

Lessons Learned From Leakage Through a Subgrade Slab

Geotextile/Bentonite/Geotextile Composite Waterproofing Membrane

By Dr. Ian D. Peggs

ABSTRACT

To protect a basement from high groundwater flooding during spring snowmelt runoff, a geotextile/bentonite/geotextile composite waterproofing liner (membrane) was installed on drainage rock prior to pouring footers, stem walls, and floor slab. Nevertheless, leakage occurred between slab and stem wall. Bentonite rope and grout sealant were placed in the gap, but leakage still occurred. Polyurethane grout was injected between footer and slab and between slab and stem wall, but leakage persisted. A core was removed from the edge of the slab. Multiple layers of membrane were found, and the side of the footer was bulbous and extremely rough. The membrane was not bonded to it. The loose membrane was not uniformly confined between footer side and drainage rock as required in order to mobilize the bentonite's low hydraulic conductivity. The membrane was also punctured. The failure investigation is described.

A bentonite composite membrane must be uniformly confined between two surfaces with an adequate pressure to generate its barrier performance characteristics. When a drainage layer is also required, it must be

done in such a way so as not to compromise the barrier performance.

BACKGROUND

To eliminate the potential for water infiltration into a basement at high groundwater levels (during spring snowmelt runoff), a geotextile/bentonite/geotextile composite membrane was installed underneath the basement floor slab, under the footings, and up the exterior of the stem walls. The membrane was placed on <1-inch drain rock.

Despite this precaution, leakage between the floor slab and stem walls occurred in the first spring. Repairs were made by removing fiberboard expansion joint strip and replacing it with bentonite rope and grout sealant. There was more leakage in spring two years later.

This time, repairs were made by attempting to inject polyurethane grout through many angled holes at the edge of the floor slab into any space between the bottom of the floor slab and the top of the

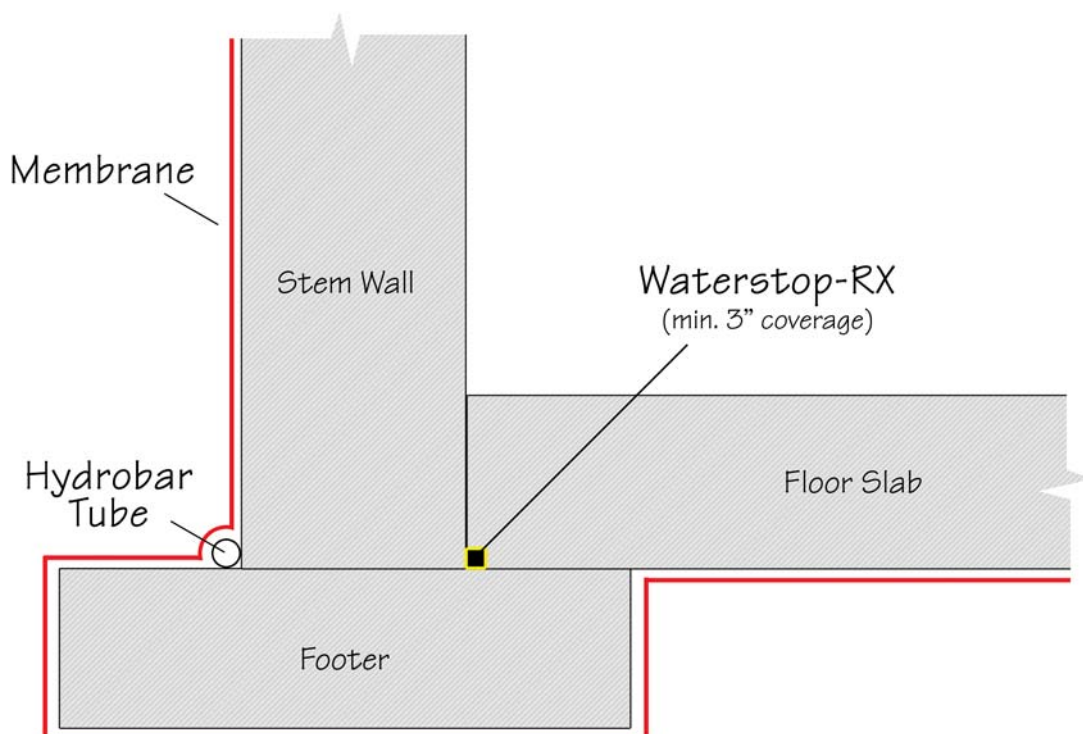


Figure 1 – Recommended cross section with hydrostatic head (CETCO).

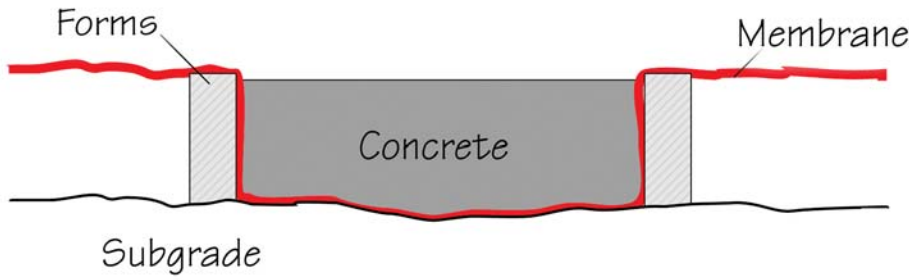


Figure 2 – Cross section of footing forms and membrane (red).

footing, and between the edge of the floor slab and the stem wall. Despite these attempted repairs, leaks continued.

MEMBRANE

The membrane is a well-established, bentonite-based containment product. It is one of a family of liners called geosynthetic clay liners (GCL). The same product is used extensively in municipal solid waste landfills and in leachate pond-lining systems.

The bentonite powder is contained between two geotextiles (one a woven and the other a nonwoven), needle-punched together to provide containment of the bentonite, placing some restrictions on lateral displacement of the material and increasing internal shear strength. The free ends of the needle-punched fibers penetrating the thickness of the liner on the woven geotextile side provide anchorage to curing concrete.

When it is hydrated and unconfined, bentonite swells to many times its dry volume. If it is prevented from swelling by uniform confining pressure, its internal layered platelet microstructure causes it to become effectively impermeable to water. However, the confining pressure must be adequate, and it must be uniform.

Figure 1 shows a membrane manufacturer's recommended slab-on-footing cross section for placement of the membrane when there is

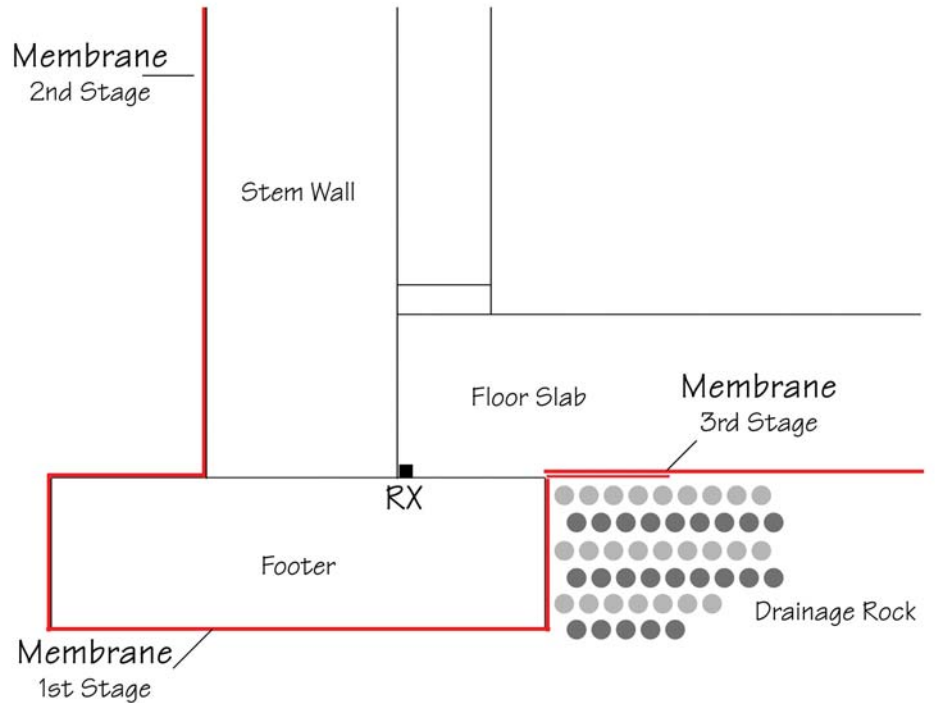


Figure 3 – Schematic of membrane location.



Figure 4 – Locations of core (C) and grout injection holes (at arrows).

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Figure 5 – Membrane layers on underside of core. Section on footing to left of dotted line.

a high hydrostatic pressure on the liner. The membrane is under the slab, down the inside edge of the footing, under the footing, up the outside edge of the footing, over the outside top of the footing, then up the outside stem wall. The membrane is bonded to and in intimate contact with the concrete at all locations. Clearly, this cannot be done with one piece of material; joints are necessary, most notably at the inside edge of the

footing and at the underside of the slab.

In Figure 1, it should be noted that there is no expansion joint filler between the edge of the slab and the wall. More important, there is a waterstop at the triple point between slab, footing, and stem wall that prevents water from the outside and under the slab from rising between the stem wall and the edge of the floor slab. In the actual basement installation, the waterstop was

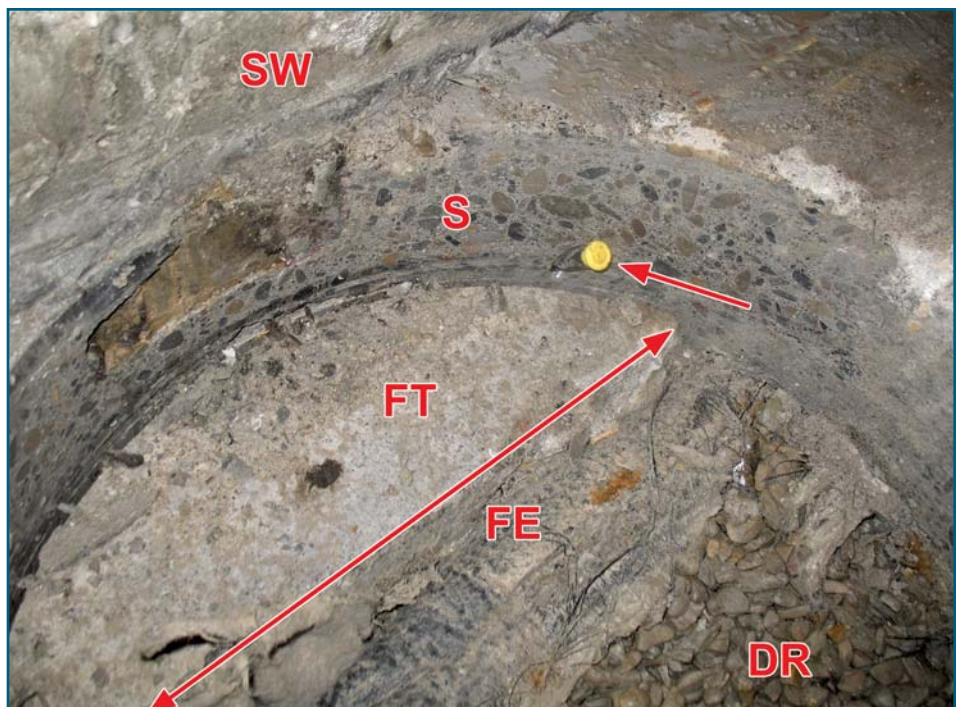


Figure 6 – Screwdriver (yellow top) in grout injection hole (arrowed). SW – stem wall; S – floor slab; FT – footing top; FE – footing edge; DR – drain rock.

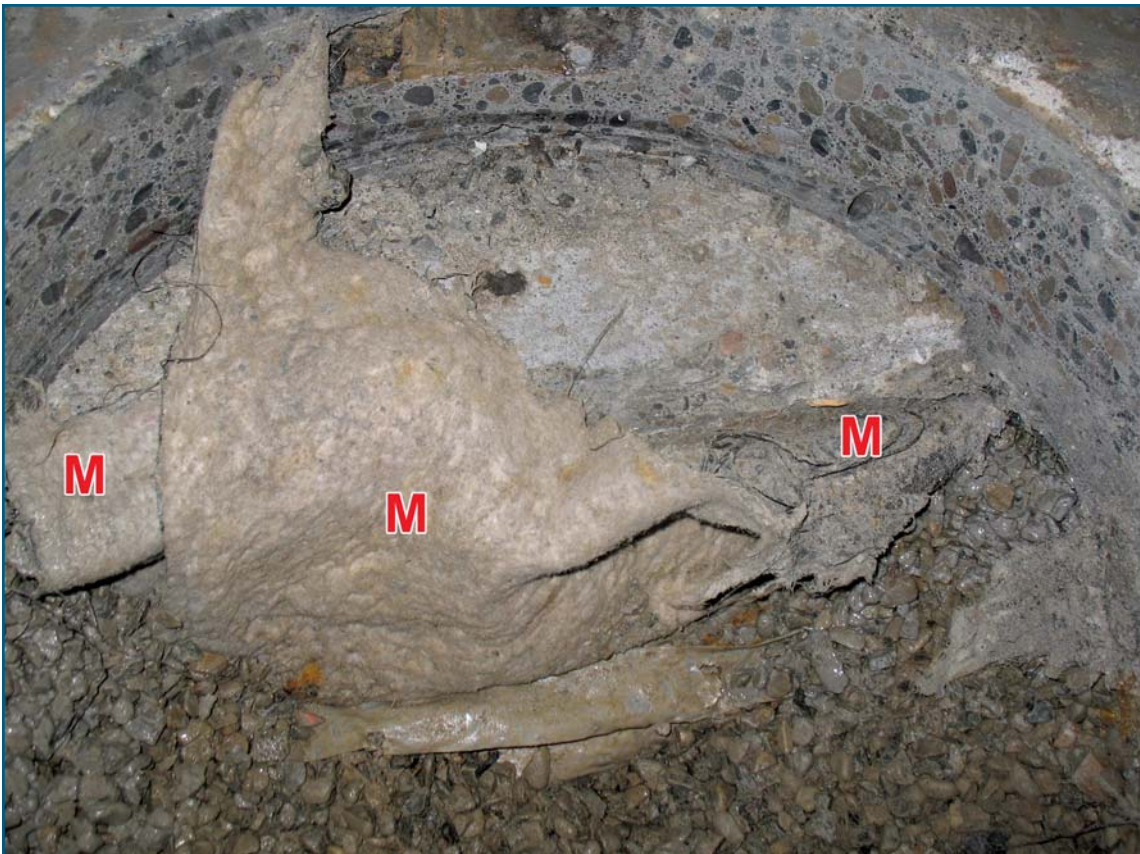


Figure 7 – Three layers of membrane (M) up the side of the footing.

incorrectly placed between the center of the stem wall and footing, and there was a fiber-board expansion joint filler in the upper half of the edge of the floor slab. Thus, there was nothing to stop potential upwards water infiltration from under the slab and then between slab and stem wall. The expansion joint filler is not intended to function as a waterstop.

Typically, as shown in Figure 2, the forms are placed for the footing, and the membrane is placed inside the forms on subgrade and up the sides. There should be free flaps outside of the footing forms to overlap with the yet-to-be-placed membrane under the slab. Then, when the concrete is

poured, it bonds intimately with the membrane on the underside and both sides of the footing. Thus, the membrane under the footing is well confined between concrete and subgrade.

When the footing forms are removed, the slab subgrade drain rock can be placed and compacted, thus applying a confining pressure on the membrane bonded to the sides of the footing. The membrane flap outside the footer is folded over on top of the periphery of the slab subgrade. The under-slab membrane is placed on the subgrade and is overlapped on the peripheral flap to make a seal, as shown in Figure 3. The floor slab is poured, and the membrane is confined between the subgrade and the concrete slab, as is the joint at the periphery. Subsequently, when the rising groundwater contacts the membrane, the membrane hydrates but cannot expand, so it becomes impermeable.

The slab subgrade drainage rock was simply specified to be <0.75 in but was actually <1.0 in. There were many low-radius corners and fractured edges in the drainage rock; and, of course, the void space is necessary for it to act as a drain. However, when used as a primary barrier system in landfills, the subgrade for the GCL is required to have no particle size



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larger than 0.75 in, and at least 80% fines passing a #60 sieve (0.010 in). The danger is that the individual stones will penetrate the membrane and laterally displace the bentonite, providing puncturing points where there is no bentonite and therefore causing a potential for leakage. This is not a major problem where the membrane is intimately bonded to the concrete, since there is (or should be) no interface void space along which the "leaking" water can laterally disperse to a crack or some other penetrating flaw in the concrete. However, if there are locations where the membrane is not bonded or held intimately in contact with the concrete, this could be a problem.

SITE INVESTIGATION

A 24-in diameter core was removed from the floor slab as close to the stem wall as possible where studs had been removed (Figure 4) from the outside wall. The core included a hole drilled for grout injection during the second repair.

When the core was removed, there were a few layers of membrane with various degrees of bonding attached to them (Figure 5). In the hole, the "smooth" top surface of the footing was obvious, but there was no evidence of repair grout on the top of the footing nor on the underside of the core above the footing, despite the fact that the injector hole went beyond the interface and into the footing (Figure 6). This hole was not filled with grout as it would have been had injection been successful.

There were several layers of membrane emerging from the vertical interface between gravel and footing (Figure 7). A rebar dowel between slab and stem wall had been cut. The rebar dowel was incorporated to help ensure the floor slab would not rise independently of the footing due to hydrostatic pressure.

The gravel was removed, the membrane layers separated, and the side of the footing exposed. Figure 8 shows the smooth side of the footing; but below it, there was a large, rough mass of concrete bulging out under the floor slab. There was no membrane bonded to the side of the footing nor to this rough, bulging mass. There was an overhang/channel (Figure 9) between the bottom of the smooth part of the footing and the bulging mass that would preclude the application of a uniform confining pressure on the membrane at that location. The channel would also allow passage and dispersal of leaked water behind the membrane.



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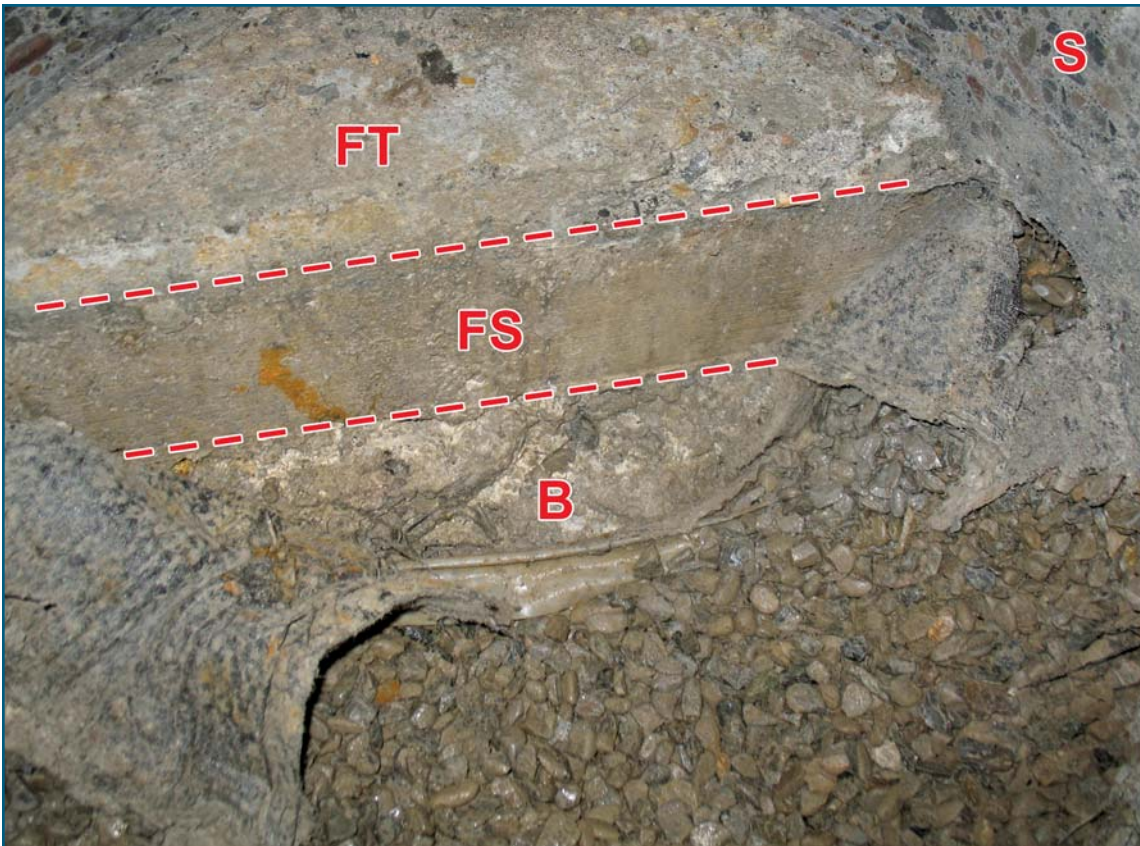


Figure 8 – Smooth side of footing (FS) with bulging concrete (B) below. Footing top – (FT); Slab – (S).

Attempts to sort out the layers of membrane revealed three or four layers. During separation of the membrane layers, there was one location where it was possible to put two fingers through a hole/gap from drain rock side to footing side (Figure 10). There had been a lump in the concrete bulge penetrating the liner at this location. This would have been a significant leak. It was also possible to reach well down the bulging concrete between concrete and membrane and to feel significant cavities in the concrete surface, even with the gravel in place. Thus, there had been inadequate and uneven confining pressure at these locations.

DISCUSSION

What appears to have happened is that the membrane was laid for the footing and the forms were placed not immediately on top of but above the membrane, as shown in Figure 11. The membrane was not placed up the inside of the footing forms but left on the subgrade outside the forms. The concrete was poured into the forms, but much of it slumped underneath and spread outside the forms to generate the large bulge. Thus, the membrane was not bonded to the sides of the footings.

When the forms were removed, there was insufficient excess membrane to wrap around the outside of the bulge under the slumped footing, then up the smooth side of the footing to leave a flap for the joint with the edge of the floor slab membrane. Therefore, several pieces of membrane were used to fill in the gap. None of this infilling membrane was bonded to the concrete. The surface of the bulge was extremely rough and could not possibly impose a uniform confining pressure on the liner. The proud sections of the concrete bulge penetrated the membrane, and the membrane bridged the cavities. Together with the drainage gravel, holes were punched in the membrane or separated the multiple overlaps.

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Figure 9 – Channel-like cavity in footing between smooth side (above dotted line) and bulge.

adjacent to the footing may also have separated the membrane overlaps via shearing actions on the material not bonded to the concrete. Rock may also have been forced between the overlaps where they were not nailed to the concrete. The membrane leaked. The leaking water worked its way upwards through the cavities in the footing/membrane interface and from there up

to the top of the footing. Since there was no waterstop at the triple point and since the grout repair had not filled the footer/slab and stem wall /slab gaps, leakage continued up the stem wall/slab interface to emerge into the basement at those locations where the initial bentonite rope and grout repair was not effective.

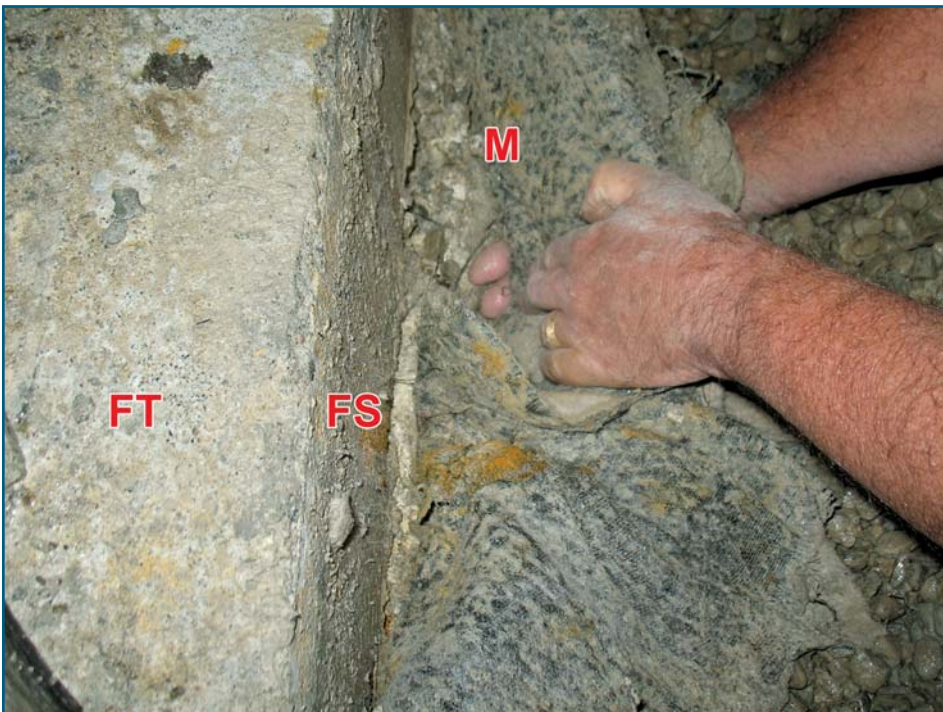


Figure 10 – Large hole through membrane layer (M). Footing side – (FS); Footing top – (FT).



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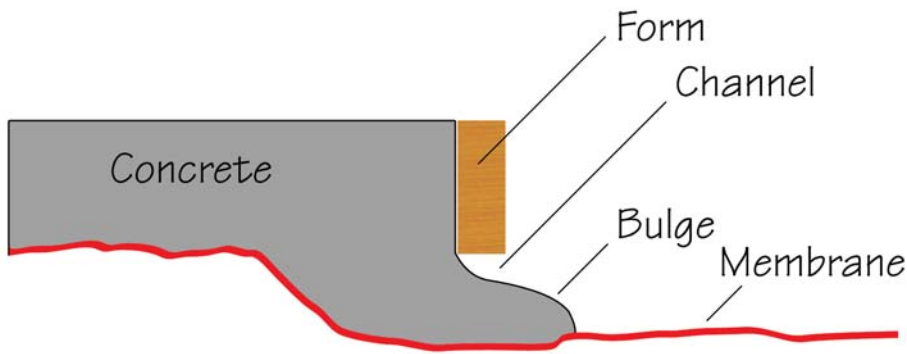


Figure 11 – Cross section of poured footing on basement side.

CAUSE OF LEAKAGE

There were four major construction errors that contributed to the leakage:


1. The membrane was not placed fully inside the footing forms, so it did not bond to the inside edge of the footing.
2. The footing forms were built too high such that concrete slumped outwards underneath them, eliminating or minimizing the free flap for the overlap with the slab membrane.
3. The membrane was placed in an unsatisfactory way (several pieces) and on an unsatisfactory footing surface that caused the membrane to be penetrated and not have adequate uniform confining pressure to be sufficiently impermeable.
4. The waterstop was placed between

stem wall and footing and not in the triple point between footing, stem wall, and floor slab.

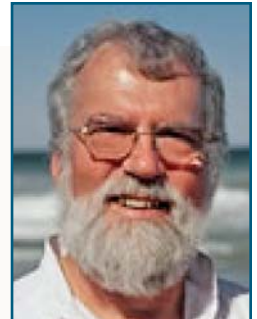
When properly placed on smooth, uniformly firm surfaces, with adequate overlaps and adequate uniform confining pressures, and when fully bonded to concrete, the family of GCLs will generate more than adequate resistance to the passage of water.

CONCLUSIONS

A GCL waterproofing membrane must be uniformly confined at adequate pressure between two surfaces in order to mobilize a sufficiently low hydraulic conductivity to act as a water barrier.

When drainage systems are required in association with the GCL, they must be designed and installed so as not to compromise the barrier performance of the GCL. 

Dr. Ian D. Peggs



Dr. Ian D. Peggs, a materials science engineer, has been involved with the performance of engineering plastics and geosynthetics for 30 years. He founded the Geosyntech testing laboratory in Edmonton in 1982 and then the GeoSyntec testing laboratory, with Joe Fluet and Dr. J.P. Giroud, in 1986. He started I-CORP International in 1991. In 1996, he received a special IGS Award for his work on the influence of microstructure on the performance of HDPE geomembranes. In 1998, Peggs initiated the www.geosynthetica.net technical resource Web site. I-CORP presently has clients in over 30 countries. Dr. Peggs's special interests are quality assurance, nondestructive testing, liner leak location, weld evaluation, solar energy from geosynthetics, nanotechnology in geosynthetics, failure/forensic analysis, and expert witness work.

TOP 10 GREEN CITIES

Even in a tough economy, green roofing grew by 16% in North America in 2009, according to Green Roofs for Healthy Cities (GRHC). An estimated 10 million sq ft were added last year, the organization claims. The top ten "green cities" for 2009 were: Chicago, IL; Washington, DC; Minneapolis, MN; Baltimore, MD; Newtown Square, PA; New York, NY; Redmond, WA; Montreal, PQ; Quebec City, PQ; and Milwaukee, WI.

