube kept the prefabricated panel floating during the process of submerging.

	
Figure 8. Local project facility plant for prefabrication of geomembrane panels (Genap, 2015)	Figure 9. Local project facility plant for prefabrication of geomembrane panels (Genap, 2015)

5.2 *Geomembrane installation by submerging*

The subsoil of the embankments was prepared by grading and levelling to a surface which was most appropriate knowing the circumstances. At the subsoil a non-woven geotextile was installed (1000 gram/m^2) to minimize the risk of damaging the geomembrane by sharp stones or irregularities from the embankment. After installation of the protective geotextiles the prefabricated geomembranes packages were placed on the top of the dam by a wheel crane and deployed by unrolling the package. Ballast bags keep the membrane in place and ensure that the membrane is wind fixed. To pull the membrane on the water surface ropes are installed from the membrane through pulleys that are attached to the temporary anchor poles and back to a winch on the Dam. After filling air tubes in front and on the side of the sheets the winch will pull the membrane slowly and tightly over the water surface (see figure 10 and 11).

	
Figure 10. Floating geomembranes panels before submerging under water (Witteveen+Bos supervision staff, 2015)	Figure 11. Winches and cables for positioning the geomembrane panels (Witteveen+Bos supervision staff, 2015)

After exact positioning the air tubes are deflated and the membrane is submerged gradual, knowing the volume weight of the geomembranes is heavier than the water in place. A drawing with the sequence of geomembrane installation is given in figure 12.

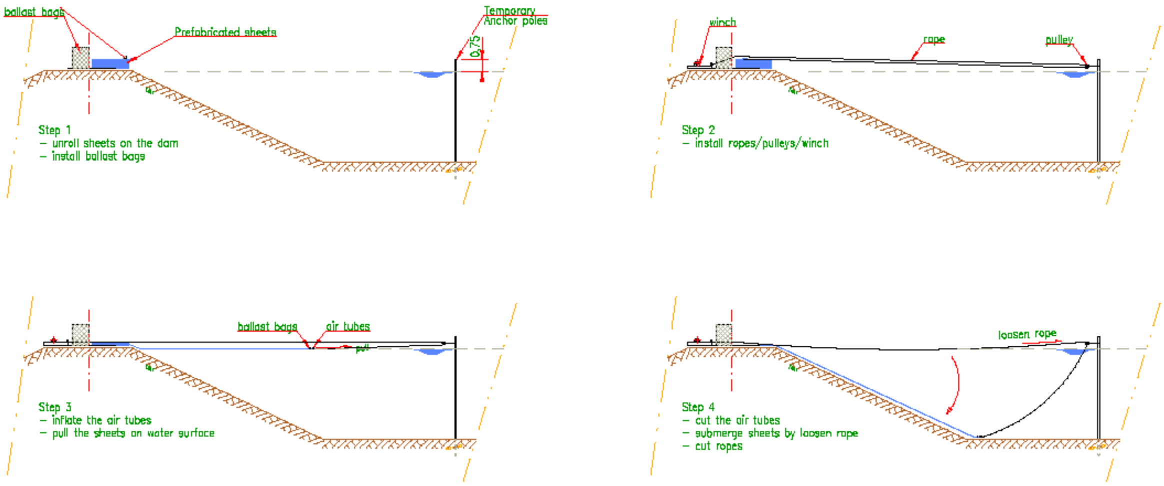


Figure 12. Sequence of submerging the geomembrane (Genap BV, 2015)

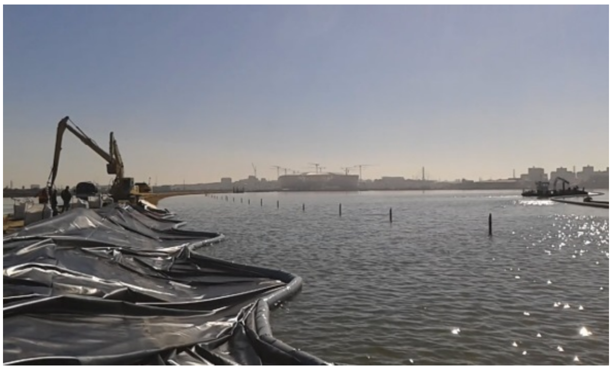


Figure 13. Deployment of Fabricated panels on North Dam (Genap, 2015)

Figure 14. North Dam Geomembrane Installation (Genap, 2015)

The construction works started with the North dam (see figure 13 and 14). The Road Dam was wider and had a more extensive cross-section as compared to the North Dam. After installation of the geomembrane a non-woven geotextile (1000 gram/m^2) was installed on the topside to minimize the risk of damaging the geomembrane by puncture. At the Road dam quarry run (0-35 kilo) was used on top of the geotextile layers as backfill material. Applying backfill between the two parallel bunds the final Road dam reached a very wide crest width of 34 meters (see figure 15 and 16).

Figure 15. Road Dam Geomembrane Installation (Genap, 2015)

Figure 16. Road Dam Installation (Genap, 2015)

6 CONCLUSIONS

The Ministry of Economy and Industry of the Republic of Azerbaijan is making a major effort aimed at the remediation and rehabilitation of the lakes around Baku. These lakes adjacent to the capital of the Republic of Azerbaijan are ecologically and environmentally heavily impaired. Since mid 2013 strong efforts were made in preparation and remediation works of the Boyuk Shor Lake. One of the key components of the project was the construction of two large dams, closing off the 250 ha from the remaining part of the lake. Knowing the severe environmental circumstances a high resistant geomembrane was needed as containment barrier, blocking the main stream of oil pollution entering the remediated lake. A lot of project challenges had to be taken into account, knowing the transport of materials and equipment, working method, suitability of the subsoil, weather circumstances, etc. To ensure the durability the geomembranes was protected by a non-woven geotextile at both sideways of the geomembrane (subsoil and top). By means of winches and cables all geosynthetics were put in place, submerged and installed under water. The project resulted in the isolation and cleans up of the lake bottom by dredging, environmental safe storage of the sediments, construction of a boulevard and park. In May 2015 the project was successfully finished in total building period of less than two years.

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