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FIRST DOUBLE LINER
Part 1: How it was built 40 years ago

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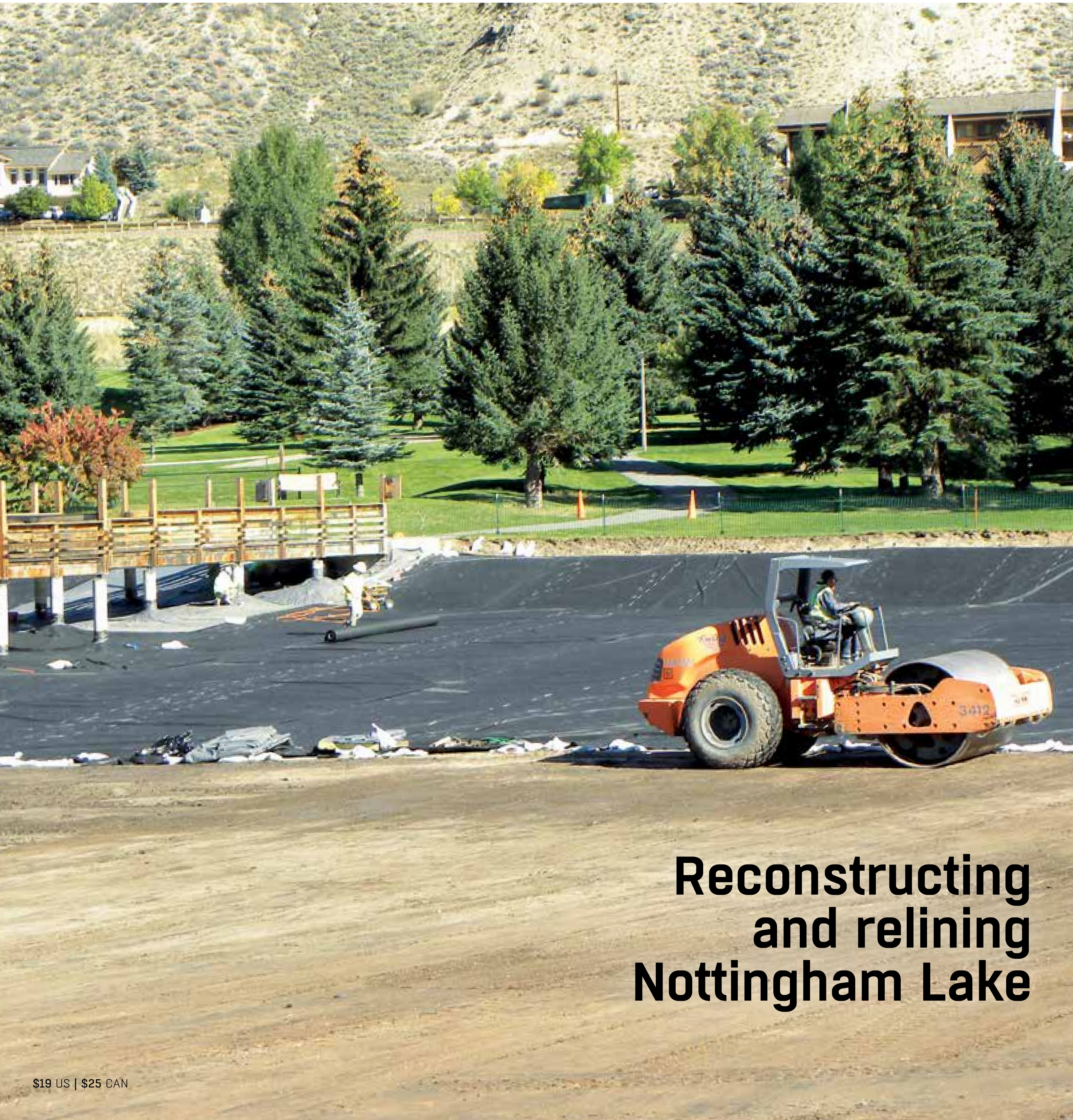

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PART 1

The first double geomembrane liner 40 years later

By J.P. Giroud and J.P. Gourc

Introduction

The first double liner with two geomembranes was constructed in June 1974 and has been in continuous service since then. The double-lined structure is a water reservoir located in Pont-de-Claix, near Grenoble in southeastern France. The geotechnical study showed that strict leakage control was necessary to avoid a risk of slope instability. A double liner was designed and constructed—a new concept at the time.

This article is intended to contribute to the history of the geosynthetics discipline by presenting the development of a concept—the double liner—that is an essential feature of a number of structures containing liquids and waste and describing the construction and performance of this landmark reservoir, the first structure constructed using a double liner with two geomembranes. This article will also serve as a reference document for tests performed in the future when the geomembrane is removed.

Liner

A liner is a layer of low-permeability material generally used as a barrier to liquid or, in some cases, gas. In the case where a liner is a barrier to liquid, its functions are: (i) to contain a liquid as in a reservoir or a dam; or (ii) to promote liquid flow above the liner, as in a canal; or (iii) to promote liquid flow in a permeable layer, as in a leachate collection layer in a waste storage landfill—where the leachate conveyed to an outlet—or as in a leakage collection layer in a landfill or a reservoir.

The material of choice for constructing liners is a geomembrane. Mineral barriers, such as clay layers and bentonite geocomposites, are not as impermeable as geomembranes. An efficient way to use a clay layer or a bentonite geocomposite is to place it immediately under a geomembrane to form a composite liner. (A composite liner is not a double liner, but it may be a component of a double liner.)

Double liner

In the terminology of geosynthetics engineering, a double liner consists of two liners separated by a drainage layer. The upper liner is called the primary liner and the lower liner is called the secondary liner. The purpose of the drainage layer is to collect, convey, detect, and remove leakage that may occur through the primary liner, hence the terminology

EDITOR'S NOTE

The paper authored by Giroud and Gourc and the oral presentation by Dr. Giroud were originally presented at the 10th International Conference on Geosynthetics in Berlin, Germany on September 24, 2014. This article is revised and edited for *Geosynthetics* magazine's style and length. Part 2 will run in the April/May 2015 issue of *Geosynthetics*. –R.B.

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All figures courtesy of the authors

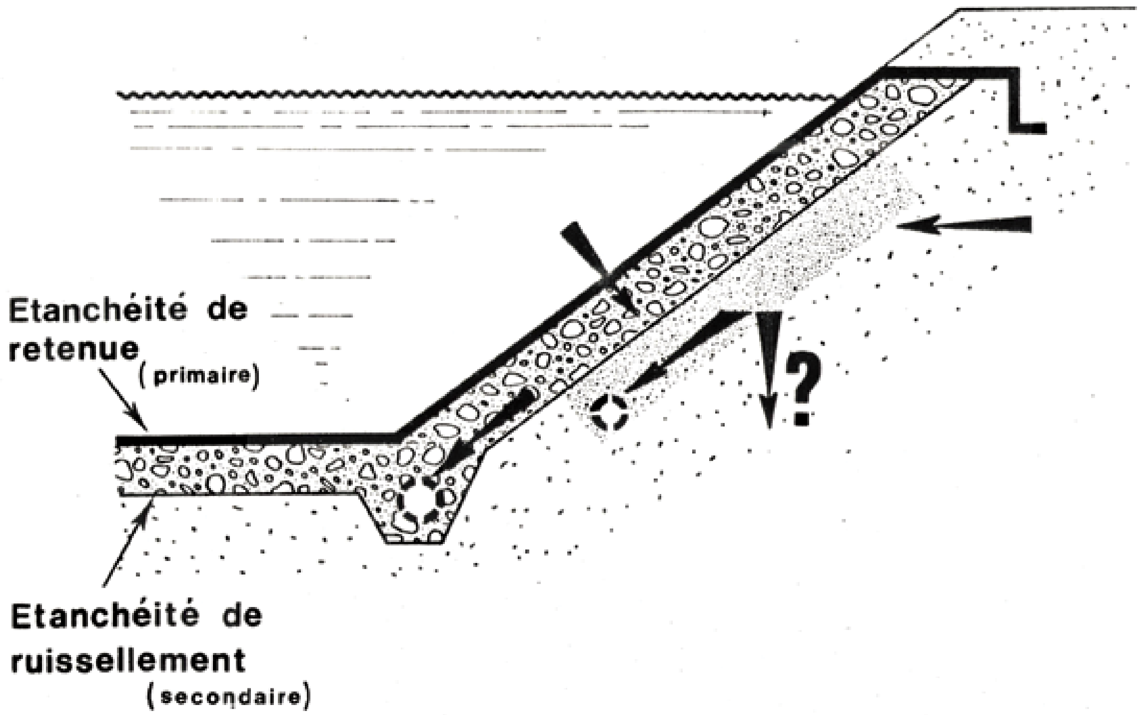

FIGURE 1 Reproduction of the figure used to present the concept of the double liner (Giroud, 1973). The English translation of the original French wording is: (1) Liner for containment (primary); (2) Liner for liquid flow (secondary). The question mark indicates that water collected by an underdrain that is not underlain by a geomembrane liner may not reach the outlet.

FIGURE 2 Aerial view at the end of geomembrane installation. The shape of the reservoir minimizes the impact of excavation on the stability of the east slope and the weight of the dike on the west slope. The reservoir proportions are distorted because the photo was taken at an angle (as evidenced by the fact that the intake structure on the 1V:2H southwest slope is hardly visible).

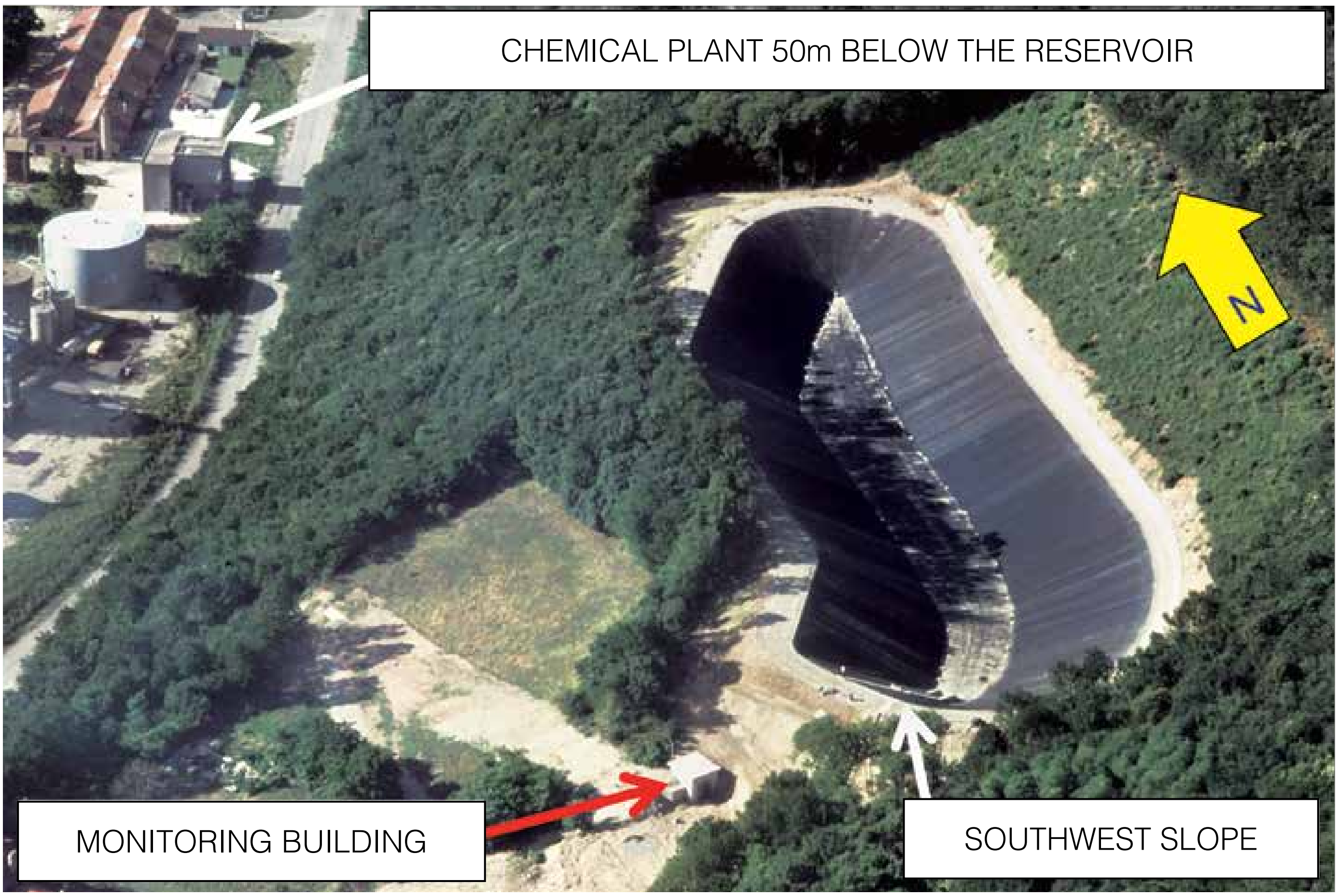

FIGURE 3 Southwest end of the reservoir showing: water intake structure, spillway, and butyl rubber geomembrane. The butyl rubber geomembrane is unreinforced, except at the top of the slope where a strip of reinforced butyl rubber geomembrane is used around the entire perimeter (except at the spillway) above the level marked by the yellow arrows and in the anchor trench.

"leakage collection, detection, and removal layer" or simply "leakage collection layer" or "leakage detection layer." The secondary liner plays an essential role. The only suitable material for a secondary liner is a geomembrane because the leakage rate through the primary liner is generally so small that, if the secondary liner is a soil, even clay, much of the leakage collected will flow through the soil rather than being conveyed, detected, and removed.

The double liner concept was presented in a lecture in Paris in 1973 and was described in the subsequent paper (Giroud, 1973) using **Figure 1**. The double liner concept is that the thickness of liquid flowing in the leakage collection layer must be as small as possible and less than the thickness of the layer. As a result, the hydraulic head on the secondary liner is small. Consequently, there is little leakage into the ground, even if the geomembrane secondary liner contains some holes.

The flow capacity of the leakage collection layer is essential. This layer must have an appropriate slope and the material of this layer must have high hydraulic conductivity to rapidly convey the flow with a hydraulic head as small as possible.

As often mentioned by the senior author, it must be recognized that "all liners leak or may leak" and that "a leak should only be a leak" (i.e., a loss of liquid without detrimental consequences). A leak should not trigger an unacceptable problem. Unacceptable problems include: (i) environmental problems such as pollution of the ground (if the liquid is a contaminant); and (ii) geotechnical problems such as deterioration by water intrusion of the soil supporting the liner system due, for example, to erosion (piping), dissolution, or increased pore water pressure and reduction in shear strength causing instability. In such cases, a double liner should be used.

Prior to the Pont-de-Claix Reservoir, the senior author investigated the failure of a reservoir liner in 1972 (Giroud and Goldstein, 1982) and recommended that repair be done using a double liner. This was constructed in 1973 with a butyl rubber geomembrane primary liner and a bituminous concrete secondary liner.

During the same period, the senior author was involved in working sessions for the use of a double liner for the La Coche Reservoir (France), which was constructed with a reinforced concrete primary liner (constructed in 1974–1975) and a 1mm-thick reinforced PVC geomembrane secondary liner (installed in 1973) (Rosset, 1973; Darves and Merk, 1976).

The 1973 lecture and paper by the senior author and these two examples of double liners with one geomembrane and one traditional liner show that the double liner concept was in the air but it remained to be implemented with two geomembranes.

The site and the reservoir

The climate

The water reservoir is located 8km from the center of Grenoble, the French city with the largest difference between summer and winter temperatures. Typical temperatures are:

- Yearly average temperature: 12.5 C (54.5 F)
- Hottest month, average temperature: 21.0 C (70 F)
- Hottest month, average of maximum daily temperatures: 27.5 C (81.5 F)
- Maximum temperature: 39.5 C (103 F)
- Coldest month, average temperature: 2.2 C (36 F)
- Coldest month, average of minimum daily temperatures: -1.6 C (29 F)
- Minimum temperature: -20.3 C (-4.5 F)

It appears that the geomembrane was exposed to relatively high temperatures for a temperate climate. However, at the site, the temperatures may have been attenuated from the above values by the presence of high trees. The yearly average rainfall is 934mm, distributed almost uniformly during the year.

An exceptional site

The water reservoir is located on a 60m-wide quasi-horizontal area located at elevation 295m. This area forms a sort of bench between an upper slope and a lower slope. Both slopes have an angle of 33° (i.e., 1V:1.54H). The upper slope is 90m high between elevations 295m and 385m. The lower slope is 50m high between elevation 295m and the horizontal ground at elevation 245m. A large chemical plant (owner of the reservoir) was, and still is, located on the horizontal ground at elevation 245m.

The geotechnical investigation conducted in 1972 under the responsibility of the senior author showed that the soil below the reservoir location consisted of: (i) rounded cobbles (up to 300mm size) between elevations 295m and 265m; and (ii) clay below elevation 265m. No groundwater was found in the cobble mass. The cobbles were bound together by a small amount of fine particles. The resulting cohesion significantly contributed to the stability of the slope. However, due to the high permeability of the cobble mass, the fine particles could be washed out in case of massive intrusion of water into the cobble mass.

The crest of the reservoir is at elevation 301m. The reservoir was constructed using cut and fill (below and above elevation 295m) and it does not apply significant load on the slope. Stability analyses showed that the slope was stable, but could become unstable in case of major leakage of water from the reservoir, which would wash the fine particles, thereby reducing the cohesion of the cobble mass. Any risk of instability was unacceptable due to the presence of the chemical plant at the toe of the slope **(Figure 2).** A landslide on the chemical plant could cause a toxic gas release and pollution of a nearby river, which would have a serious impact on the people in the vicinity (500,000 in the 1970s, 750,000 now).

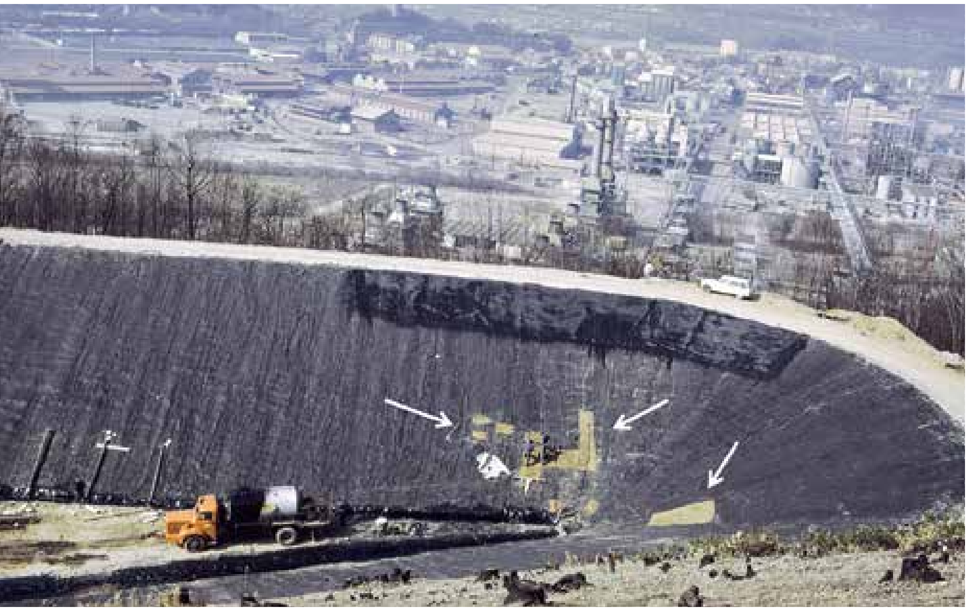

FIGURE 4 Placement of the bituminous geomembrane used as a secondary liner: In several areas, the in-situ geomembrane is being redone as shown by the white arrows. The chemical plant is located 56m below the crest of the reservoir.

FIGURE 5 Spraying of hot bitumen on a polyester, needle-punched, nonwoven geotextile (photo taken at another site).

Safety had to be ensured in case of large leakage, hence the use of a double liner. In a report written in 1972 for the reservoir, the senior author wrote (translated from French): "Waters leaking through the liner must be collected by a drain. It is important that the bottom of the drain be sufficiently impermeable so the collected waters are conveyed to the outlet and do not percolate into the ground. Therefore, a double liner should be constructed: a containment liner and a liner for flow."

The reservoir

The reservoir **(Figure 2)** is 195m long and 55m wide, with 1V:2H sideslopes. The depth of the reservoir is 11m at the south end and 9m at the north end. The capacity of the reservoir is 40,000m^3. The lined surface area is about 10,000m^2.

The reservoir's function is to provide an emergency supply of water for the chemical plant located 50m below in case of failure of the normal water supply for the plant. The concrete water intake structure located at the southwest end of the reservoir is shown in **Figure 3.** The reservoir can be emptied in fewer than five hours with the normal consumption of water by the chemical plant (2.5m^3/s). Because of this condition, it was decided that the geomembrane should not be covered with a layer of material that could become unstable in case of rapid drawdown. The chemical plant never experienced an interruption of normal water supply. As a result, the reservoir has never been completely emptied since it entered service in 1974 (which may have played a role in the excellent performance of the liner).

Relevant aspects of design and construction

The secondary liner

The secondary liner, a bituminous geomembrane made in situ by spraying hot bitumen on a polyester, needle-punched, nonwoven geotextile, was installed in February 1974 by Colas **(Figure 4).**

Information regarding the actual installation of the bituminous geomembrane at the Pont-de-Claix Reservoir is limited. Typically in the early 1970s in France, bituminous geomembranes were produced in situ as follows:

- a polyester, needle-punched, nonwoven geotextile with a mass per unit area of 400–600g/m^2 was placed on the ground.

- about 6–10kg/m² of hot bitumen were sprayed directly onto the geotextile **(Figure 5)** to obtain a geomembrane about 8–10mm thick.

With a bituminous geomembrane produced in situ, it was difficult to produce a uniform thickness of bitumen, especially on slopes. In fact, it was necessary to redo some areas that were visibly not satisfactory (shown by white arrows in **Figure 4**).

In 1975, this technique was replaced by bituminous geomembranes manufactured in a plant.

The leakage collection layer and the leakage removal pipes

The leakage collection layer consists of a layer of rounded gravel (0.2m-thick on slopes and 0.3m minimum at bottom) stabilized with a small amount of mortar (i.e., sand plus cement). Exact composition:

- 1900kg/m³ of rounded gravel, size 15–25mm.
- 100kg/m³ of cement.
- 100kg/m³ of sand.

This leakage collection layer was placed directly on top of the bituminous geomembrane **(Figure 6).**

A field test conducted in October 1973 showed that angular sand particles attached to gravel by cement were protruding at the gravel surface. The senior author then recommended laboratory hydrostatic tests to select a geotextile cushion to be placed between the gravel layer and the primary liner geomembrane. Such tests were rare at that time. The tests were conducted at CTGREF (now called IRSTEA) and a polyester, needle-punched, nonwoven geotextile with a mass per unit area of 400g/m² was selected.

The gravel leakage collection layer on the bituminous geomembrane at the toe of the slope is shown in **Figure 7**, and the completed leakage collection layer is shown in **Figure 8**. During construction, cracks appeared in the mortar-stabilized gravel across the slope (**Figure 9**). Laboratory hydrostatic tests were conducted on a specimen of the actual leakage collection layer with a wide crack to evaluate the ability of the geomembrane primary liner and supporting geotextile to bridge the cracks.

The leakage collected by the gravel layer is directed toward two perforated pipes located along the east and west edges, respectively, of the reservoir bottom. These pipes have a diameter of 300mm **(Figure 7)** and a longitudinal slope from north to south of 1.3%. The east half of the bottom has a 1% slope toward the east pipe and the west half of the bottom has a 1% slope toward the west pipe. Therefore, the east (west) pipe collects leakage from the east (west) slope and the east (west) half of the bottom. The two pipes have separate out-

FIGURE 6 Construction in progress with the leakage collection layer directly on top of the bituminous geomembrane.

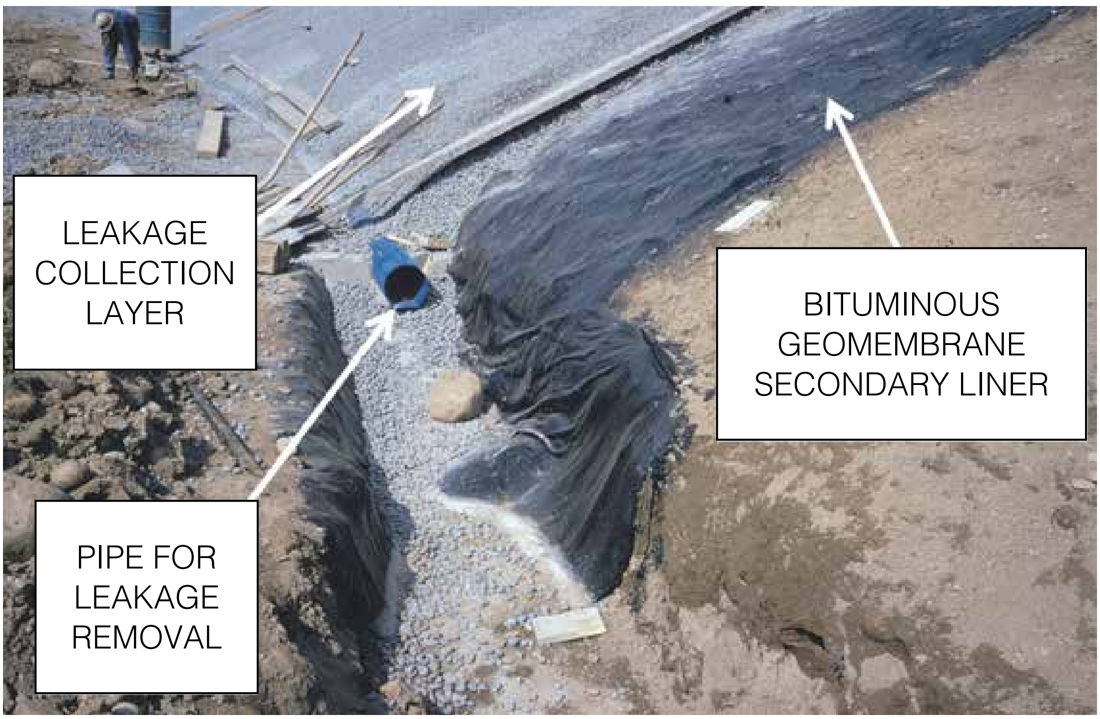

FIGURE 7 Toe of the east slope: The perforated pipe runs along the entire toe of the east slope (and a similar pipe runs on the west side).

lets in the monitoring building **(Figure 2)**. Therefore, if leakage is detected, it is possible to determine whether the leak is on the east half or the west half of the reservoir. The maximum width of the bottom is 15 m. Therefore, the maximum flow path from a leak at the bottom to a pipe is 7.5m. The required flow capacity of the leakage collection layer was calculated by considering one 1cm² hole every meter of the 155m-long line running north-south in the middle of the bottom. The classical Bernoulli equation was used to calculate the leakage rate under a head of 10m.

FIGURE 8 Completed leakage collection layer: The chemical plant is on the horizontal ground, 56m below the crest of the reservoir.

Acknowledgments

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FIGURE 9 Cracks in the leakage collection layer due to some sliding of the gravel layer on the slippery bitumen surface.

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