GeoAmericas 2016
3RD PAN-AMERICAN CONFERENCE ON GEOSYNTHETICS
10-13 APRIL 2016 • MIAMI BEACH • USA

REPAIRING OF A GEOMEMBRANE LINING SYSTEM (GLS) USED FOR RAFT WATERPROOFING OF CIVIL ENGINEERING BUILDINGS

C. HAQUET, K.L. NAIT-ALI, F. AYRINHAC, Polymer Materials Team, Civil Engineering Service, EDF/CEIDRE/TEGG, FRANCE

ABSTRACT

The use of a geomembrane lining system (GLS) as tanking system for civil engineering buildings is difficult, especially when the GLS cannot be visited for maintenance in case of waterproofing deficiency during its service life. There are few documented researches and case studies on this issue, which should be discussed and solved in a collegial way. The installation procedure is dependent on the specifications and required properties of the GLS, hence the partitioning of the geomembrane is considered as an option for technical and cost reasons. This paper is a summary of repairing procedure of a non-partitioned GLS used for civil engineering buildings, in an innovative way. Several years after its installation, some leaks were detected in a building, revealing the leakiness of the waterproofing device. In order to repair the inaccessible GLS underground, the injection of aqua-reactive polymeric resins was proposed. The injection was performed in two steps: first, an aqua-reactive resin with low curing-time was injected in order to create a polymeric partitioning between the GLS and the concrete raft. When the partitioning had been performed, a second aqua-reactive resin, with longer curing-time, was injected in order to fill the partitions created on the first step. The injection parameters raise questions, which were assessed through a mockup, especially the pressure and viscosity of each aqua-reactive resin to be used in order to impregnate the GLS without mechanical damage, the complete filling of compartments, the chemical inertia of the resins, and finally their durability. A testing program and mockup were proposed and performed before the full scale repair.

1. INTRODUCTION

The protection of Civil Engineering structures and buildings (e.g. power stations) from flooding and chemicals requires the use of a geomembrane lining system (GLS), which is a permanent measure that cannot be visited or repaired (BRE Special Digest, 2005). The GLS consists in a waterproof geomembrane, designed for the service duration of the structure, and protections like geotextiles to protect the geomembrane against mechanical damage for in-service duration and during operation (Fascicule n°10, CFG, 1991). The service life of the GLS is commonly considered as being equivalent to the concrete service duration. Generally, the installation of this type of system under-slab requires a compartmentalization when the protected surface is larger than 200-400 m² (depending on the hydraulic pressure). But this compartmentalization is still considered as an option that is not economical and difficult to achieve. The geomembranes have to be welded on plastics strips like waterstops (used to seal construction joints in concrete structures) in order to implement compartments with a size corresponding to the hydraulic pressure to which it will be subjected (J.L. MAHUET, 2005). The aim of the compartmentalization is multiple: to resist the hydraulic pressure; to avoid folds during installation, which would develop stresses under tension and generate local cracking; to allow the repairing of the waterproofing system or, to be more specific, the rehabilitation of the waterproofing system by injection of aqua-reactive resins into the compartments. This last point is the main reason for compartments. As the GLS cannot be accessed in-service, the compartments will allow a localization of the leakage and the possibility to repair by injecting a resin into the affected compartment.

When important leakages are measured in a Civil Engineering structure protected by a non-compartmentalized geomembrane, the question is how to repair the waterproofing system? How to make sure that the repairing will not affect all the GLS surface when a leak is detected?

The aim of this paper is to propose an innovative method for the repairing of non-compartmentalized GLS used for the protection of Civil Engineering structures. The following proposed solution has been imagined in order to avoid generalized injections by creating artificial compartments by the optimized combination of aqua-reactive resins curing-time and injection process parameters. Its efficiency was assessed on a representative mockup test designed for this purpose.

2. TECHNICAL APPROACH

The repairing of the GLS main function is not an easy task as there is no possibility to see or control the efficiency of the works except if an interruption of the leaks is observed. But behind the concrete structures, the injection will be performed blindly.

It is important to take into consideration that aqua-reactive resins have a service duration of about 10-20 years depending on the environment (chemicals, hydraulic pressure, temperature etc.). So repair can become a recurrent task. If no compartment is installed, the repair will have to consider the total surface each time a leak is detected. On large surfaces of protected concrete, this task can become very expensive.

The idea is thus to create compartments by the injection of resins that will have a suitable curing-time to form a solid and uniform column of resin. When the columns will be injected and solidified, they will form compartments that could be, in a second time, injected by a more common aqua-reactive resin as it would be the case for compartmentalized GLS.

As it represents an innovative method, a suitability test is necessary in order to confirm the technical relevance of:

- the perforation method for injectors installation without damaging the geomembrane,
- the implementation of the artificial compartments with a suitable resin on the appropriate width,
- the efficiency and conservation of these artificial compartments during their filling, and
- the complete filling of compartments.

The purpose of the injection is to fill from top to bottom a partitioned area to substitute infiltration water by aqua-reactive resin that will fully occupy the available space between the concrete wall and the defective GLS. Only complete filling of the compartment could avoid the by-pass of repaired zones (J.L. MAHUET, 2006).

3. MATERIALS AND TECHNIQUES

3.1 GLS and compressible material

The GLS system used for the suitability test consists of a 2 mm thick non-compatible bitumen (NBC) PVC-P geomembrane protected by a thick geotextile (600 g/m²) placed on both sides of the geomembrane. The protective sheet of the GLS that is behind the geomembrane was not integrated in the mockup because it was not considered relevant to add it. A compressible material (expanded polystyrene foam) was added in order to be close to the current state of the back of the geomembrane from a mechanical point of view. The chosen GLS was finally, representative of what can be found under-slab of Civil Engineering structures.

3.2 Aqua-reactive resins

The two aqua-reactive resins used for the suitability test are both hydrophilic, cross-linked methacrylate gel. They have a water consistency and swell reversibly in contact with water.

Resins are based on three components. They consist of a resin (A1), an accelerator (A2) and a catalyst (B2) which is diluted in water. Mixing the components leads to an in-situ reaction forming an elastic gel, which is able to absorb and desorb water.

The resin used for carrying out compartments, Resin α, is a very fast-curing hydrogel with high elasticity presenting a curing-time of around 30 seconds at 20°C depending of the mixing ratio "part A (A1 + A2) / part B (B2)".

The resin used for filling compartments, Resin β, is a low viscosity hydrogel with high stability. Component B2 has been changed to component B2L, which is a modified catalyst allowing longer curing-time. Thus, Resin β presents a curing-time of around 80 minutes at 20°C depending on the concrete wall temperature.

3.3 Injection materials and parameters

In order to perform injection, a complete injection system has to be used. The injection system comprises a mixer, injection pump, injectors / air vents, links pump-injectors and materials able to follow injection parameters, such as weigh scale, manometer, flowmeter, etc.

The following injection parameters have been chosen for the on-site mockup. Some of them will be fixed definitively after the suitability test.

Table 1. Injection parameters chosen for suitability test

Injection Parameters	Carrying out compartments	Filling compartments
Type of injector	Drilled injectors	Drilled injectors
Spacing between injectors (m)	0.80	1.0
Maximum injection pressure (bar)	3	3
Minimum resin viscosity (mPa.s)	3	3
Target curing-time (min)	0.50	80

3.4 Preliminary tests

Some tests were performed beforehand in order to verify the chemical compatibility between the resins and the GLS, the effect of the injection process on the GLS integrity and the perforation method for injectors installation. The aim and conclusions of these tests are presented hereafter.

3.4.1 Compatibility between aqua-reactive resins

Resins samples were cast into identical molds in order to measure their interface mechanical resistance. The test was performed by tensile test, once the resins had solidified. The tests showed no rupture at the interface. The samples broke in a cohesive way for Resin α, which corresponds to the resin showing the lowest tear strength. Thus, the compatibility between those two resins is considered as compliant to the expected behavior at the interface.

3.4.2 Compatibility between aqua-reactive resins and the geomembrane

When the resins will be in contact with the geomembrane, they have to show a chemical inertia. In the case of a PVC-P geomembrane, it means that the plasticizers shall not diffuse into the resins due to chemical affinity or solubilization during the service life of the geomembrane that can reach 50 to 100 years.

In order to demonstrate the chemical compatibility of these materials, a test was performed. Samples of PVC-P geomembranes were exposed to Resin β during 5 weeks at 20°C (+/-2°C). Two types of PVC-P were tested: not bitumen compatible (NBC) and bitumen compatible (BC), which are commonly present on the market for this application. Five test specimens per geomembrane were embedded into the resin in separated containers. Once the resin solidification was obtained, the containers were filled by water. After five weeks of exposure, the resins were removed and the specimens tested by tensile tests according to ISO 527-2.

The results are presented in the following Table 2.

Table 2. Mechanical properties of aged and unaged PVC-P geomembrane samples.

Geomembrane	Tensile strength before ageing (N/mm²)	Tensile strength after ageing (N/mm²)
PVC-P BC	10.41	10.66
PVC-P NBC	9.85	9.85

The evolution of elongation at break was unchanged for both types of geomembrane. This test shows no loss of mechanical performance after exposure to the resins.

These tests are considered as preliminary tests. Long-term tests are on-going and will give more detailed information on the chemical interaction between these geomembranes and the aqua-reactive resins. The measure of plasticizer loss is one of the parameters that will be followed during these tests.

3.4.3 Determination of perforation method

The perforation method has to be determined in order to avoid damage to the geomembrane during injector installation. Firstly, concrete reinforcing bars have to be detected with non-destructive detection system consisting of a scanner employing the induction principle. The scanner locates rebars accurately and reliably within concrete structures. Secondly, coring is carried out thanks to a drilling machine equipped with 20 mm diameter drill allowing it to stop the perforation at the predefined depth. This parameter is fixed at 50 mm short of the concrete wall width. Then a slight beating is applied on a punch to produce a crack inside the 50 mm remaining concrete.

This method confirms the possibility to install injectors without damage on geomembrane for the future works.

3.4.4 Effect of injection pressure on the geomembrane integrity

The aim of this test is to assess the maximum injection pressure that the geomembrane can bear during the injection works without mechanical damage. It will allow the demonstration that the deformation of the geomembrane will not lead to a loss of mechanical performance after the works.

In a cylindrical container (diameter: 400 mm; height: 700 mm), a bloc of compressible material (expanded polystyrene) is first placed. Then, the geomembrane is fixed by welding between the container and its lid. Water pressure is applied at the top and the distance between the geomembrane and the compressible material allows the geomembrane deformation during the test. Water pressure is increased by steps of 0.5 bar during 5 minutes.

Three tests were performed on the geomembrane and the average value of the pressure leading to the rupture of the geomembrane was measured to be 4.25 bars minimum.

This test confirms the use of an injection pressure of 3 bars during the suitability test on mockup which will avoid bursting of the geomembrane.

4. TESTS AND RESULTS

4.1 Mockup dimensions and controls

The mockup is designed to include 2 compartments, each 6 meters long. The mockup itself was 14 meters long and about 3.5 meters high. Three injectors per injection profile were placed with a spacing of 0.8 meters. Another injection profile was placed at a distance of 1 meter from the first one. Thus, two distances of injectors could be tested during this suitability test (see Figure 1).

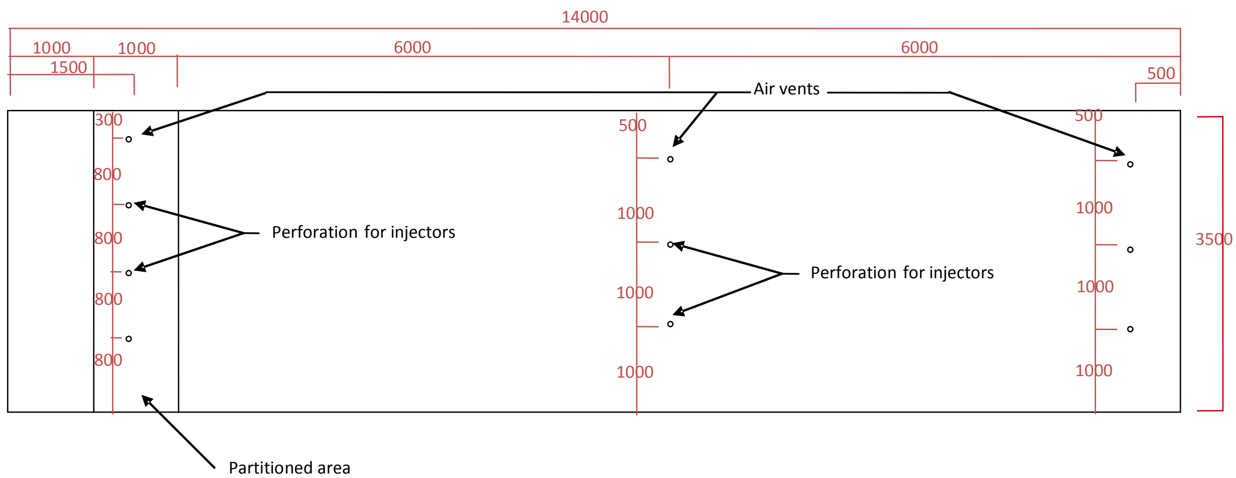

Figure 1. Mockup drawing with dimensions (in mm) and position of injectors

The walls were made of transparent poly(methyl methacrylate) (PMMA) walls (20 mm thick each) in order to observe the movement of the injected resins during the test. Once the mockup was built, the space between the PMMA wall and the GLS was partly filled by water in order to be closer to real cases (see Figure 2).

Figure 2. Mockup during the injection tests (left) and position of injectors on an injection profile (right)

During the injection, the following parameters were controlled:

- Curing-time of the resins before injection,
- Control of pressure during the injections,
- Displacement mode of the resin during the injection (linear or radial),
- The continuity at the interface of Resin α and Resin β, and
- The rate of displacement of both resins.

All these controls will allow the confirmation of the repair method or the identification of improvement areas for future works.

In parallel with the mockup test, some samples were prepared into separated containers in order to verify, in the conditions of the suitability tests: Resin α and Resin β interface resistance, and the effect of PVC-P (NCB) in contact with both resins. These prepared samples will be tested and the results analyzed in a future testing program.

4.2 Injection of compartments – Resin α

Before injection, 4 mixtures of Resin α were prepared by varying the following parameters: B2 (catalyst) amount and B1 (water) temperature, components A1 and A2 remaining unchanged respectively equal to 20.0 kg and 0.5 kg. Potlife (time to reach a mixing viscosity of 100 mPa.s according to the supplier) was measured for each mixture. Results are described on the following Table 3.

Table 3. Potlife of Resin α measured for 4 mixtures prepared.

Mixture number	Formulation	Potlife (sec)
1	M_{B1} = 17.0 kg / T_{B1} = 23/24°C M_{B2} = 1.0 kg	10 to 15
2	M_{B1} = 17.0 kg / T_{B1} = 14°C M_{B2} = 1.0 kg	20
3	M_{B1} = 17.0 kg / T_{B1} = 23/24°C M_{B2} = 0.8 kg	24
4	M_{B1} = 17.0 kg / T_{B1} = 23/24°C M_{B2} = 0.5 kg	30

The mixture number 4 was selected to perform injection on the mockup.

Taking into account the low curing-time of Resin α, the applied injection method was different from the one usually chosen for injection works. Indeed, the usual injection method starts at the lowest point of injection until resurgence appears at the next one. Then, injection in the first injection point is closed and the next one is injected. This operation is repeated until the last injection point. This usual method allows us to be sure that all cracks, voids and interstices in concrete are filled with resin. In our case, resurgences are not desired due to the risk of blocking second injector by cross-linked resin.

On the mockup, injection was started at the lowest injection point. From the beginning of injection, a radial displacement of Resin α was observed as expected. The radial displacement reached a radius from 0.40 m to 0.60 m after 4 liters of injected resin (see Figure 3). At this time, injection was stopped on the first point in order to be pursued on the second one where the resin behavior was the same. Injection of about 3-4 liters with a pressure of 1.5 bars allowed a contact between cross-linked resin injected from the first injection point and resin injected from the second one (see Figure 4). After a short time, the interface between both injection points was no longer visible. This suggests that a homogeneous contact occurs at the interface of both points of injection, even if the first one is already cross-linked.

Figure 3. Radial displacement during injection of Resin α from the lowest point of injection

Figure 4. Radial displacement during injection of Resin α from the second point of injection and contact with the first injection

Injection was performed until the last injection point. Then the second column of resin was created. Thus, a compartment of 6 meters long was obtained.

4.3 Filling the compartments – Resin β

There were no specific problems during the preparation of Resin β. The curing-time was as expected. During the injection, the displacement of resin profile was as expected, but due to the injection pressure, the mockup leaked. This was due to the PMMA walls unclamping under the applied pressure. Thus, it was not possible to observe the complete filling of the compartments.

4.4 Mockup dismantling

Once the injections were completed, the mockup was dismantled in order to observe the injections profile and GLS impregnation.

It was observed that the injection profile was radial and homogeneous (see Figure 5). The interface between two injection spots was good and it does not show any defects or untreated areas.

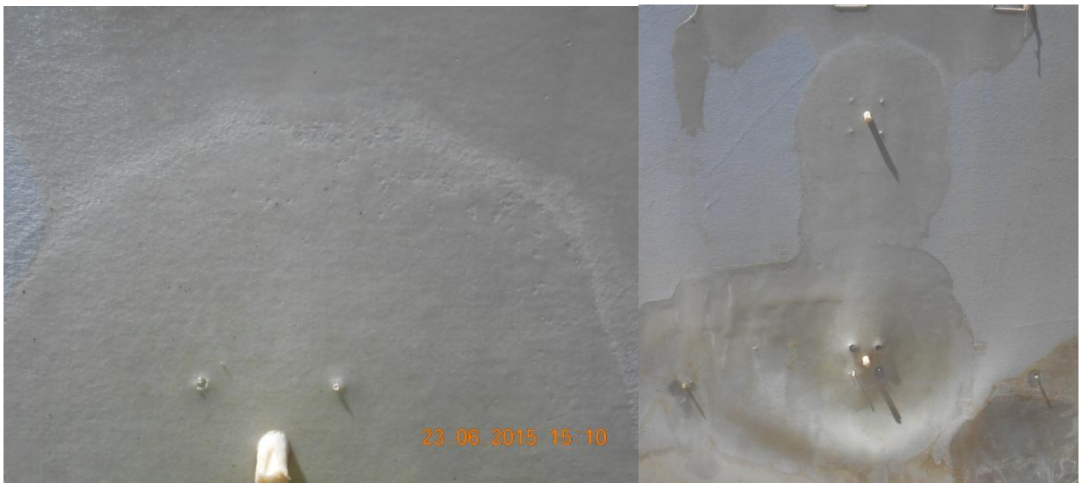

Figure 5. Injection profile around the injector (left) and interface between two injection spots (right)

The impregnation of the non-woven geotextile was considered satisfying as the impregnation looked complete but some tests will be performed in order to make sure that it is effectively the case.

No problems due to preparation of the resins or to the injection itself were detected. The main problem was the resistance of the mockup to the applied pressure. This problem will be solved during works because this type of problem cannot occur when the walls are made of thick reinforced concrete, as used for civil engineering structures.

5. CONCLUSIONS

This suitability test shows through the construction of a representative mockup that the proposed repairing method is technically possible onsite during repair works. The observed leakage was due to the mockup design under pressure and to the displacement of the PMMA walls. This movement could not occur between a concrete wall and a GLS on a Civil Engineering building where the resistance to pressure is much higher.

The compartments were created as expected, forming homogeneous columns and partitioned areas that could be filled by an aqua-reactive resin, as would be the case for a pre-partitioned geomembrane. The complete filling of compartments was not validated, but it was not the main concern of this suitability test because it is a work that is usually performed on partitioned geomembranes. Nevertheless, it is necessary to control the injection pressure to avoid the rupture or damage of the compartmentalization screens.

From this suitability test, we can consider that the repair method is technically possible onsite if a representative mockup is built for each work in order to fix the injection parameters and mixtures/curing-time of resins.

The results of additional ongoing tests, performed in the context of this mockup, will confirm the durability of the proposed solution.

REFERENCES

BRE Special Digest. Concrete in aggressive ground, *Building Research Establishment*, 2005, UK.

CFG Fascicule n°10. Recommandations générales pour la réalisation d'étanchéités par géomembranes, *Comité Français des Géosynthétiques*, 1991, FRANCE.

J.L. MAHUET, Design of protection barriers to geomembrane waterproofing systems, *AFTES – Tunnels et Ouvrages Souterrains*, 2005, FRANCE.

J.L MAHUET, Recommendations on waterproofing treatments in underground structures, *AFTES – Tunnels ou Ouvrages Souterrains*, 2006, FRANCE.

ISO 527-2. Plastics : Determination of tensile properties – Part 2: Test conditions for moulding and extrusion plastics. *International Organization for Standardization*, 2012.