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DURABILITY OF PVC-P GEOMEMBRANES IN HYDRAULIC STRUCTURES

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Abstract: Various parameters contribute to the correct assessment of the durability of PVC-P geomembranes. One of the most important is real analysis obtained through field work to observe the phenomena of natural degradation. For a better definition of the real durability of PVC-P geomembranes, geomembrane samples from several types of hydraulic structures were collected from all over the world, over the last 25 years. This paper presents a summary of the results of the analysis carried out and demonstrates the importance of data collection in the field in understanding the durability of PVC-P geomembranes.

Keywords: durability, lifetime prediction, long-term behaviour.

DURABILITY

Durability is defined as being the period of time during which a geomembrane remains watertight, taking into account the aging of the material and the effects of mechanical and physical action. Due to their excellent mechanical resistance and easy weldability, PVC-P geomembranes present many advantages when applied to hydraulic structures. The durability and associated price of PVC-P geomembranes largely depend on the formulation of the product. Even when carrying out accelerated aging tests, it is necessary to wait quite a long time to achieve a correct analysis of the long term behaviour of a certain formulation. It is important not only to know the aging mechanism, but also the behaviour of the geomembrane and welding, over time, in a situation of permanent elongation and puncturing. Lastly, it is essential to compare theoretical information with information on long term real behaviour.

The use of PVC-P geomembranes in hydraulic structures greatly developed all over the world in the early 1980s. Nowadays we can reliably assess the long term behaviour of several hydraulic structures spread throughout the world (Fayoux and Van Der Sype, 2000). Understanding aging (the evolution of the properties of a product over time) is necessary, but not sufficient to achieve good durability. The design of the waterproofing system often has a determinant role in durability.

AGING OF PVC-P GEOMEMBRANES

Plasticized PVC is constituted by a mixture of the following components:

- PVC Resin – Represents approximately 60% of total weight (rigid product, very chemically resistant). Resin is characterised by the “K value” (molecular weight and viscosity). A high value corresponds to high mechanical characteristics and good flexibility at low temperatures, but its welding may become more difficult. It can be observe that very low values are accompanied by important creep of the product on long slopes.
- Plasticizers – Confer flexibility to the final product and represent approximately 35% of total weight.
- Lubricants – Help to improve the process.
- Pigments – Confer a certain colouring and may also, depending on the pigment, assist in UV and heat stabilization. Good examples of pigments that assist in geomembrane stabilization are carbon black (confers a black colouring to the geomembrane) and/or titan dioxide (confers a light colouring and reduces the temperature of the geomembrane, during exposure).
- Heat stabilisers – Avoid thermal decomposition during the process or welding.
- UV stabilisers – Guarantee or improve the protection of the PVC-P geomembrane relative to UV action.
- Chalk – Are added to reduce the cost of the geomembranes. They increase the mass, the porosity of the geomembrane and the sensitivity to acid products. On the other hand they can slightly increase fire resistance.
- Recycled – PVC-P geomembranes can use recycled PVC. This recycled material has the advantage of reducing the cost of the product without detracting from its final quality, including its mechanical characteristics. To ensure this, the recycled material should be chosen with great care, there should be good control at the factory and there should also be a good system for its incorporation in the manufacturing process.
- Other additives – Fungicides, fire resistant additives, amongst others, can also be used.

The formulation may have a significant effect on the behaviour of the geomembrane, especially in the long term. Distinctions between different formulations do not appear in a short period of time, but only in the long term. PVC-P aging is the result of two possible mechanisms: plasticizer loss and degradation of PVC resin.

Degradation of PVC resin

This essentially occurs under high temperatures during the process (and welding, if excessive temperature is used). Thermal stabilisers are added to protect the geomembrane during the process and welding. After the process is concluded, it’s necessary that a quantity of the residual stabiliser remain in the geomembrane. Degradation of the PVC resin may also occur during the life of the geomembrane, through UV action and high temperatures. This problem does not normally appear in well formulated geomembranes. It is relatively simple to achieve a well stabilised geomembrane over a long period of time. Micro-cracks may appear when the stabiliser is insufficient. In the beginning, the micro-cracks are only superficial and the geomembrane may still resist during some years. The product becomes more brittle (due to the concentration of stress) and the surface with micro-cracks becomes more difficult to weld, despite it being easy to continue to weld the lower face of the geomembrane.

Plasticizer loss

Plasticizer loss is the most common form of aging of the PVC-P geomembranes. The initial quantity of the plasticizer is approximately 35% of the weight of the geomembrane in correctly plasticised formulas. Plasticizer loss induces an increase in rigidity, easily detectable through the increase of the modulus in the tensile test. In the same test, a reduction of the strain at failure and an increase of the stress at failure can be observed. During the same period, low temperature brittleness increases, from approximately -30º to 0ºC or more. In cases of impact on the geomembrane, star-shaped failures may be visible in each impact zone (Fayoux and Van Der Sype, 2000).

Simultaneously, an isotropic shrinkage is observed due to the loss of volume. Plasticizer loss first occurs in the interior of the geomembrane to the surface by diffusion, and then from the surface to the external environment by evaporation. The phenomenon of plasticizer diffusion through the geomembrane is very frequently associated with Fick's law. However, Fick's law is no longer valid when we study the long term behaviour of a geomembrane. The phenomenon of plasticizer loss is never linear. The combination of a variety of actions during the life of the geomembrane may increase or reduce plasticizer loss. Plasticizer loss is a superficial phenomenon and may be expressed in grams per m^2 and per year. It depends only on the environment and the composition of the geomembrane and not its thickness.

According to the formula, durability may vary between 1 to 2 years for cheap and poorly formulated geomembranes, to over 20 years. This situation can be explained by poor stabilisation, poor UV protection, maladjusted plasticizers, excess of chalk, poor quality of the raw materials and use of recycled products, whose characteristics have not been controlled (Fayoux and Van Der Sype, 2000).

GENERAL APPROACH TO THE STUDY OF DURABILITY

Analysis of the different solicitations and actions influencing durability

The analysis of the different solicitations and actions should be carried out during the life cycle of the geomembrane: before, during and after installation. The analysis should take into account the factory storage conditions, storage at the works, transport, installation, normal life and maintenance. The effect of these actions should be compared to the characteristics of the geomembrane, including the aging effect (Fayoux, 1990)

Minimum quantity of plasticizer admissible to ensure durability

This value depends on the actions on the geomembrane as well as the type of plasticizer used. In the case of our geomembranes, based on the various tests carried out and observations in the field, a residual value of plasticizer of approximately 20% on average (this value may vary according to the external environment, type of application and design of the waterproofing system) allows the geomembrane to remain watertight.

Relationship between durability and design of the waterproofing system

The durability of a PVC-P geomembrane also greatly depends on the design of the waterproofing system. Design often takes on a crucial role, largely due to the poor technical understanding that designers, in general, have in relation to this type of material. Projects frequently appear, which do not take into account the specific particularities of this type of material. However, sometimes it is during the installation of the waterproofing system that the main problems emerge. These weaknesses occur associated both to poor project design and to failures during the installation. This paper presents several cases studied spread all over the world, demonstrating the good durability of PVC-P geomembranes in hydraulic structures, as long as they are correctly formulated. We also want to present a typical example of a durability problem associated to the design of the waterproofing system.

BARLOVENTO RESERVOIR (CANARY ISLANDS, SPAIN) 1991-2005

The reservoir is located on the island of La Palma (Canary Islands), close to the sea at an altitude of 700 metres. The initial waterproofing was carried out in 1976 with compacted volcanic clay, but it never worked. The initial solution with a 6 metre layer of clay rapidly became altered with the appearance of cracks due to the effect of shrinkage (Figure 1). All the attempts to restore the layer of clay failed. This case study was initially published by Fayoux and Potie (2006). The rehabilitation of the waterproofing was done in 1991 using a PVC-P geomembrane (Figure 2).

Its characteristics are:

- Area of the geomembrane: 250,000 m^2
- Depth of the reservoir: 30 metres
- Slopes: 1.5 (horizontal) / 1 (vertical)
- Geomembrane: 1.5 mm thick PVC-P, not reinforced on the bottom and reinforced on the slopes.
- Control of the flow rate of the drains
- Piezometers (cells)
- Settlement gauges

Figure 1. Barlovento, initial waterproofing carried out in 1976 with compacted volcanic clay

Figure 2. Barlovento, waterproofing with PVC-P geomembrane

Structure of the bottom of the reservoir

It is formed by a 1.5 mm thick homogenous geomembrane, not protected, placed on top of a 280 g/m^2 needle-punched geotextile, a supporting 0.1 metre layer of compacted sand, a 500 g/m^2 needle-punched geotextile, a 0.4 metre drainage layer, a network of collecting and discharge drains and a 500 g/m^2 needle-punched geotextile impregnated with an bitumen emulsion to respect filtering conditions in relation to the clay support. This structure was studied to support differential settlement that may reach up to 1 metre. The monitoring of the bottom of the lake is assured by a series of measuring devices and piezometers.

Structure of the reservoir slopes

The structure of the slopes is 2.75 (horizontal) by 1 (vertical). The slopes are lined with an unprotected 1.5 mm PVC-P geomembrane reinforced, placed on a 500 g/m^2 needle-punched geotextile and a layer of porous concrete. This last layer ensures the drainage under the geomembrane and the mechanical resistance of the support to wave action (length approximately 600 m). Stability against wind action is assured through anchoring trenches, filled with porous concrete. There is an anchor on the top, an anchor at the base of the slope and 3 to 4 intermediary anchors in the slope. The reservoir was subject to strong storms with winds over 140 km/h, without damaging the geomembrane. The horizontal weldings on the slope situated at the anchorage lines also resist well over time.

Long term behaviour of the geomembrane

After 13 years of exposure to a tropical climate, the geomembrane continues flexible presenting limited plasticizer loss, thus guaranteeing high life durability. The geomembrane is monitored in a regular manner by the Spanish administration. CEDEX has regularly issued several reports. The latest report shows the evolution of the 13 year old geomembrane (Figure 3).

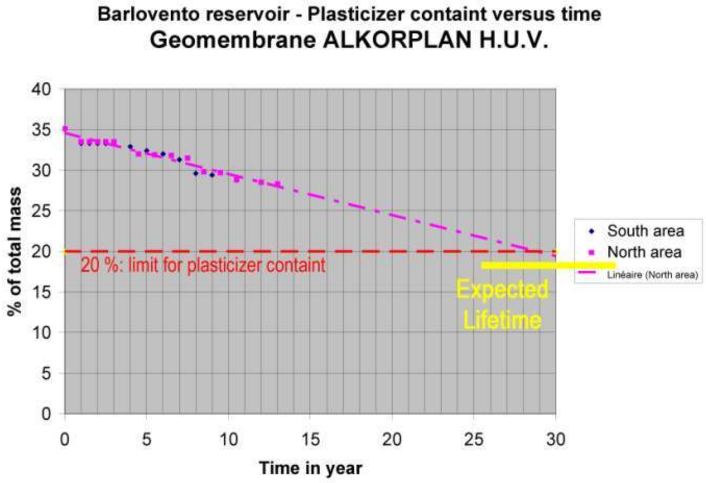

Figure 3. Barlovento, plasticizer content over time

Plasticizer loss in relation to the original samples does not exceed 26% (corresponding to a plasticizer content of approximately 26%) in any of the samples considered, with the reduction being similar in all the samples independently of their orientation. The flexibility test at low temperatures carried out at -20ºC, was surpassed in all samples. The mechanical characteristics remain very stable: Strength at failure remained practically constant over time (approximately 1400 N/50 mm in the longitudinal sense ± 7%). Elongation at failure shows a slight increase, from 23 to 25% in the longitudinal sense and 25 to 28% in the transversal sense. It is important to take into account that we are analysing a reinforced geomembrane, which imposes deformability. Tensile test on the welding present constant results, both in the prefabricated welding and in the welding carried out *in situ*. The samples were always taken outside the water and therefore subject to maximum exposure. It should be taken into account that the PVC-P geomembranes secure their function with a quantity of plasticizer in the order of 20%. The geomembrane also presents a good margin in terms of durability. In fact, this formulation has been requested by the island's administration for new projects.

EXPERIENCE IN 7 DAMS (TAHITI) 1984 – 2004

In 2004 an audit took place at 7 dams built in Tahiti. This audit allowed deep knowledge about the durability of PVC-P geomembranes in tropical climates. The geomembrane of the dams is exposed to UV action and the waterproofing system used amongst them is very similar (Figure 4). The geomembranes were installed between 1984 and 1993 and the samples were taken at the end of 2003. Table 1 presents a summary of the results obtained, showing the results of tests carried out on 28/11/2003 (index "a") and those relative to February 2004 (index "b").

Figure 4. Typical dam in Tahiti; 1.0 mm PVC-P Geomembrane

All the products, except Papenoo H, present a normal evolution, taking into account the thickness of the geomembranes and climate. Based on the laboratory results (independently of all the extrapolation considerations which may lead to other priorities), the evaluation in terms of the state of the geomembrane is as follows:

1. Papenoo H (far from the normal durability values): the geomembrane formulation is not adapted to tropical climates, but to countries in central Europe. This may have been due to a mistake on the part of the client, since the client was French.
2. C2 (exceeded the usual plasticizer loss limits).
3. VAITE 2 and AB are theoretically at the same level, with a plasticizer content corresponding more or less to the limit to which the waterproofing begins to be difficult to be maintained. Geomembrane AB has a reinforced. The reinforced may limit the propagation of tearing. VAITE 2, despite have slightly lower plasticizer content than AB, appears, in the field, to be in better condition (less repairs and specific points are in a good state). This situation may be explained by the design system used, which enables VAITE 2 to present better durability, despite in practice present a lower plasticizer content. This fact demonstrates the importance of design in a waterproofing system.
4. Tahinu and Vainavenave also have a good reserve of life in terms of their plasticizer content. However, these 2 structures present some problems, stress on the geomembrane, due to insufficient drainage.
5. The Vainavenave geomembrane should be monitored to check if the problem of micro-cracks is stabilising or continues to evolve.

The results of the tests indicate that, with the exception of Papenoo H, the geomembranes present a life expectancy of 15 to 20 years per mm of thickness, which is very positive, taking into account the fact that they are situated in a tropical zone.

Normally, we consider that up to content in the order of 20%, the geomembrane adequately secures its waterproofing function. The 20% limit corresponds to observations made in temperate or Mediterranean climates, where there is a possibility of cold weather. As we can see, taking into account the climatic temperature in Tahiti, the structures supported a plasticizer loss that was slightly above normal. The importance of the repairs in some structures, where the plasticizer content is clearly higher, indicate that most of the incidents originate in design problems and are expressed in mechanical phenomena and not in the aging of the geomembrane.

Table 1. Designation of the samples and results of the Tahiti Dams' tests

Sample Number	Location	Date of installation	Years	Plasticizer content (%)	Thickness (mm)	Strenght at failure (Mpa)	Elongation at failure (%)	Modulus at Failure (Mpa)	Modulus at 10% (Mpa)	Visual inspection
1a	Tahinu Risberme	Nov-92	10.8	28.4	1.022	18.18	278.6	6.53		Blue grey Not discoloured
1b					0.94	20.4	300	6.80	24.00	
2a	Tahinu, 2 m from the top	Nov-92	10.8	27.38	0.886	16.56	234	7.08		Black Very Flexible
2b					0.89	16.8	235	7.15	22.00	
3a	Vainavenave, 2 m from the top	Nov-93	9.8	27.15	0.803	14.6	197.4	7.40		Blue grey Slightly fissured
3b					0.78	19.1	210	9.10	38.00	
a	Vainavenave, 2 m from the top	Nov-93	9.8	25.3	0.783					Blue grey Flexible Discoloured Slightly fissured
b					0.73	16.5	124	13.31	42.00	
a	Vainavenave, Repair 1	Between 1993 and 2001		26.9	0.884	23.84	245	9.73		Blue grey Discoloured Slightly fissured
b					0.87	20.9	242	8.64	35.00	
a	Vainavenave, Repair 2	2003		30.5	1.492	17.76	304.4	5.83		Blue grey Not discoloured
b					1.54	17.1	274	6.24	17.00	
4a	VAITE 2	Oct-87	15.9	19.39	0.884	22.58	216.4	10.43		Black Non wired
4b					0.93	17.3	189	9.15	50.00	
6a	Papenoo H, 2 m from the top	Sep-91	12.0	5.72	0.706	25.96	18.3	141.86		Black Non wired Very rigid
6b					0.7	16.6	17	97.65	644.00	
6b at peak					0.7	21.56	6	359.33		Measured at peak
5a	AB (F3), 2 m from the top	Jul-86	17.2	20.69	0.91					Wired Flexible
5b						37	38.7	95.61	249	
7a	C2, 2 m from the top	Jun-84	19.3	16.52	1.04					Black Wired Relatively rigid
7b					1	38.7	50	77.40	436	

Note: Index of samples: "a" tests on 28/11/03; "b" tests in February 2004; n.v. results not valid. The plasticizer content was not evaluated again in February 2004; the values were taken at the end of November

EXPERIENCE IN CANALS IN PORTUGAL (CHAVES) 1994/95 – 2007

Chaves Canal was one of the first canals in Portugal to be rehabilitated with a PVC-P geomembrane. Its rehabilitation occurred towards the end of 1994 and has been the object of study, up to today. The canal is located in an area where the ground-water level, especially in the winter, reaches a height above ground greater than that of the water level inside the canal (the action of these uplift pressure was one of the principal criterion in the project design). The waterproofing project was, at the time, developed by the company Renolit, due to the low level of knowledge which the entities involved had at the time on this type of material (Figure 13). The company BBF – Tecnologias do Ambiente was responsible for project implementation, under the permanent supervision of Renolit technical staff during the construction phase. The main characteristics of Chaves canal waterproofing system are as follows:

- Area of the geomembrane: 40,000 m2
- Support
- Longitudinal drainage
- Crushed gravel: 8/16

- Geotextile: 500g/m2
- Geosynthetic drainage
- Geomembrane: 1.5 mm thick PVC-P
- Protection of the geomembrane
- Light ballast concrete (125 mm thickness)
- Mechanical fixation: Stainless steel bar

Long term behaviour of the geomembrane

In April 2007, 12 and a half years after the installation date, geomembrane samples were taken from Chaves Canal, to analyse their behaviour. Samples were collected from 3 different zones (Figure 5). As shown in Figure 5, Zone 1 and Zone 2 are situated in a part of the canal which is always in shade; in Zone 1 the velocity of the water is higher (start-up zone) and Zone 3 is completely exposed to the sun. Samples 3, 4, 7 and 8 face East and samples 2, 1, 5 and 6 face West.

Figure 5. Chaves Canal, location of the samples *(Zone 1, Zone 2 and Zone 3)*

All the samples analysed present a good reserve in terms of plasticizer content. The mechanical characteristics present reasonable values taking into account the age of the project. The canal Zone, above the waterline, facing East, appears to be where the geomembrane is in its best state of conservation (sample 3 with 29% of plasticizer and sample 8 with 27% of plasticizer). The samples below the waterline, in Zone 1 and Zone 3, and the samples above the waterline facing West, in Zone 1 and Zone 3, present very similar values (between 22 and 23% of plasticizer, for samples 2, 5, 6 and 7). The samples from Zone 1 are difficult to interpret. Firstly, they do not permit us to conclude, in this case, the existence of a direct relationship between plasticizer loss and velocity of water flow (comparison between Zone 1 and Zone 2). On the other hand, sample 4, above the waterline, facing East presents a low value, 23% of plasticizer, in comparison with the other samples also facing East and above the waterline. This difference may however be explained by the existence of water, coming from outside the canal, at sample 4 creating the ideal environment for the development of vegetation and consequently microorganisms. Another conclusion may be the fact that the samples in best condition (plasticizer content), present the same mechanical characteristics as the samples which are in worst condition. This situation is explained by the fact that the samples in best condition are situated above the waterline, exposed to UV action, presenting phenomena of superficial micro-cracks. This phenomenon considerably reduces the mechanical resistance of the PVC-P geomembranes.

As strange as this may seem, UV action is not the main action responsible for the aging of the geomembrane of Chave Canal. There are other phenomena, in the samples below the waterline, which are revealed as or more important than UV action. These phenomena were studied in-depth in laboratories and nowadays the PVC-P geomembranes of this company are reinforced for improved resistance to these phenomena.

Table 2. Designation of the samples and results of the Chaves Canal tests

Samples	% Plasticizer	Strength at failure (Mpa) (L)		Elongation at failure (%) (L)		Modulus 50% (L)		Modulus 100% (L)	
1	23.81	N.D.							
2	22.81								
3	29.26	12.99	13.17	192.15	192.07	7.24	7.24	10.33	10.56
		13.35		191.98		7.23		10.79	
4	23.20	11.97	11.97	190.43	190.43	8.85	8.85	11.37	11.37
5	22.44	12.37	12.30	203.38	206.87	8.22	8.20	10.72	10.67
		12.23		210.35		8.17		10.61	
6	22.45	12.31	12.21	210.52	204.81	8.02	8.29	10.45	10.72
		12.10		199.10		8.56		10.99	
7	22.16	12.46	11.03	169.25	165.64	9.67	9.69	12.12	12.16
		9.60		162.03		9.70		12.19	
8	26.99	12.40	12.30	208.78	210.31	8.41	8.23	10.90	10.75
		12.19		211.83		8.06		10.61	

Over the years Chaves Canal has demonstrated being one of the best examples of a waterproofing project and design using PVC-P geomembranes, found in Portugal. Based on laboratory analysis of the samples taken, in the climatic situation and above all based on in-depth knowledge of the method of design of the waterproofing system, we can state that the geomembrane installed in Chaves Canal has a predicted durability greater than 20 years (Figure 6).

Figure 6. Chaves Canal, 12 and a half years later

Relationship between canal durability and its design in Portugal

In 2006 samples were taken from PVC-P geomembrane installed in Campilhas Canal (Alentejo, not very distant from the sea). This canal presented serious problems, given that the geomembrane had apparently reached the end of its life at only 7 years old. 10 samples were taken from 2 different Zones (Figure 7). In Zone 1, which has a lower development, samples were taken from the bottom, bottom of the slopes (from both sides of the canal) and above the waterline (from both sides of the canal). In Zone 2, which has a higher development, samples were also taken from the bottom, bottom of the slopes (from both sides of the canal) and above the waterline (from both sides of the canal). The geomembrane has the same formulation as that in Chaves, solar orientation is completely the same as that in Chaves and average temperatures only vary slightly in the winter. Differences in terms of UV action are not significant either. The ideal conditions were created for us to be able to understand what had happened at Campilhas.

Figure 7. Campilhas Canal, location of the samples *(Zone 1, Zone 2)*

The result of the laboratory analysis of the samples was, surprising perhaps for some, given the visible state of deterioration of the canal. The minimum value found of the plasticizer content was 28%, compared with 22% at Chaves Canal. The Campilhas geomembrane was practically as new, especially above the waterline. Similarly to Chaves Canal, here the geomembrane was also in a better condition above the waterline, exposed to UV action, than below the waterline. Therefore there are no significant differences between the behaviour of the samples from Campilhas and Chaves.

Table 3. Designation of the samples and results from the Campilhas Canal tests

Samples	Location	% Plasticizer	Samples	Location	% Plasticizer
0	Reference	35.1	0	Reference	35.1
1	Zone 1 Waterline	29.0	6 B	Zone 2 Waterline (lower)	30.1
2	Zone 1 Below the waterline	27.9	7	Zone 2 Below the waterline	27.9
3 A	Zone 1 Waterline (lower)	29.0	8 A	Zone 2 Waterline (higher)	33.6
3 B	Zone 1 Waterline (higher)	29.0	8 B	Zone 2 Waterline (lower)	28.5
4	Zone 1 Below the waterline	30.7	9	Zone 2 Below the Waterline	28.3
5	Zone 1 Bottom	32.9	10	Zone 2 Bottom	29.9
6 A	Zone 2 Waterline (higher)	33.9			

The geomembranes at Campilhas and Chaves are so similar that it can be said that both have lost on average 1% of plasticizer per year, to a more serious situation. Hence, Campilhas has lost 7% (from 35% to 28% of plasticizer) and Chaves has lost 13% (from 35% to 22% of plasticizer). So, how to explain what occurred in Campilhas? The only significant difference between Chaves Canal and Campilhas Canals was the design of the waterproofing system. The design of Campilhas Canal did not take into account the typical particularities of this type of material when subject to mechanical action, physical and chemical action, and the aging. his is a typical example of how the design of a waterproofing system may negatively influence the durability. This influence is such that the durability of Campilhas Canal was approximately 3 times lower than that predicted for Chaves Canal.

CONCLUSION

In order to be able to precisely define the durability of a PVC-P geomembrane it is indispensable to have an understanding of its real behaviour in the long term. It is important that the study of real long term understanding is as wide ranging as possible, permitting the coverage of the greatest number of hypotheses according to climatic and other variations which may occur. The relationship between the accelerated aging tests and real behaviour of the PVC-P geomembranes is only achieved through in-depth knowledge of real behaviour in the long term. The design of the waterproofing system is one of the fundamental elements required to achieve good durability. As long as they are correctly formulated, PVC-P geomembranes present good durability, even in extreme situations of mechanical, physical or chemical action.

REFERENCES

Blanco, M. A. E. 2000. Aspectos más relevantes del comportamiento en obra de los materiales sintéticos utilizados como geomembranas impermeabilizantes en embalses ubicados en la Comunidad Autónoma de Canarias. Ingeniería Civil, 117/2000, pp. 25-35.

Fayoux, D. 1990. Durability of PVC geomembranes and resistance to puncturing, Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products, Vol. 2, The Hague, Holland, pp. 561-565.

Fayoux, D., Goussé, F. and Rummens, F. 1993. Assessment on a PVC geomembrane in a landfill after ten years, Proceedings of SARDINIA 93, Fourth International Landfill Symposium, Vol. 1, S. Margherita di Pula, Cagliari, Sardinia, Italy, pp. 369-378.

Fayoux, D. and Van Der Sype, D. 2000. Durability of PVC-P geomembranes - assessment after very long UV exposure, Proceedings of the 2nd European geosynthetics conference, Patron Editore: Bologna, pp. 651-656.

Fayoux, D. 2004. La impermeabilización del embalse de la laguna de Barlovento Jornadas sobre impermeabilización con materiales sintéticos" Isla de la Palma, CEDEX / Consejo Insular de Aguas de La Palma.

Fayoux, D. and Potie, G. 2006. L'emploi des géomembranes dans les îles de Tenerife et de la Palma (îles Canaries), Proceedings of the Rencontres Géosynthétiques 2006, Montpellier, France, pp. 465-472.

Girard, H., Poulain, D., Benneton, J-P. and Fayoux, D. 2002. Durability of PVC-P geomembranes used in hydraulic structures: feedback on experience, Proceedings of the Geosynthetic – 7th ICG, Nice, France, pp. 707-712.