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First results of monitoring of a radioactive waste landfill cap constructed with a bituminous geomembrane

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ABSTRACT: The Manche landfill repository at a a coastal site receives low and moderate activity solid radioactive wastes with short to moderate half lives. A suitable capping was required to ensure durability during the regulation 300-year monitoring period. A multilayer system based on a bituminous geomembrane was selected to control rainwater seepage. The paper presents the geotechnical and hydraulic observations made in the initial years of monitoring the first landfill repository in France, built in 1969 by the national radioactive waste management authority ANDRA.

1. INTRODUCTION

France, like all industrialised countries, is faced with a radioactive waste disposal problem. ANDRA decided to isolate waste of low and moderate activity in a surface landfill in order to protect the environment over the years.

In 25 years, the Manche landfill has received some 530,000 m^3 of waste of low to moderate activity covering an area of approximately 12 hectares.

2. GENERAL DESCRIPTION OF REPOSITORY

Waste delivered in concrete drums is stacked. If the containers are inadequate, it is placed in a monolithic concrete cell structure.

During the emplacement phase, the stacks and cell monoliths were temporarily covered with a thin layer of compacted soil. Both stand on a concrete raft that collects all the water seeping through the containers, already protected at various levels by horizontal concrete slabs. Water is collected by a Separate Buried Gravity Drainage system. In the settling tanks at the lower end of this system, flow rate and radioactivity are continuously monitored before sending the water to COGEMA (Compagnie Générale des Matières Nucléaires) for treatment.

The geological formations on which the rafts are founded consists of sandstone and shale. Foundation settlement under the applied loads was uniform and did not exceed 5cm.

3. CAP DESIGN CRITERIA

3.1. Purpose

The cap was required to isolate the waste throughout the 300-year monitoring period against external impacts of natural (rainfall, erosion, weather changes, etc.), human and animal origin.

3.2. Design Criteria

The cap meets three main criteria:

1 Watertightness

Watertightness means that the amount of water reaching the structures must not exceed a few litres per square metre per year.

2 Durability

The capping must remain watertight for a period of 300 years. It must retain its properties of controlling infiltration over the whole of this period, using materials offering the best assurances of durability.

3 Protection

This criterion concerns chiefly impacts other than seepage - erosion, temperature effects, etc. A thickness of material properly placed and grassed forms the top of the cap.

Photo 1 - Aerial view of cap construction

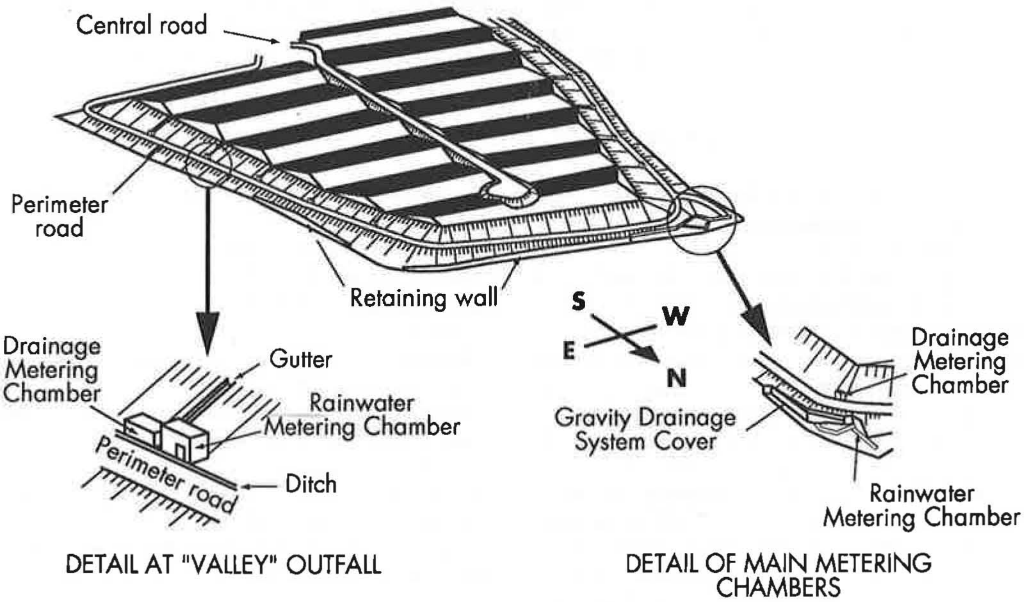

Figure 1 "Ridge Roof" cap system
(Drainage metering chamber and runoff metering chamber at outfall from each "valley")

3.3. *Cap Design*

The above criteria prompted ANDRA to adopt a multilayer concept, with alternating layers of different permeabilities. The low permeability material selected was a bituminous geomembrane. This material offers the best assurances of durability and capability of accommodating settlement in the underlying layer.

To provide for monitoring and repair if necessary, the cap was designed in such a way that any flaws could be identified on panels of restricted size.

4. DESCRIPTION OF CAP

4.1. *General Description*

In external appearance, the cap consists of a series of sloping surfaces resembling a pitched roof, at angles of 6 to 14% alternatively. [1, 2] (Photo 1). The maximum size of each 'roof' panel is 140m x 25m. The distance between 'ridges' is not more than 50m, equivalent to the length of a roll of Coletanche NTP4.

At the sides, the cap has a face slope of 2.3H for 1V at the top and 1.5H for 1V at the bottom. The maximum height of the top slope is of the order of 22m.

4.2. *Multilayer System*

From bottom to top, the multilayer system comprises:

- Base course from coarse material providing the necessary fall for the cap and providing a semi-impervious buffer material between the repository and the cap.
- Fine sand drain layer providing support to the bituminous membrane against puncturing and collecting any resulting seepage water.
- Coletanche NTP4 bituminous membrane.
- Fine sand drain layer to prevent any head of water developing, even temporarily, on the membrane and collect all water infiltrating past the biological barrier.
- Semi-impervious layer of compacted coarse material regulating the flow of seepage to the membrane and protecting it against burrowing animals and root damage.
- Layer of grassed topsoil.

Details at each low point are as follows (figure 1):

a) At the outfall from the lower drain layer, two small trenches with 150mm approx. i.d. drain pipes. These trenches are cut in the base course and separated from each other by a small ridge of coarse material to separate drainage from a south-facing 'roof' panel. In order to keep water from seeping into the repository, the bottom of the ditch is lined with a bituminous membrane anchored in the base course. A geotextile is laid between the membrane and underlying coarse material as protection against puncturing.

b) The geomembrane is systematically reinforced at each low point over a width equivalent to the prefabricated roll width (4 metres).

c) At the outfall from the upper drain layer, a rolled gravel strip measuring approximately 0.70m in cross section containing a drain pipe of 200mm inside diameter approx. A geotextile prevents any risks of contamination of the gravel.

4.3. *Cap Drainage System*

All the water draining from the cap is collected by a system surrounding the repository. Surface runoff and seepage are not allowed to mix.

4.3.1. *Surface Runoff*

Surface runoff collects in reinforced concrete drainage ditches at the bottom of the 'roof' slope. At the end of each 'valley,' there are drainage ditches conveying the water to the bottom of the perimeter slope.

Drain inlets are provided at the foot of each 'roof' slope to collect water from the panel. From each inlet, there is a pipe to the main drain pipe approximately 1m in diameter, large enough for a man to enter. This main collects the runoff and discharges it to the total-flow measurement chamber at the north-west corner of the repository.

4.3.2. *Seepage*

There are two systems collecting seepage, from above and below the bituminous membrane (fig. 2). Seepage from above the membrane is collected by a sand layer and a drain pipe in a gravel strip.

Seepage from below the membrane is collected by a layer of sand and two drain pipes. The purpose of this underdrainage system is to detect any damage to the bituminous membrane. Each pipe enables the integrity of the membrane to be assessed by measuring the drain discharge, and identifies the leaky panel.

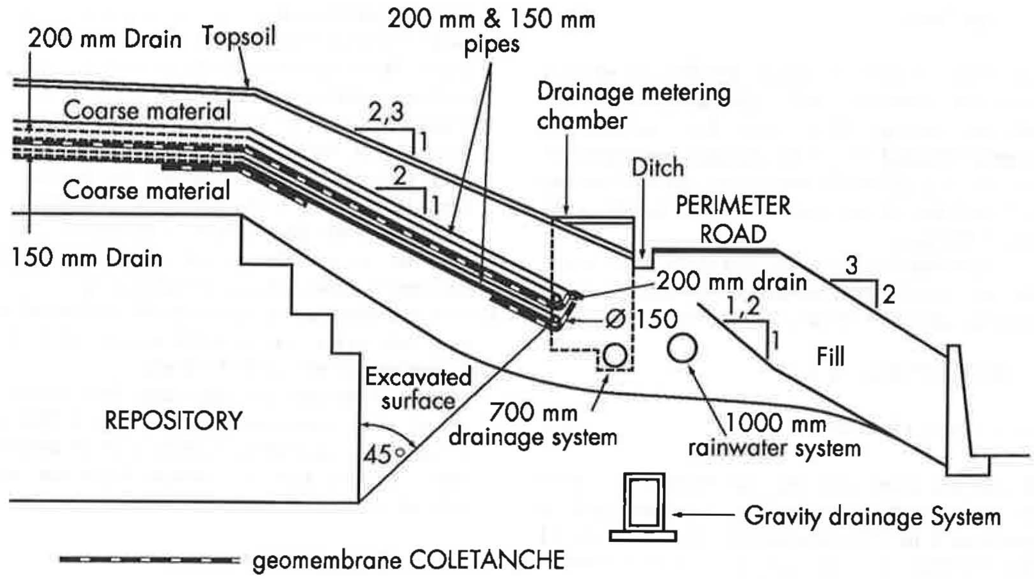

Figure 2 : SECTION THROUGH DRAIN SYSTEM.

All these pipes discharge to measuring chambers. These chambers are connected together by a main drain conveying seepage to the total-flow measurement chamber.

4.3.3. Total-Flow Measurement Chamber

The drainage collection chambers, each with its flowmeter, is connected to the total-flow measurement chamber.

5. GEOMEMBRANE

A bituminous geomembrane was the obvious choice for the following reasons:
- Bitumen has a long history of use
- It has a proven in situ performance record
- It is thick enough to resist any microbial attack
- It is deformable and impervious
- It is easy to lay and seal against concrete structures.

ANDRA and their engineer considered, as early as the preliminary design phase, that a cap capable of retaining its effectiveness for 300 years could only consist of natural materials like clay or bitumen. A cap consisting solely of compacted clay was discarded because of the sensitivity of clay to drying.

Only a bituminous membrane was considered worth subjecting to performance studies. Before selecting the Coletanche NTP4 bituminous geomembrane, ANDRA ordered a large number of tests from specialist laboratories in France.

6. ADDITIONAL TESTS ON BITUMINOUS GEOMEMBRANE

6.1. Structure

The bituminous geomembrane consists of a continuous-fibre needle-punched polyester geotextile impregnated and surfaced with filled Shell Mexphalte 100/40 blown bitumen. It is 5.6mm thick and weighs 6.5kg per square metre. The geotextile confers mechanical strength, while resistance to chemical and biological attack and impermeability are due to the bitumen.

6.2. Biodegradation Resistance

Native bitumen was used 4000 years ago for waterproofing and moulding objects in Mesopotamia and such objects have survived to this day without any particular deterioration. Native bitumen has existed for millions of years.

Once buried in the soil, the geomembrane might biodegrade on both sides. Tests by the US Nuclear

Regulatory Authority consisted of burying specimens of bitumen of known area in various soils exposed to bacteria and nutrient solutions [3].

Biodegradation is accompanied by the formation of CO_2. The US researchers were able to measure the average biodegradation rate of blown bitumen as $5.5\ 10^{-4}$ cm/year. By extrapolation, this research indicates that maximum biodegradation of the geomembrane at the Manche radioactive waste repository under the most severe conditions would be 3mm in 300 years. Natural ageing tests on specimens of NTP4 membrane at dams tend to confirm this extrapolation.

6.3. Permeation Coefficient

There are two different coefficients characterising the passage of water through a geomembrane:

- The effective diffusion coefficient De for water (in m^2/s^{-1}) when no pressure is applied to the water during the test.
- The coefficient of permeability K (in ms^{-1}) when a pressure is applied.

Permeation is composed partly of permeability and partly of diffusion. The French atomic energy authority CEA has a cell in its Grenoble laboratory [4] capable of measuring very low values of De (down to $10^{-17}\ m^2/s^{-1}$) and K ($10^{-19}\ ms^{-1}$). This laboratory has been able to obtain these low values by using water containing tritium.

Analysis of their results indicates, in broad terms, that seepage through the membrane is due to diffusion, not Darcy permeability. The Coletanche NTP4 membrane is found to have the best performance of all the membranes tested, in terms of the diffusion of water (De = $2\ 10^{-15}\ m^2/s^{-1}$) This diffusion coefficient represents a seepage rate of $10^{-2}\ l/m^2$/year, a very small percentage of the target criterion of a few l/m^2/year.

6.4. Friction Coefficient of Soil/Bituminous Geomembrane Interface

The friction coefficient between the bituminous geomembrane and the drain material on either side of it was measured, in order to ensure that the cap would be stable against sliding.

The French agricultural research centre CEMAGREF used the sloping surface method to determine the angles causing sliding of sand on the geomembrane. The friction angle measured in this way was 27° [5].

Photo 2 - Automatic Welding

Photo 3 - Ultrasound test on seam

6.5. Inspection and Quality Assurance Plan

Construction of the cap involved ANDRA setting up a specific quality assurance plan for all the capping work [6] which included 100% ultrasound testing of all seams (photo 2, 3).

7. CAP MONITORING SYSTEM

In addition to the regulation monitoring associated with a Basic Nuclear Installation in which the various compartments of the ecosphere are monitored by multi-point measurements inside and outside the repository, ANDRA instituted a special monitoring plan for the cap and associated works to ensure the seepage-control performance of the cap was maintained. The plan was primarily a decision-making tool (repairs, possible placement of clay to supplement the geomembrane) before being a performance monitoring tool.

Four types of monitoring are provided:

1) Visual inspection comprising external observation of the cap, condition of walls, inspection of accessible enclosures, and inspection of drain pipes by means of a small television camera.

2) Topographic survey to detect any settlement or other movement of the cap (field levelling and aerial photogrammetric surveys).
3) Collection of drainage to study and monitor the hydraulic performance of the multilayer system. This involves the following measurements:
   i) For rainwater runoff: point measurements (by measuring weir) of flow in ditch and pipe drains (by means of Polubac instruments) and total measurements at each weir.
   ii) For seepage: systematic measurements by tilting bucket meters for membrane underdrainage, and Polubac measurements of drainage from above membrane, as well as total measurements.
   iii) For any water collected by the separate buried gravity drainage system: point measurements to monitor and analyse trends.
   iv) Point tensiometer measurements to understand the hydraulic functioning of the cap panels and quantify the respective proportions of runoff, seepage and evapotranspiration.
4) Intrinsic cap monitoring by in situ sampling of pieces of geomembrane to analyse developments in membrane properties.

Drainage Monitoring

When attempting to characterise a multilayer system, monitoring the drainage from individual panels is a means of monitoring changes in the hydraulic performance of the multilayer system. The system consists of vee notch weirs with 30° and 10° notch angles, tilting bucket flowmeters, tensiometers and raingauges. The data acquisition systems to which the sensors are connected include multiplexers. With a computer, modem and appropriate software, the operator can interrogate all the sensors and recover raw data for analysis. The system also provides for remote monitoring of the drains under the membrane and automatic alarms if a flow rate setpoint is exceeded. Data from the first full year of operation (1994) and the first part of 1995 indicates, for the year considered, the following average breakdown with reference to rainfall:

- 57% evapotranspiration
- 22% surface runoff
- 21% seepage.

From these figures, field observations and multilayer properties, it is found that there is a high percentage of infiltration through the biological barrier. Visual inspection shows that discharge from the drains above the membrane, coming from the 'roof', is practically negligible, for a unit area of 3125 m^2. This fact leads to the conclusion that part of the runoff turns into seepage, mainly at the toe of the slope and at the interface between concrete structures and the biological barrier. A dam was therefore added on one panel as an experiment in order to prevent mixing. This system will be extended to all the other panels if it proves effective.

Membrane/Concrete Interface

With this system, discharge from the drains under the membrane was found to be greater than the set limit in two measurement chambers, one built in 1992 and the other, in 1994. Non-destructive tests (applying a head to the relevant drains over the membrane, camera inspection at flaws in concrete/membrane interfaces, water tests on each future structure) were implemented before backfilling.

8. CONCLUSION

A monitoring programme like the seepage monitoring system over a limited period of time (five years) will permit validation of the multilayer system selected by ANDRA for the cap.

The three other monitoring programme and a simplified seepage monitoring programme will consolidate these findings and detect any significant shortfalls below target. The programme will yield valuable data on the long term performance of a geomembrane that will enrich the store of knowledge in geomembrane science. Its effectiveness and credibility will need reliable, structured long-term archives.

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