

The 2023 Koerner Lecture

**FROM ZERO LEAK
AT END OF GEOMEMBRANE INSTALLATION
TO ZERO LEAKAGE
IN SERVICE**

By
J.P. GIROUD

Originally presented on 2023 February 07
Presented on 2023 May 18 as FGI webinar

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INTRODUCTION TO THE FGI WEBINAR

In February 2023, I presented the Koerner Lecture, a special lecture established to honor the late Robert M. Koerner.

Today, I present a short version of the lecture, which is almost one-hour long.

Therefore, there will be no time for discussion.

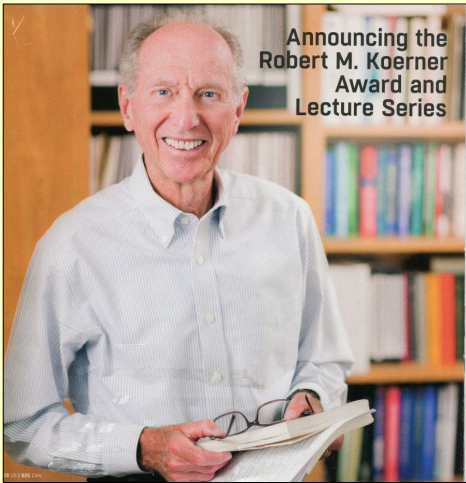
However, I will answer your questions in a podcast, which should be available shortly.

Also, the discussion of the original lecture in February will be published in *Geosynthetics*.

And, now, the lecture.

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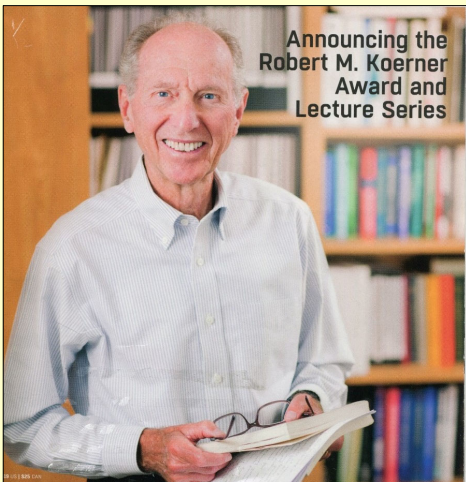


Announcing the
Robert M. Koerner
Award and
Lecture Series

First, thank you Bob
for your immense contribution to our discipline.

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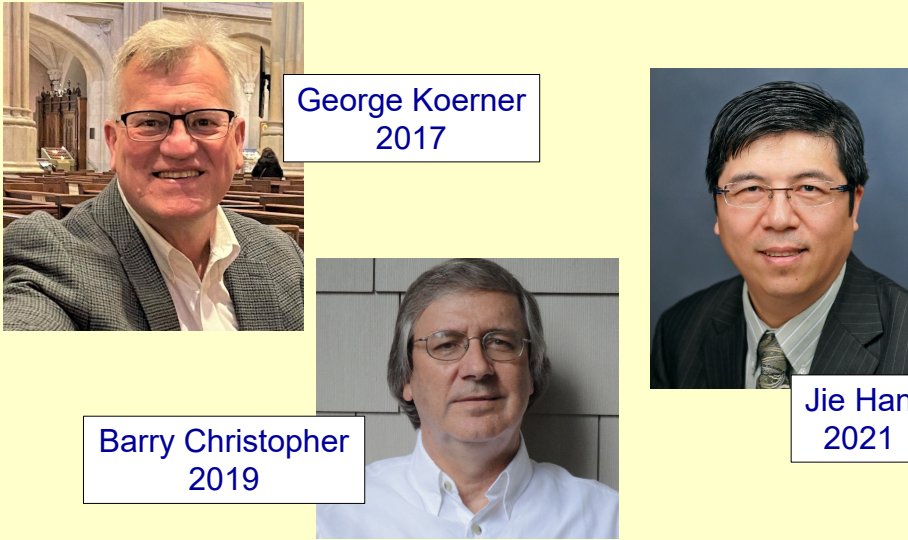
Announcing the
Robert M. Koerner
Award and
Lecture Series

I am very honored to be a Koerner Lecturer.

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From zero leak at end of geomembrane
installation to zero leakage in service



George Koerner
2017

Barry Christopher
2019

Jie Han
2021

And I am very pleased to be in good company
with former Koerner Lecturers.

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FROM ZERO LEAK
AT END OF GEOMEMBRANE INSTALLATION
TO ZERO LEAKAGE
IN SERVICE

In the past five decades,
the use of **geomembranes**,
and other geosynthetics,
has been
very beneficial to the environment,
in particular in **landfills**.

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From zero leak at end of geomembrane
installation to zero leakage in service

**FROM ZERO LEAK
AT END OF GEOMEMBRANE INSTALLATION
TO ZERO LEAKAGE
IN SERVICE**

Geomembranes are also used successfully for **liquid containment**, which is **more challenging** than waste containment *from the viewpoint of leakage*, in particular because of **higher liquid pressure**.

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Examples of **liquid containment reservoirs** will be used to address the subject of the lecture:

**FROM ZERO LEAK
AT END OF GEOMEMBRANE INSTALLATION
TO ZERO LEAKAGE
IN SERVICE**

First, the role of **design engineers**.

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Design engineers should understand that **electrical leak location is essential** to ensure that the containment facility they design **will perform** as intended.

Design engineers should cooperate with electrical leak location providers to ensure that the **designed liner configuration** is such that electrical leak location can be **successfully implemented**.

Also, **design engineers** should write leakage **specifications that can be met**.

Zero leakage is a legitimate target.
However, “**zero**” is **impossible to measure**.

Since zero leakage cannot be measured,
it is **pointless to specify zero leakage**.

Therefore, a rationally established,
acceptable leakage rate should be specified.

But, even if the specified *acceptable leakage rate*
is **reasonable**, this **is not sufficient**
if design and installation are inadequate.

This is illustrated by the following case history.

CASE HISTORY OF PONDING TEST

This case history is from my dear friend Ian Peggs who has done so much for the quality of installed geomembranes.



For a water reservoir, a maximum water surface drop of **6 mm in 14 days** was specified.

This is close to an **acceptable leakage rate** of 5000 liters/ha/day, which is typical for reservoirs. Therefore, it was a **reasonable specification**.

CASE HISTORY OF PONDING TEST

Compared to the specified **6 mm** in 14 days, here are **ponding test results**:

- After liner installation: **66 mm.**
 - **First** sequence of reservoir emptying, visual inspection, repair of holes: **22 mm.**
 - **Second** sequence: **112 mm.**
 - **Third** sequence: **23 mm.**
 - **Fourth** sequence: **130 mm.**
- All were above the specified 6 mm.

The leakage increased despite repairs !

From zero leak at end of geomembrane installation to zero leakage in service

CASE HISTORY OF PONDING TEST

The leakage increased for at least two reasons:

- **Damage** to the geomembrane by the team performing **inspections** and **repairs**; and
- **Stresses** induced in the geomembrane by *repeated displacements* of the geomembrane due to **cycles of emptying and filling** the reservoir to perform **inspections** and **repairs**.

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CASE HISTORY OF PONDING TEST

Many holes were found at the *geomembrane attachments* to **appurtenant structures** having a **complex geometry**.

Finally, a **new geomembrane liner** was installed by a **new installer**.

And the specified leakage rate was met at the **first ponding test**.

A good installer made a difference !

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Here are the lessons learned from this case history:

- Visual inspection **does not find** all holes.
- Activities of **workers** can damage the geomembrane.
- Appurtenances must be designed with a **geometry** that facilitate attachment of geomembranes.
- If a reservoir is subjected to **frequent drawdowns**, the liner should be designed accordingly.
- Frequent reservoir **drawdowns**, that are not necessary for operations, **should be avoided**.

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The foregoing discussion
showed the **importance of design**.

The following slides will illustrate
the **importance of design**
using case histories
of **geomembrane failures**,
which **generated leakage**.

In all cases, the **main cause of failure**
was a **design error**.

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From zero leak at end of geomembrane
installation to zero leakage in service

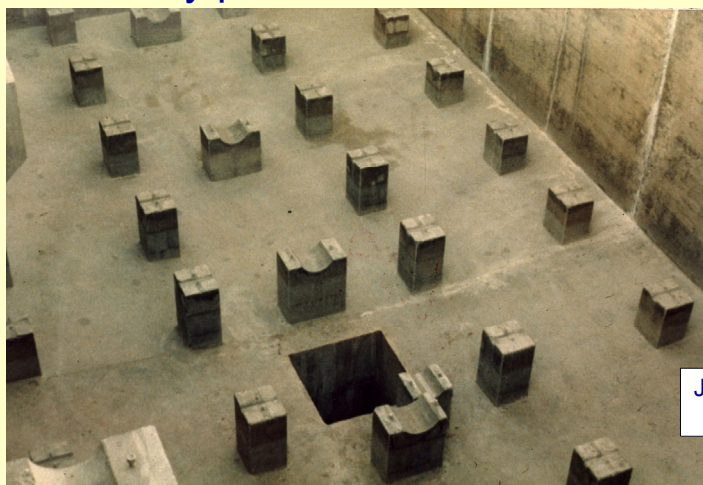
The next **CASE HISTORY** shows that

**THE DESIGN OF A CONTAINMENT FACILITY
SHOULD BE SUCH THAT
A GEOMEMBRANE LINER CAN BE INSTALLED
WITHOUT EXCESSIVE DIFFICULTY.**

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How is it possible to install a geomembrane
in this concrete reservoir
with so many pedestals ?



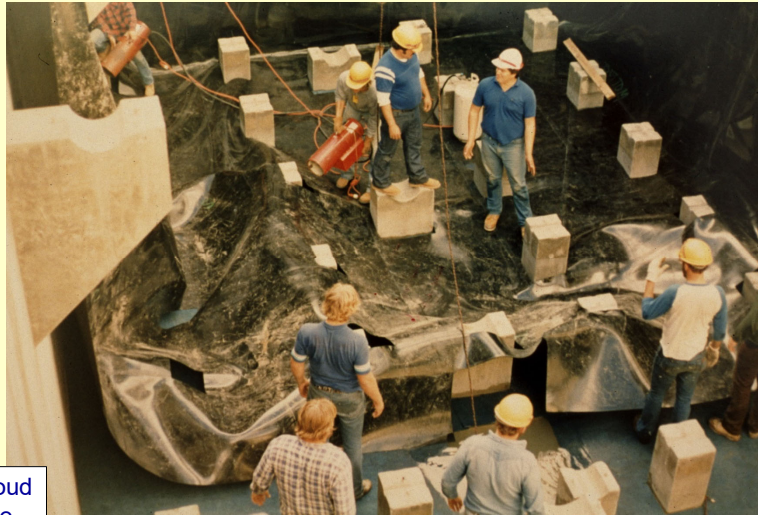
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installation to zero leakage in service

The answer is: with great difficulty.



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And the installed geomembrane . . .



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. . . had **more than 100 holes.**

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installation to zero leakage in service

The following comments can be made on this case history :

- The configuration of the reservoir was such that it was **inevitable to have many holes** in the geomembrane.
- Clearly, the cause of the holes was the **inadequate design**.

This case was from the 1980s in North America, but the problem still exists, as shown in the next slide.

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Here is an example, also in North America, but in 2022.

An acrobatic performance was needed to install the geomembrane.



Photo courtesy of R.S. Thiel

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Excessive leakage occurred in this reservoir and **extensive rework** was necessary.



Photo courtesy of R.S. Thiel

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Thanks to the rework, the leakage was significantly reduced, but not reduced to zero, even though the installer was excellent and an expert field engineer was present.



Photo courtesy of R.S. Thiel

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From zero leak at end of geomembrane installation to zero leakage in service

Clearly,
we saw examples of **designs**
that make it **impossible**,
even for the best installers,
to achieve the goal of
zero leak at end of installation.

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The next **CASE HISTORY** shows that

**BOTH
DESIGN DETAILS
AND
CONCEPTUAL DESIGN
ARE IMPORTANT.**

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installation to zero leakage in service

CASE HISTORY

- A water reservoir was constructed on a **thin layer** of natural soil overlying a **karstic formation** (*which is limestone with cavities*).
- The reservoir was close to an **abandoned quarry**, which provided an opportunity to **see the karstic formation**.

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Here is the quarry showing a cross section of the karstic formation.



Photo
J.P. Giroud

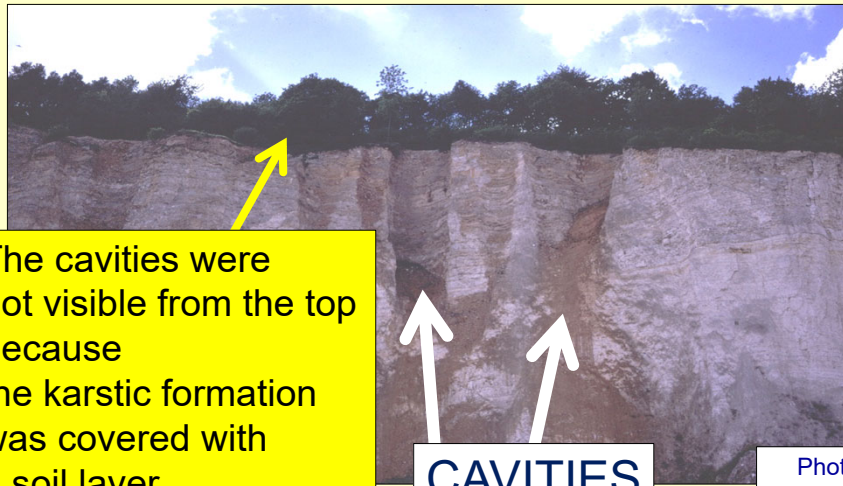
Numerous cavities could be observed.

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The reservoir was located on the top, behind the trees, not far from the quarry.



The cavities were not visible from the top because the karstic formation was covered with a soil layer.

CAVITIES

Photo
J.P. Giroud

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The quarry was observed only when the failure of the reservoir was investigated.

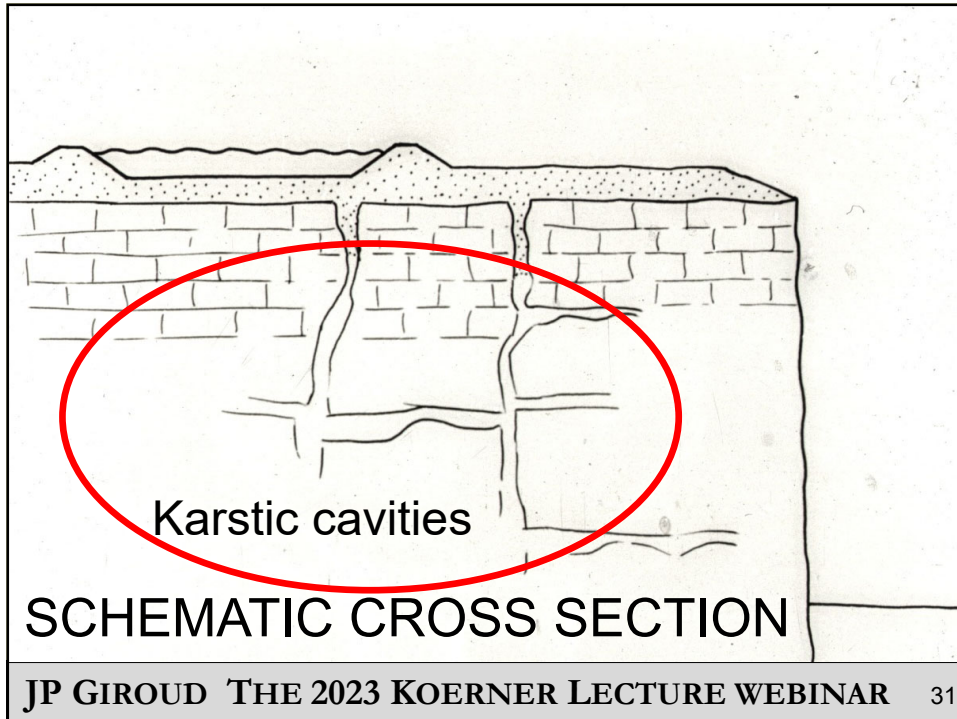
At the design stage, there was **no geological study** and the quarry was not observed.

Since the soil layer was hiding the cavities, the designer of the reservoir *ignored the situation* shown on the **following cross section.**

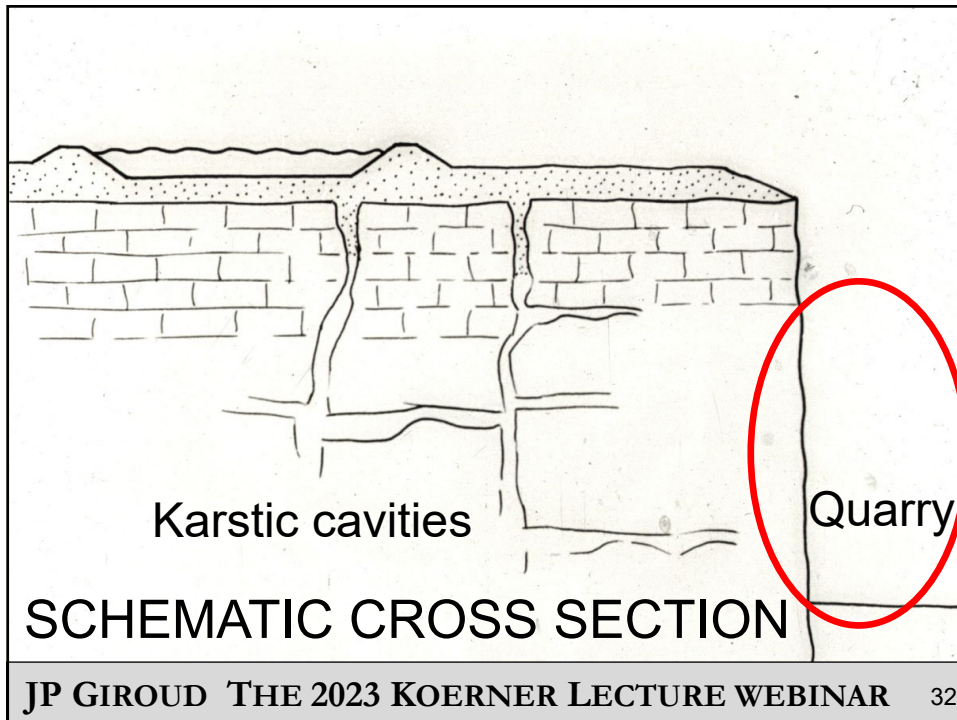
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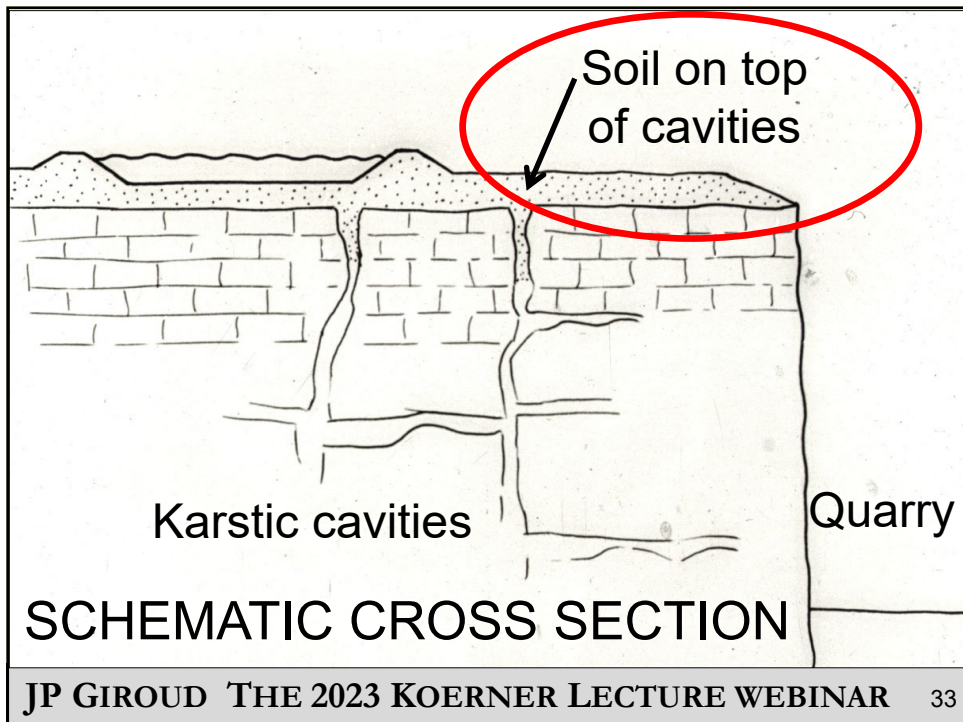


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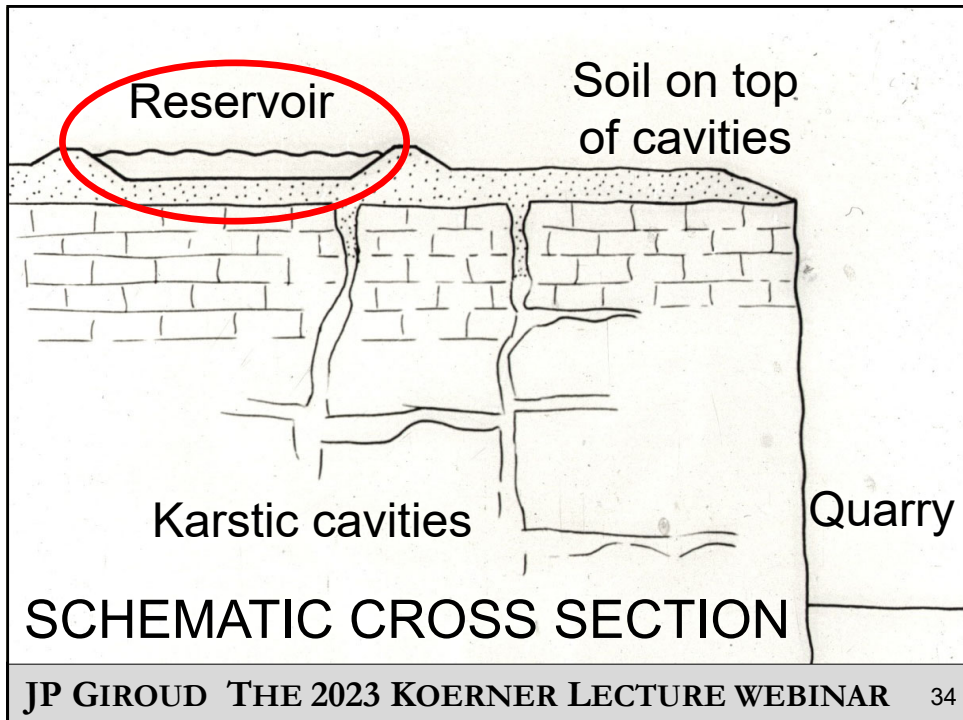


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installation to zero leakage in service



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From zero leak at end of geomembrane
installation to zero leakage in service

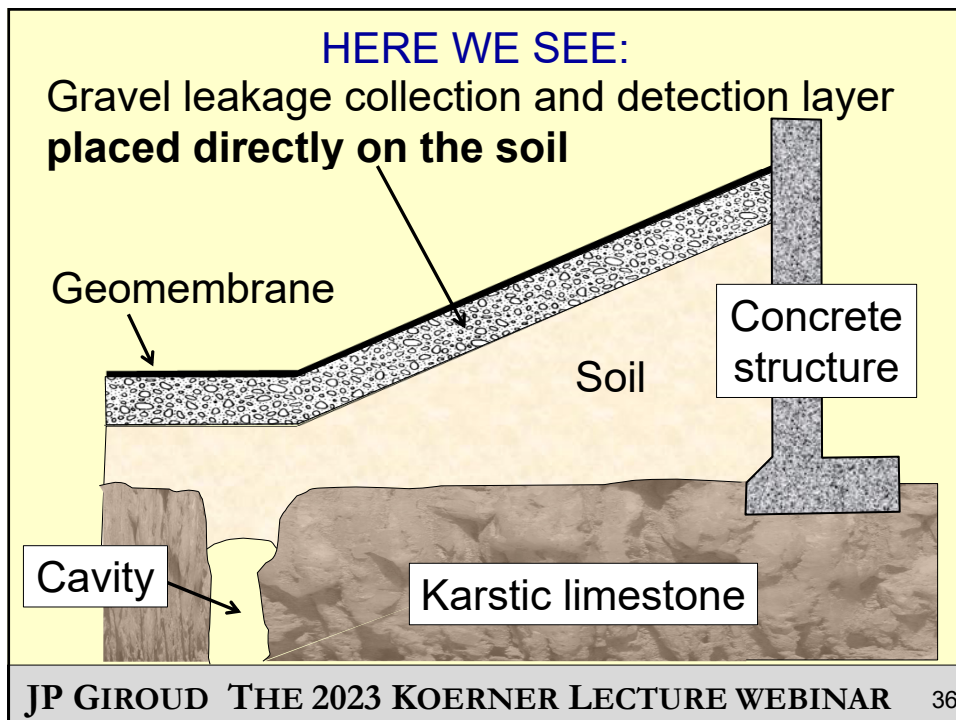
THE RESERVOIR LINER SYSTEM

- The reservoir was lined with a **single geomembrane**.
- The geomembrane was underlain by a gravel **leakage collection and detection layer placed directly on the soil**.

We will see that a **leakage collection and detection layer, placed directly on the soil, cannot prevent leakage into the ground.**

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DESCRIPTION OF FAILURE

During the **first filling** of the reservoir, **leakage** occurred at a **defective connection** between the geomembrane and the **concrete structure**.

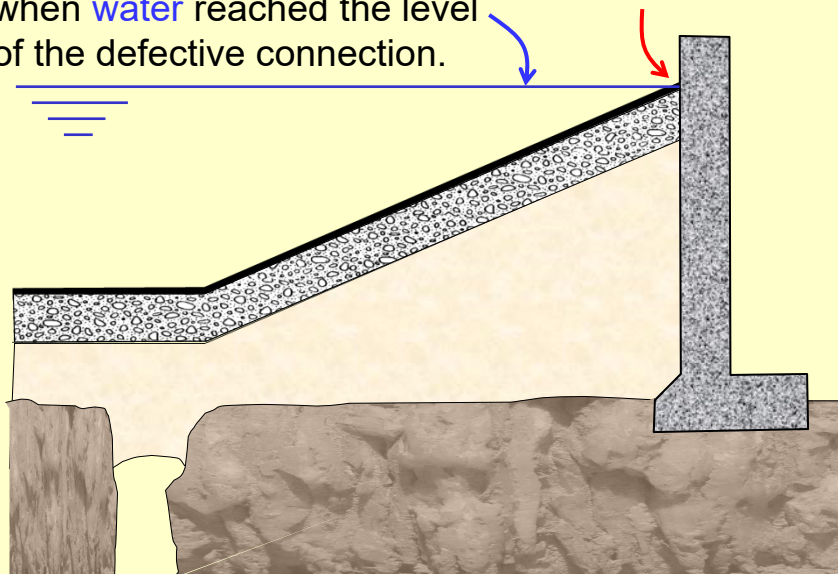
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Leakage occurred

when **water** reached the level of the defective connection.

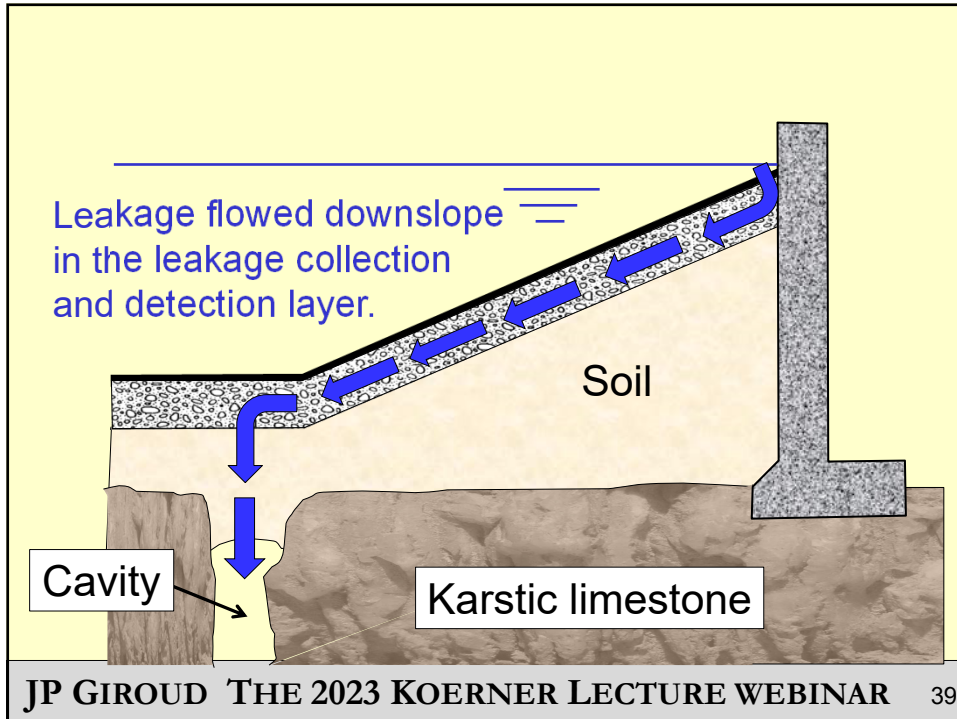
Defective connection



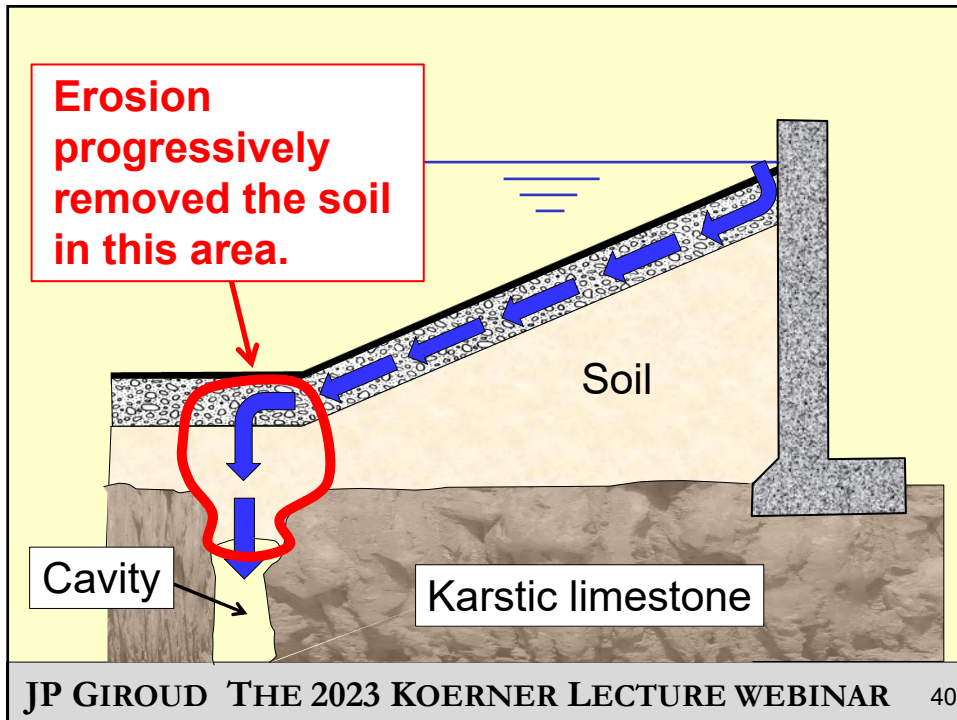
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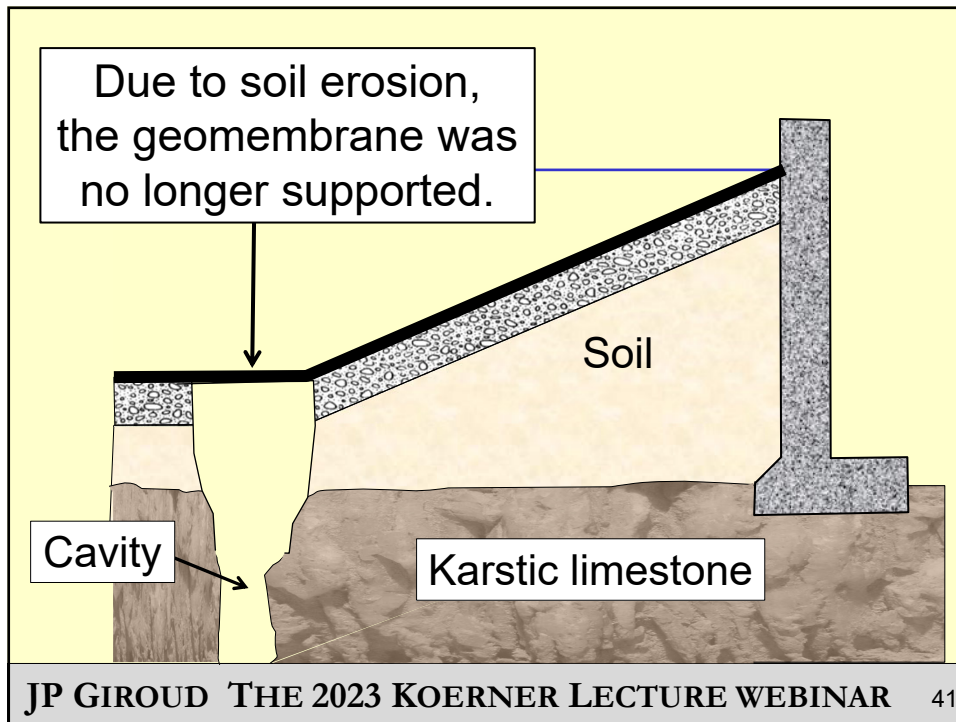


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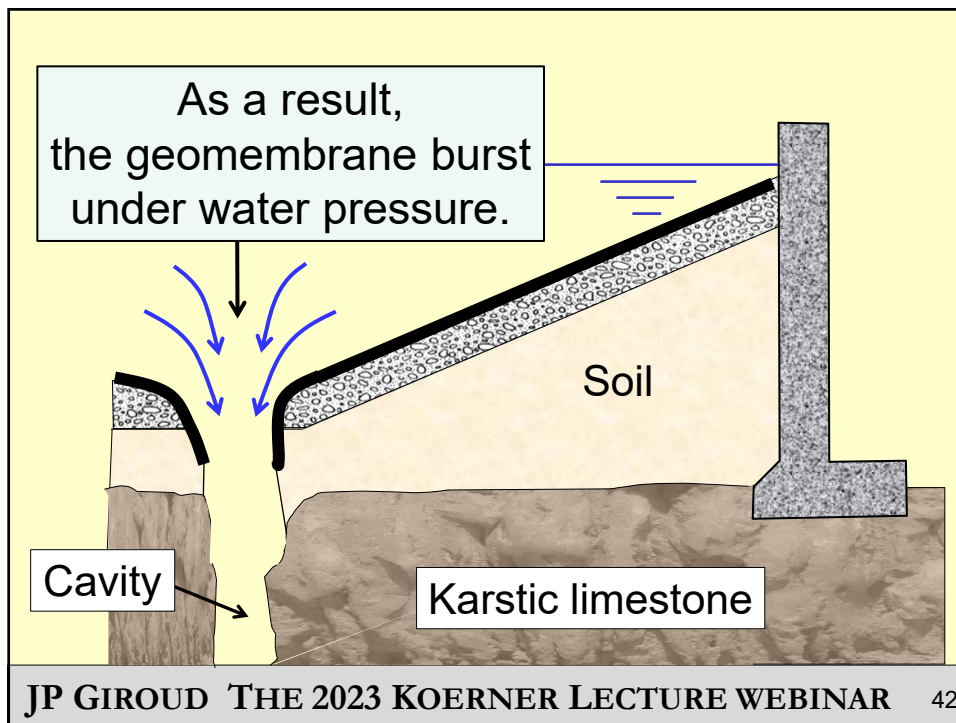


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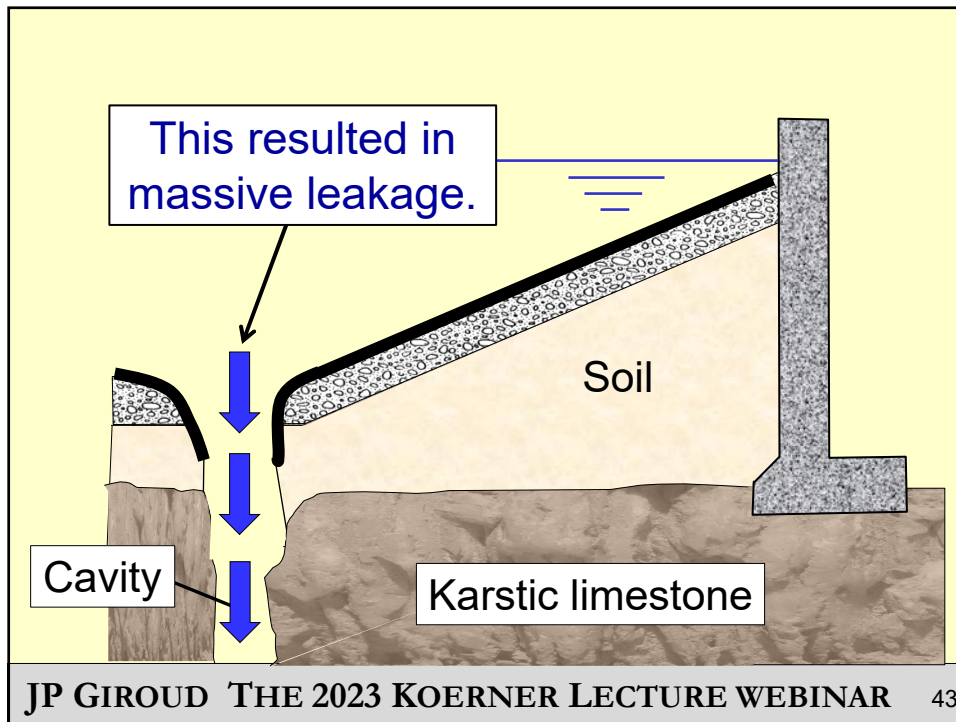


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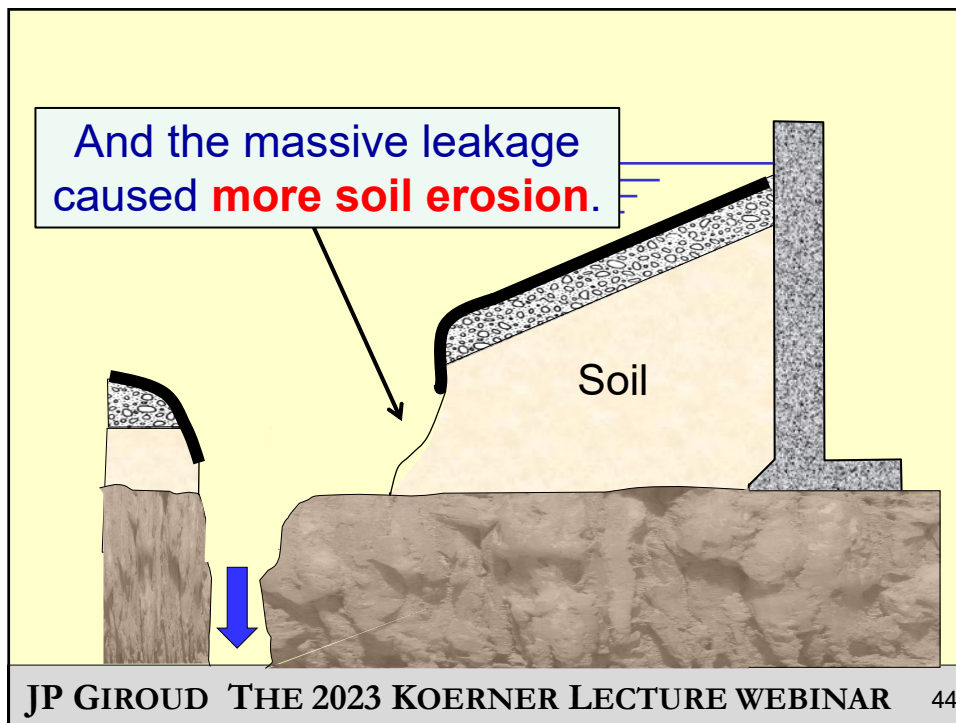


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Here is a view of the reservoir after failure.
Several cubic meters of embankment disappeared into the cavity.




FAILURE AREA

Photo
J.P. Giroud

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Here is a view of the failure area showing the concrete structure to which the geomembrane was attached.



HERE

Photo
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The defective connection was here.

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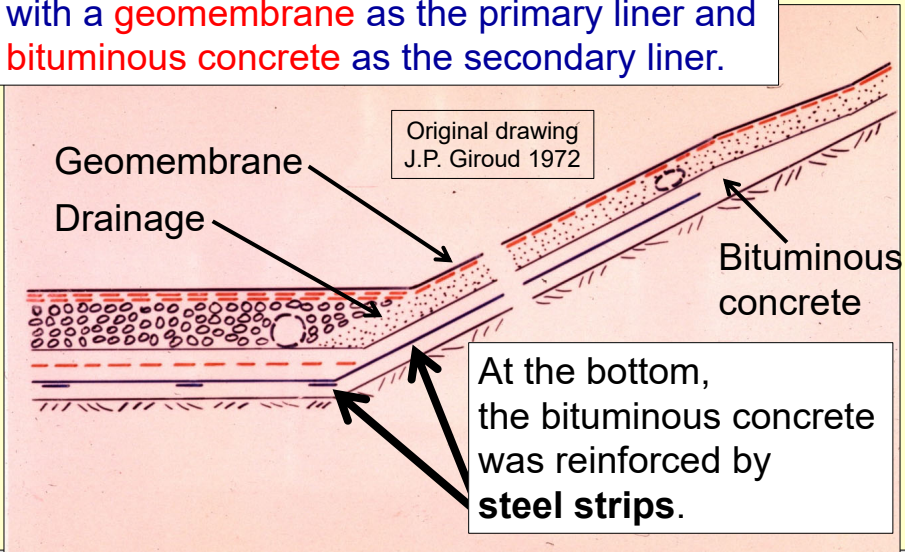
From zero leak at end of geomembrane installation to zero leakage in service

Clearly, the **failure** mechanism was **initiated by leakage** into the ground. Therefore, the solution was to achieve a *leakage rate into the ground* as close as possible to “**zero leakage**”.

I suggested a **double liner**, but this was new (in 1972), and the owner preferred to rely on **reinforcement** to bridge the cavities.

The adopted repair solution included both **double liner** and **reinforcement**.

The repair consisted in a **double liner** with a **geomembrane** as the primary liner and **bituminous concrete** as the secondary liner.



From zero leak at end of geomembrane installation to zero leakage in service

The **secondary liner**, by preventing water collected by the leakage collection and detection layer from infiltrating into the ground, was the **best way** to prevent the *same failure mechanism* from occurring again.

This was **the first double liner**, but not with two geomembranes (1972).

CONSTRUCTION OF THE REMEDIATION

Leakage collection and detection layer on the side slopes



Photo
J.P. Giroud

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STEEL STRIPS USED TO REINFORCE THE BOTTOM



Photo
J.P. Giroud

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COMMENTS ON THE REMEDIATION

- The key aspect of the repair was the **double liner**, because it addressed the **cause of the problem**, which was *leakage into the ground*.
- The **reinforcement** only addressed the **consequence of leakage**, which was erosion of geomembrane support. (*It was used to reassure the owner who did not trust the double liner.*)

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CONCLUSION OF THE CASE HISTORY

- A **detail** (poor connection) **triggered the failure.**
- But the **cause of the failure** was a **conceptual design flaw:** the leakage collection and detection layer **without a secondary liner.**
- And there was **negligence** regarding **soil investigation.**

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With an appropriate **design**, a **detail**, the **defective connection** between the geomembrane and the concrete structure, should have triggered **only a loss of water, not a major failure.**

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The lessons learned from this case:

- With a geomembrane liner,
a leak is always possible.
- Therefore,
the **potential consequences of a leak**
should **always** be **identified** and **evaluated**.
- If the consequences are unacceptable,
the **design should be improved.**

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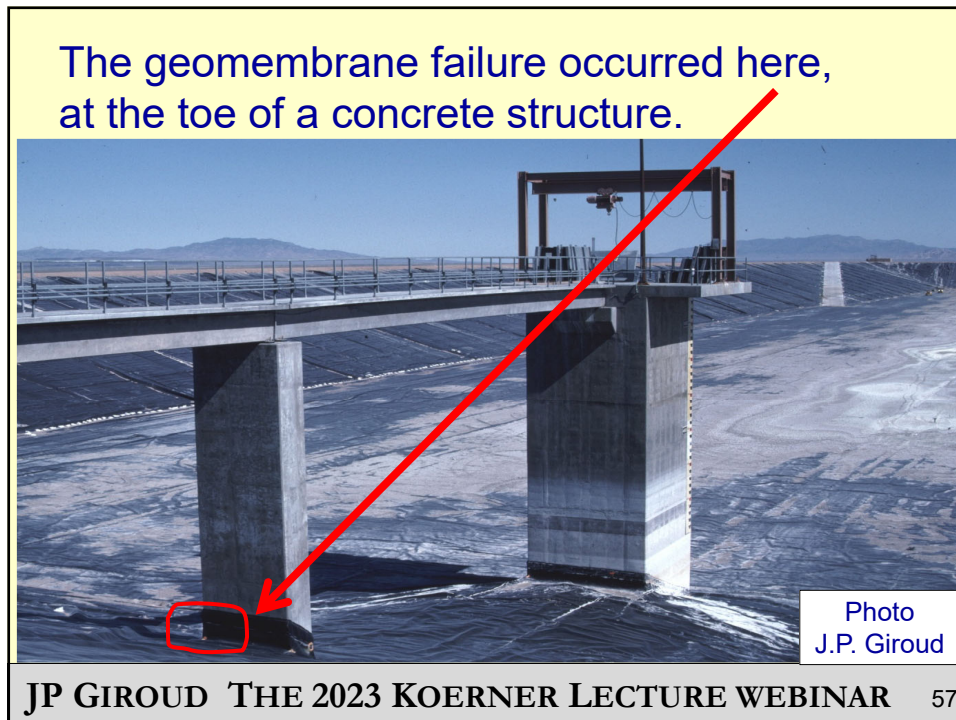
The next **CASE HISTORY** is
another example of
connection with concrete structure,
which illustrates:

**ZERO LEAK AT INSTALLATION
BUT
SIGNIFICANT LEAK
AFTER GEOMEMBRANE DISPLACEMENT**

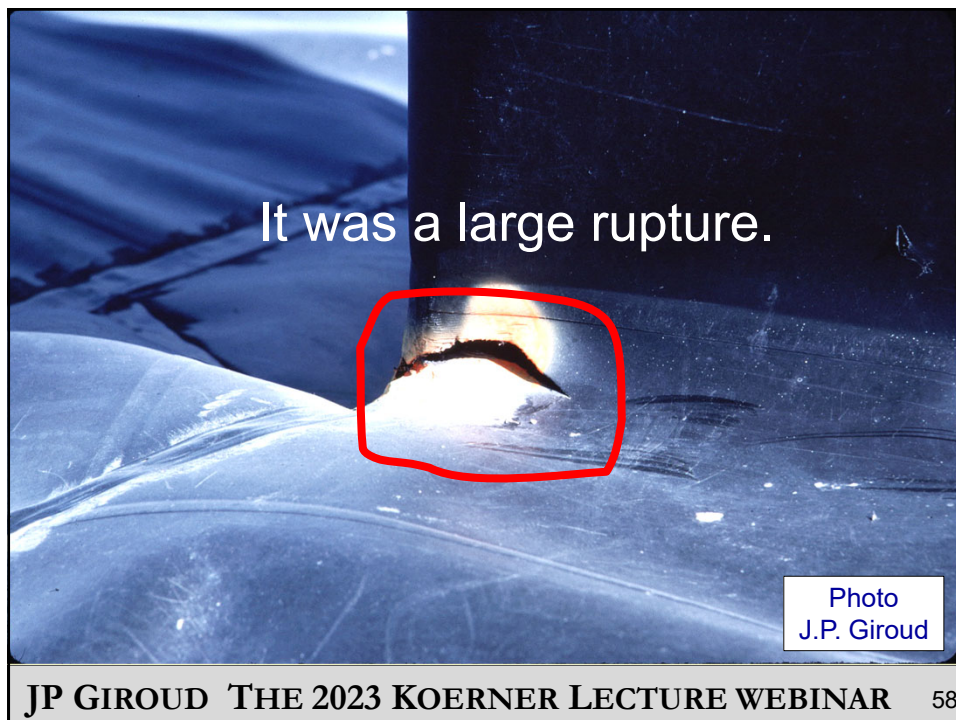
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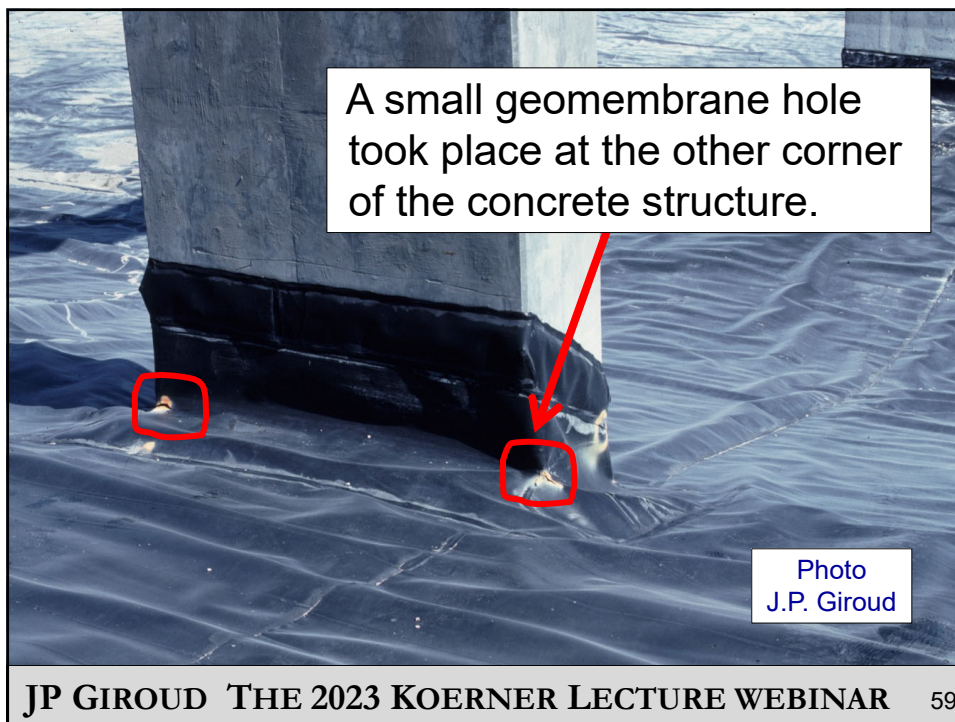


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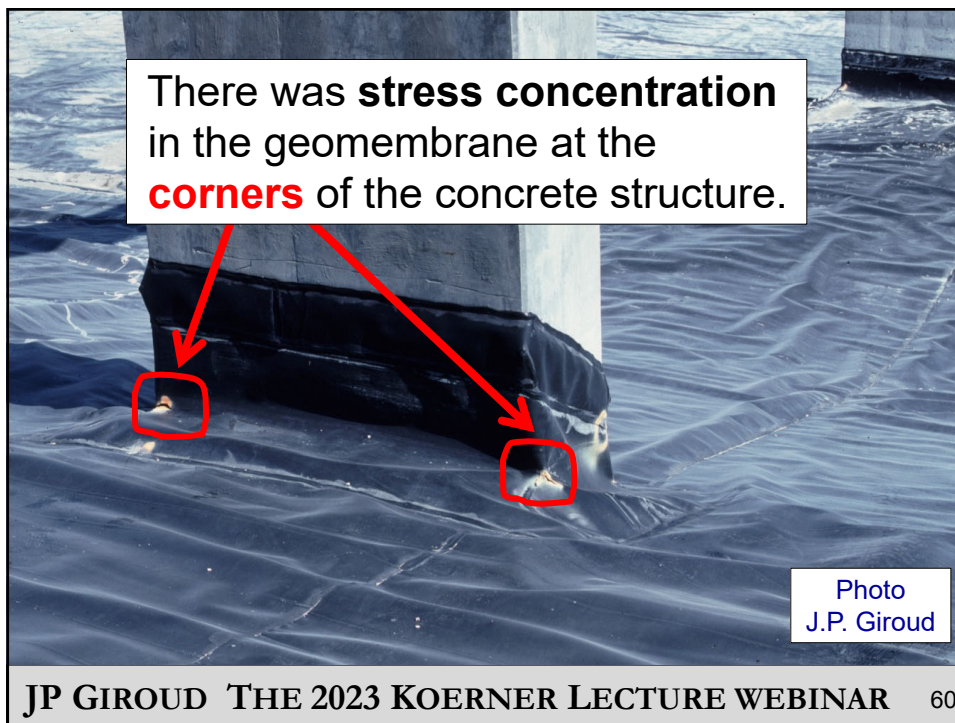


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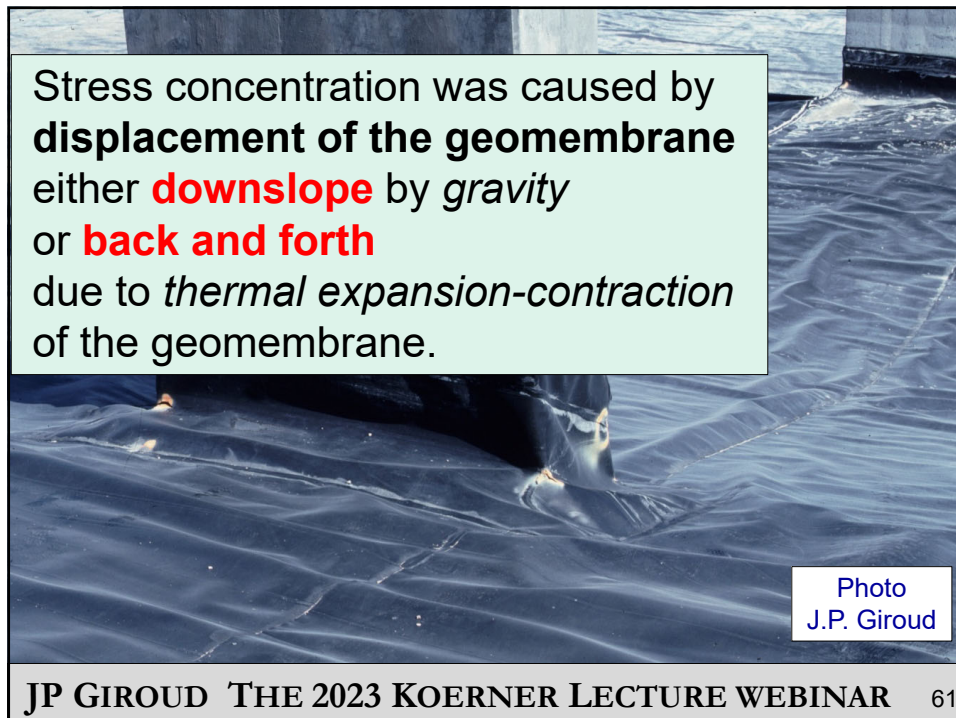


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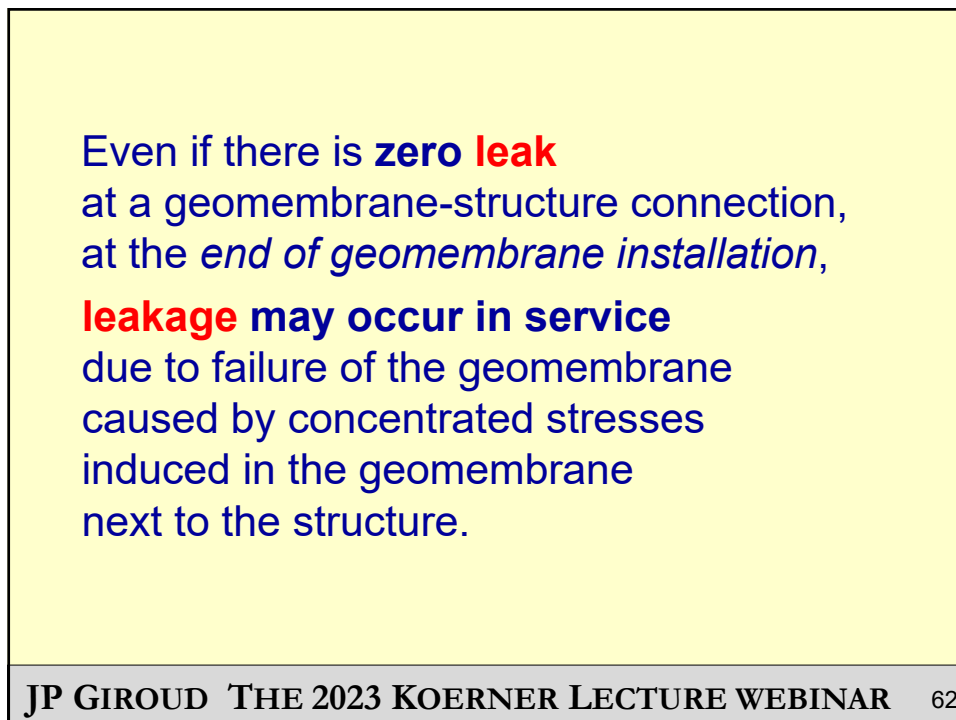


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Stress concentration occurs at the connection between a **geomembrane** and a **rigid structure** for the following reasons:

- **displacement of the geomembrane**, for example, by gravity on slope, by wind or water uplift, or by thermal-expansion-contraction;
- **settlement of the soil** or any other soil deformation next to a rigid structure; and
- **displacement of the “rigid” structure.**

The last case is rare, but it does exist.

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This wall moved toward the left . . .


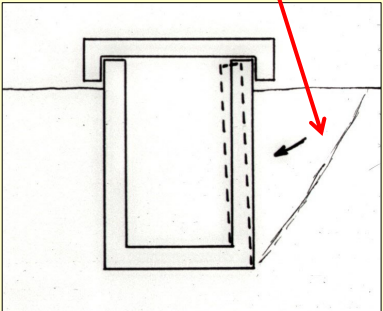


Photo J.P. Giroud

. . . because it did not resist the active soil pressure.



This was a design error.

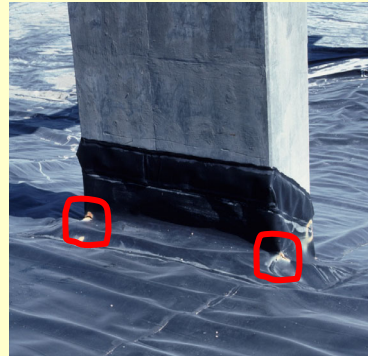
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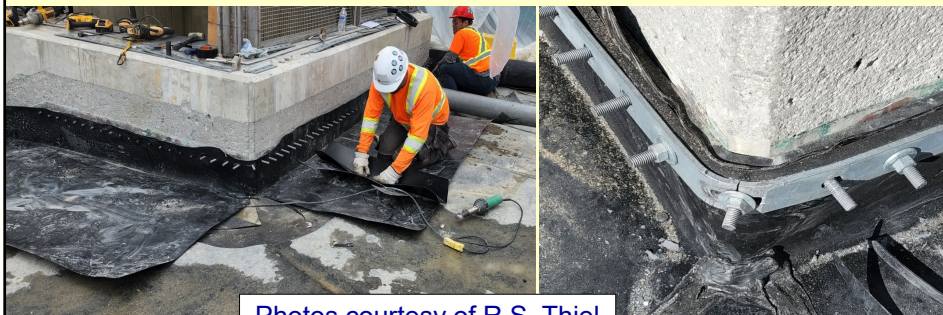
In addition to the risk of **stress concentration**, there is **another problem** with **right-angle corners**.

It is difficult to achieve a **watertight** connection between a geomembrane and a structure with **right-angle corners**.



Without watertight connections, the **zero-leak goal** at end of installation **cannot be achieved**.

These photos illustrate the **amount of care** needed to attach a geomembrane to a concrete structure with **right-angle corners**.



Photos courtesy of R.S. Thiel

From zero leak at end of geomembrane installation to zero leakage in service

Most structures do not need sharp corners.
Design engineers should **learn from the field**,
and **cooperate** with geomembrane **installers**,
to design concrete structures to which
geomembranes can be easily attached.



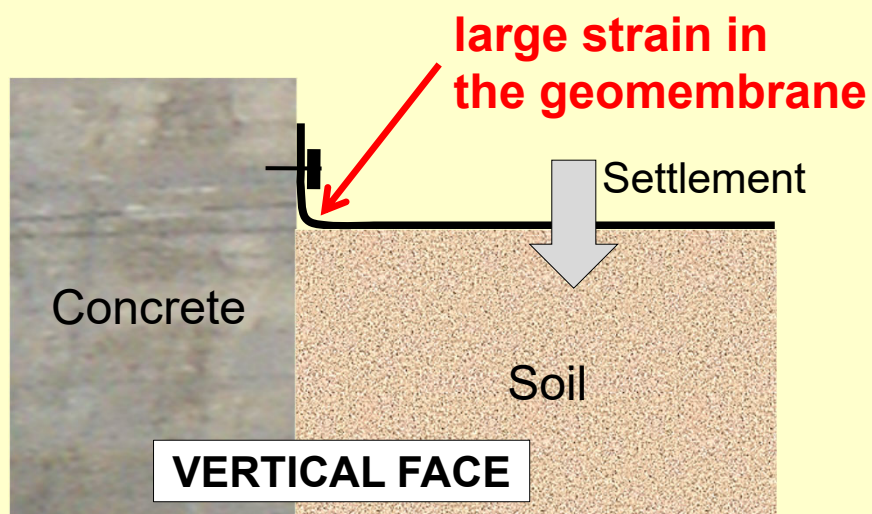
Photos courtesy of R.S. Thiel

Another aspect of the **shape of concrete structures**
to reduce the risk of stress concentration
in the geomembrane
is the **vertical profile** of the concrete structure.

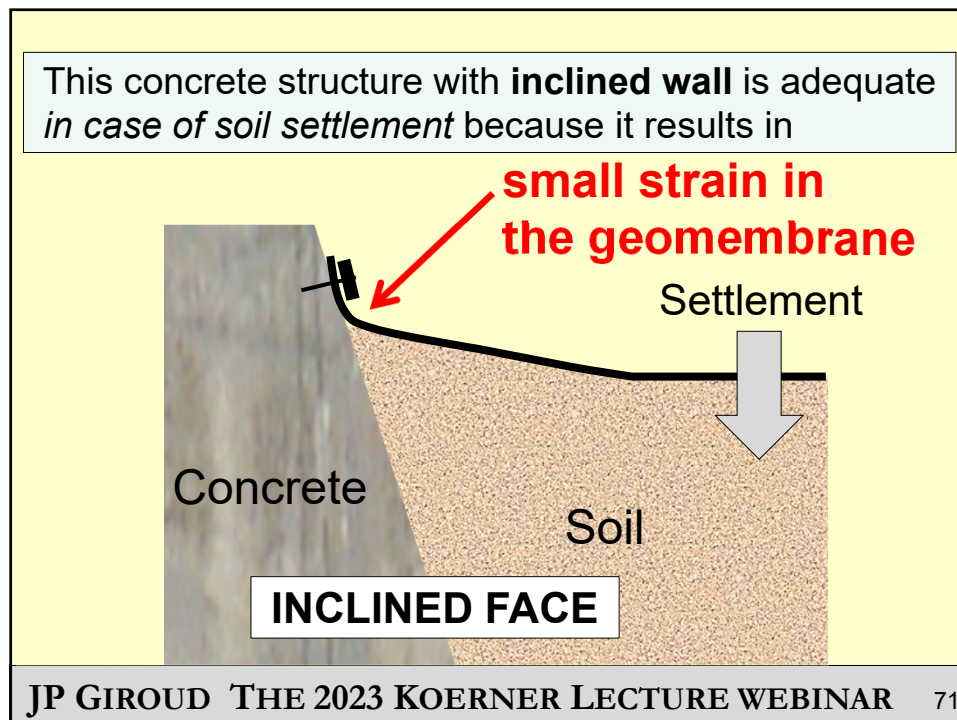
In cases where stresses
in the geomembrane
may result from **differential settlement**
between the structure
and the adjacent soil
(which supports the geomembrane)
the **vertical profile of the structure** is important.

To **minimize differential settlement**,
it is recommended
to **avoid** rigid structures with **vertical walls**,
and
to design structures with **inclined walls**.

This concrete structure with **vertical wall** is inadequate
in case of soil settlement because of



From zero leak at end of geomembrane
installation to zero leakage in service



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To conclude this discussion on the **shape of structures** to which geomembranes are attached:

- concrete structures should have **no sharp corners** to *facilitate the construction* of watertight connections and to *minimize concentrated stresses* in the geomembrane; and
- *if differential settlement can be expected*, the concrete structure should have **inclined walls**.

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The next CASE HISTORY
shows that

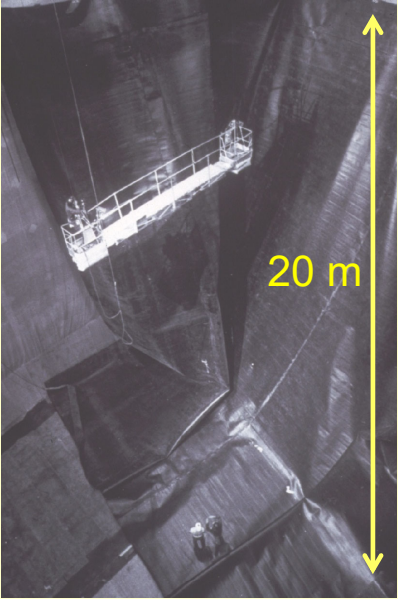
**UNDERSTANDING
GEOMEMBRANE PROPERTIES
IS
ESSENTIAL.**

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A large volume of water was needed for a physics experiment.

To contain the water , a large cavity 20 m x 20 m x 20 m was excavated in a **salt formation** (because salt, contrary to rock, is not radioactive).



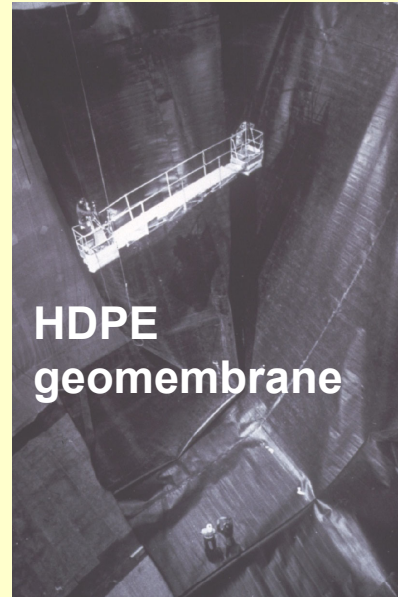
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The reservoir was to contain the **purest water** ever produced.

An **HDPE** geomembrane was selected for its **chemical inertia**, to maintain the water purity.



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I was asked to design the liner for this extraordinary reservoir.

Due to the solubility of the salt, I recommended a **double liner** with two geomembranes.



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For the leakage collection and detection layer between the two geomembranes, I selected a **geonet** (a new geosynthetic at that time, 1980) because (contrary to gravel) it is **not radioactive** and it could be **installed vertically**.



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This was the **first use** of a **geonet** for a leakage collection layer and the **first entirely geosynthetic** double liner system.



1980-1981

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From zero leak at end of geomembrane installation to zero leakage in service

The reservoir had been excavated before designing the liner system.

The reservoir had **right-angle corners**.

This is another example of structural design done **without taking into account** the requirements of geomembrane installation and performance.




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To design this challenging project, I asked for the **stress-strain curve** of the geomembrane.

This was an extraordinary request.

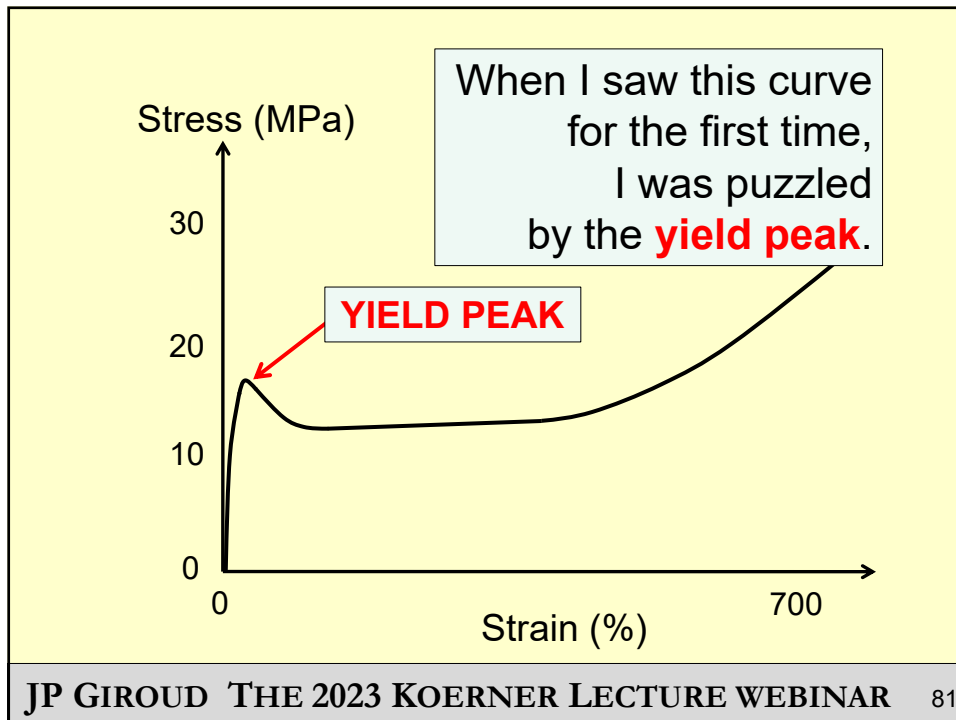
At that time (1980), it was not easy to obtain the stress-strain curve of a geomembrane !



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From zero leak at end of geomembrane installation to zero leakage in service



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After a significant amount of thinking, I understood that an HDPE geomembrane, with a **scratch on its surface**, would fail when its **average strain** is close to the **yield strain** (*which we all know today*).

Then, I calculated the strain in the geomembrane when it is **pushed into a corner** by water pressure, and I found that the strain in the geomembrane was going to be **higher than the yield strain**.

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From zero leak at end of geomembrane installation to zero leakage in service

Based on this analysis,
which was new at that time,
I predicted
that the geomembrane would fail
in a corner of the reservoir.

And I presented this prediction
in the design report,
along with the demonstration.

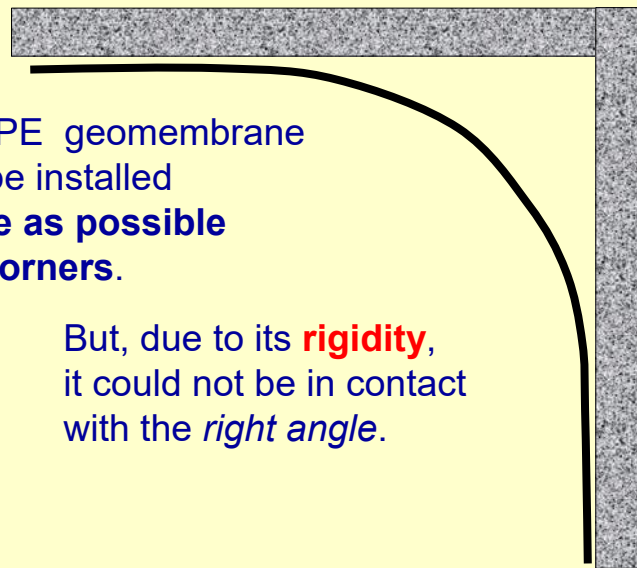
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PLAN VIEW

The HDPE geomembrane
was to be installed
as close as possible
to the corners.

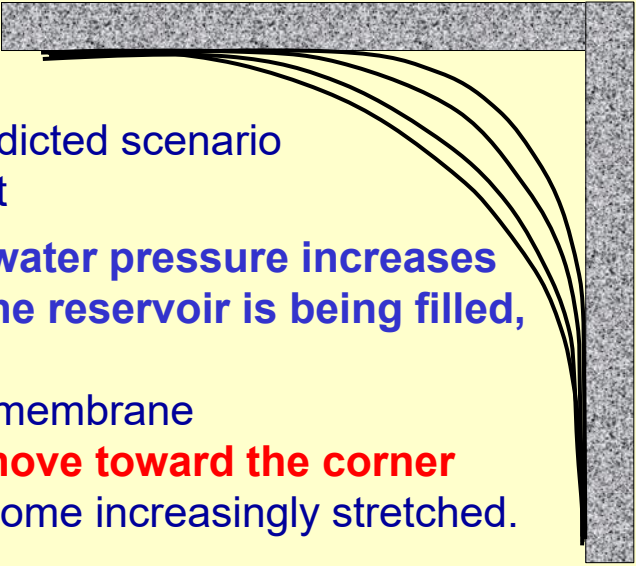
But, due to its **rigidity**,
it could not be in contact
with the *right angle*.



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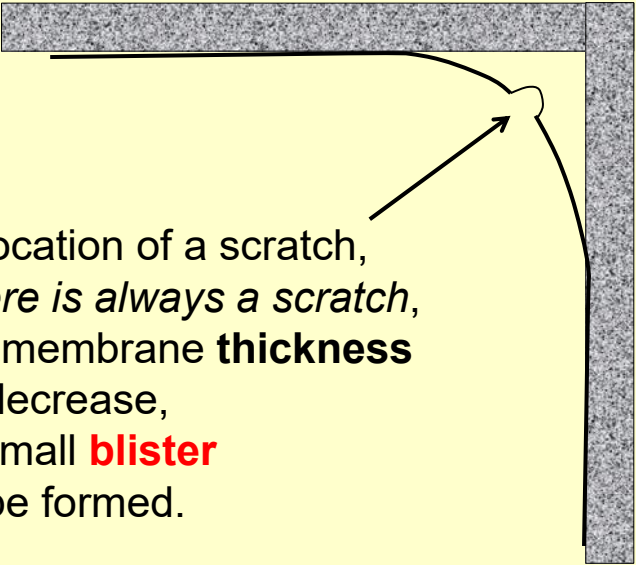
From zero leak at end of geomembrane
installation to zero leakage in service



The predicted scenario was that as the water pressure increases when the reservoir is being filled, the geomembrane would **move toward the corner** and become increasingly stretched.

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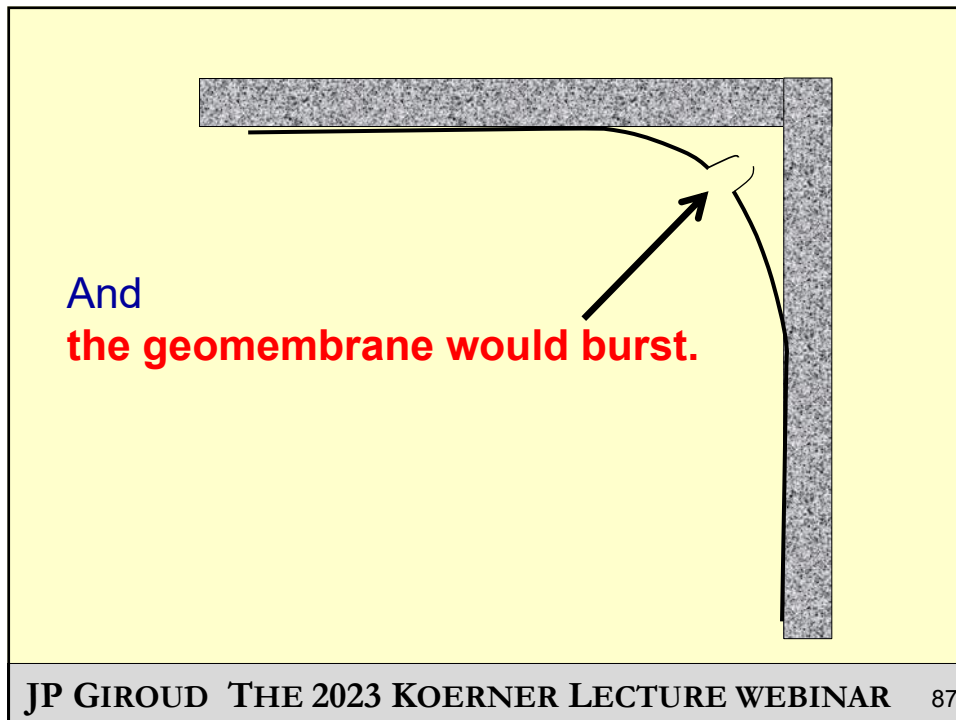


Finally, at the location of a scratch, *and there is always a scratch*, the geomembrane **thickness** would decrease, and a small **blister** would be formed.

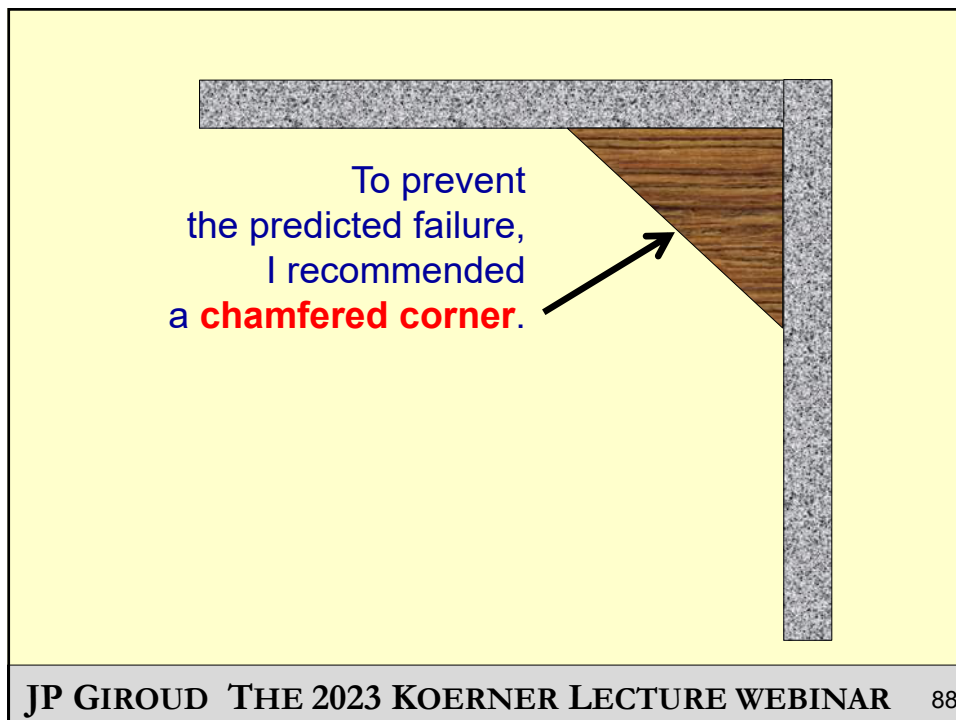
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From zero leak at end of geomembrane installation to zero leakage in service

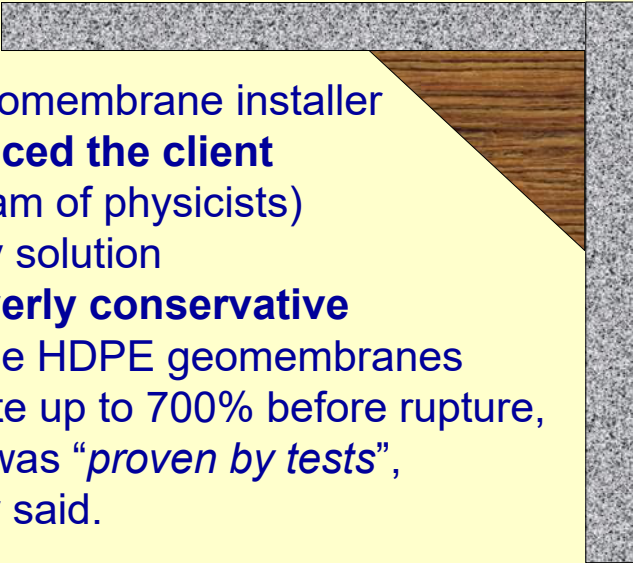


87



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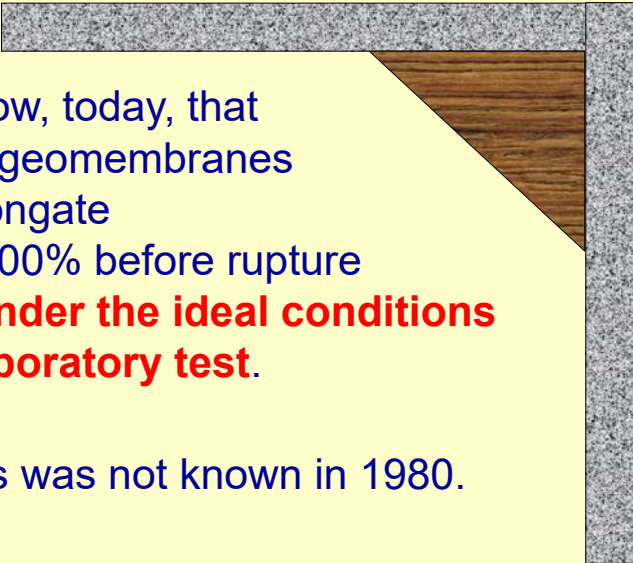
From zero leak at end of geomembrane
installation to zero leakage in service



The geomembrane installer **convinced the client** (the team of physicists) that my solution was **overly conservative** because HDPE geomembranes elongate up to 700% before rupture, which was “*proven by tests*”, as they said.

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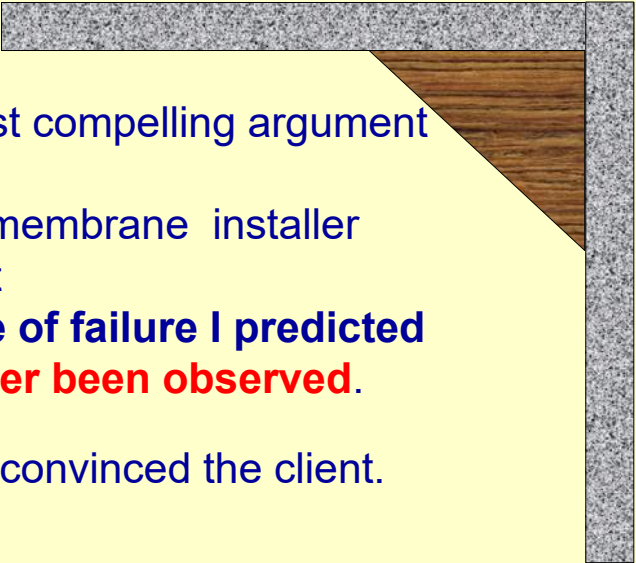
We know, today, that HDPE geomembranes can elongate up to 700% before rupture **only under the ideal conditions of a laboratory test.**

But this was not known in 1980.

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From zero leak at end of geomembrane installation to zero leakage in service

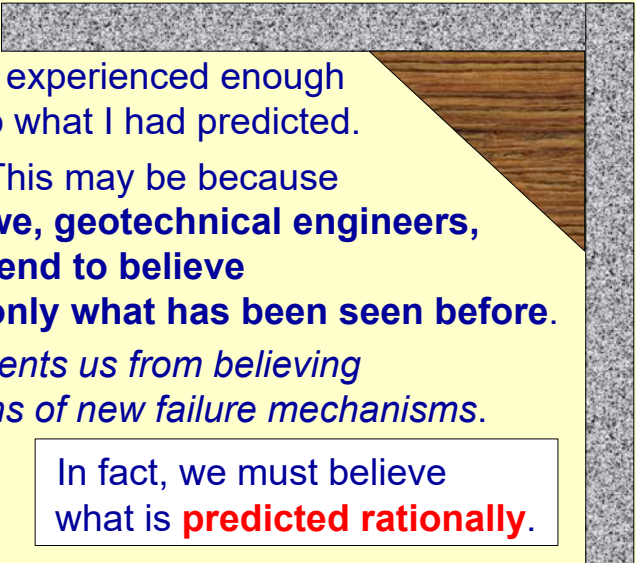


The most compelling argument used by the geomembrane installer was that **the type of failure I predicted had never been observed.**

This convinced the client.

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I was not experienced enough to stick to what I had predicted.

This may be because **we, geotechnical engineers, tend to believe only what has been seen before.**

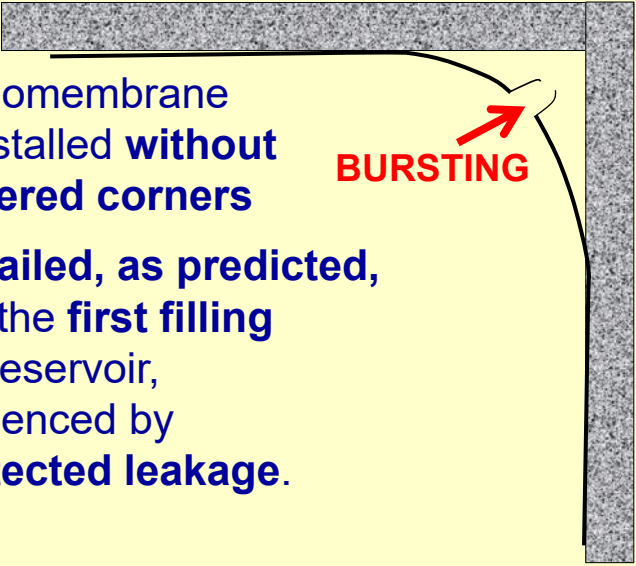
This prevents us from believing predictions of new failure mechanisms.

In fact, we must believe what is **predicted rationally.**

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From zero leak at end of geomembrane installation to zero leakage in service




The geomembrane was installed **without chamfered corners** and it **failed, as predicted,** during the **first filling** of the reservoir, as evidenced by the **detected leakage**.

BURSTING

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The diagram shows a cross-section of a concrete structure with a geomembrane lining. The corner is a sharp 90-degree angle. A red arrow points to a small hole in the geomembrane at the corner, labeled 'BURSTING'. The text explains that the failure occurred because the geomembrane was not installed with chamfered corners.

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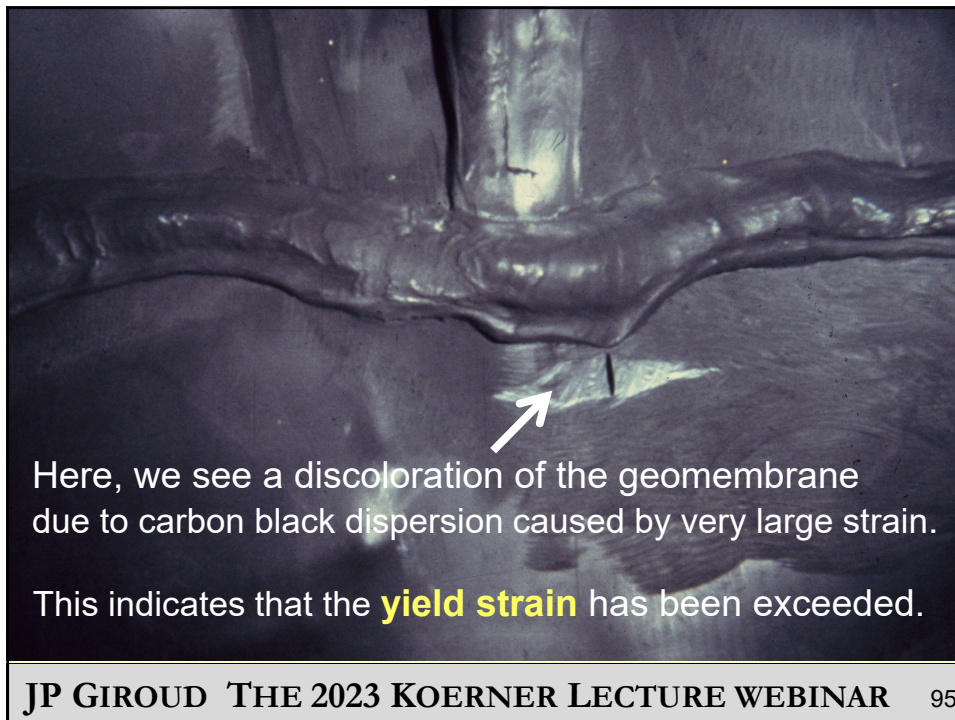
This is a **PHOTO TAKEN UNDER WATER**

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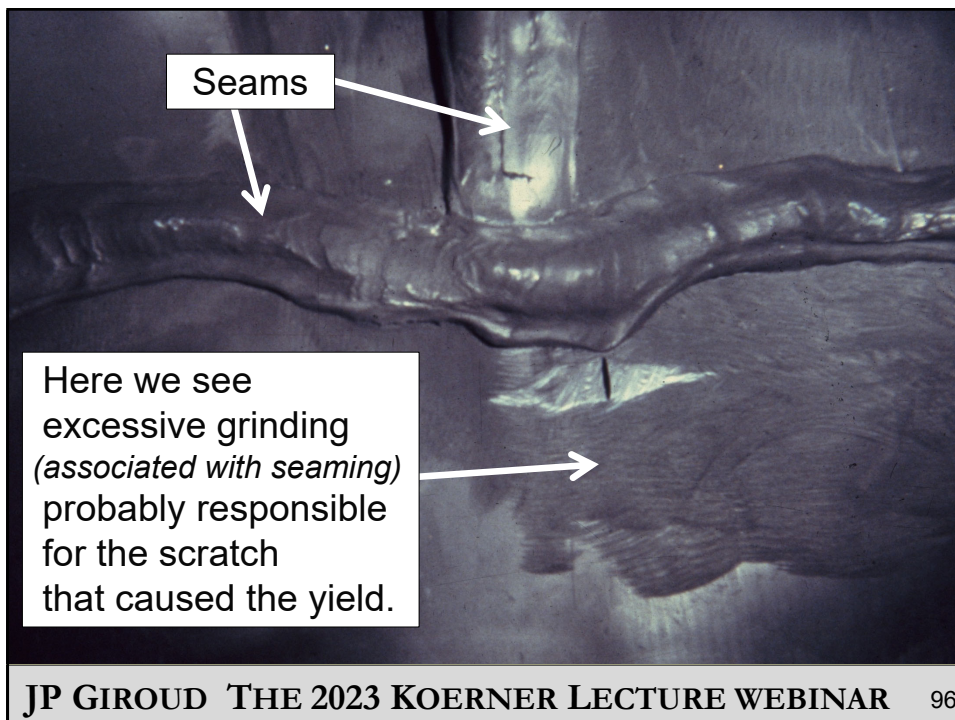
The photograph shows a dark, underwater scene. A bright, circular light source is visible, creating a lens flare effect. The light illuminates a textured surface, likely the geomembrane, which appears to have a small hole or leak. The water is dark and slightly rippled.

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From zero leak at end of geomembrane installation to zero leakage in service

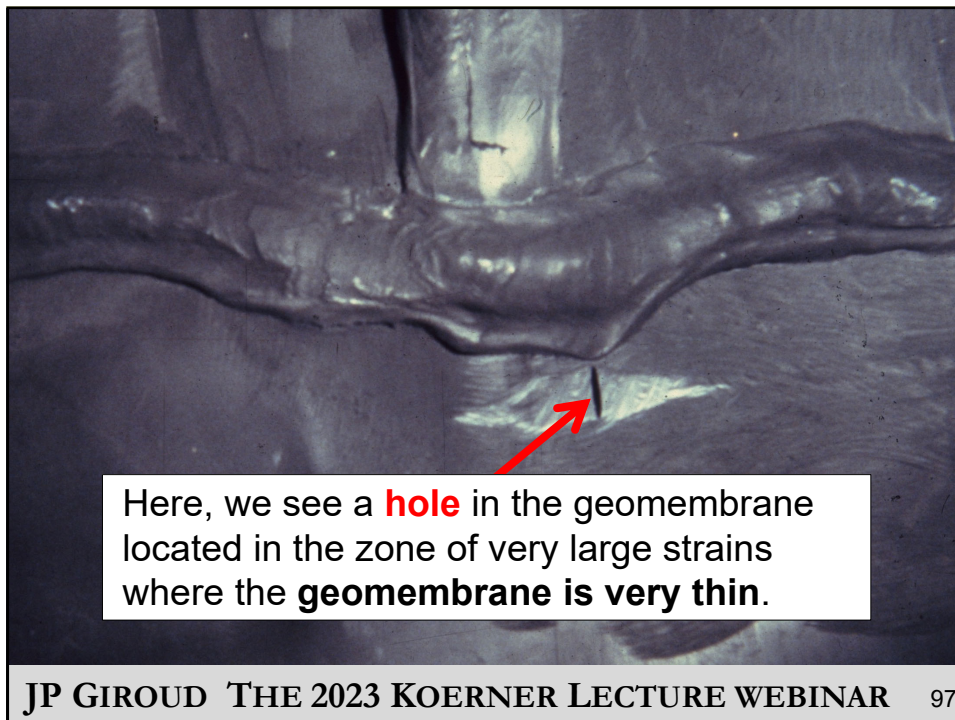


95

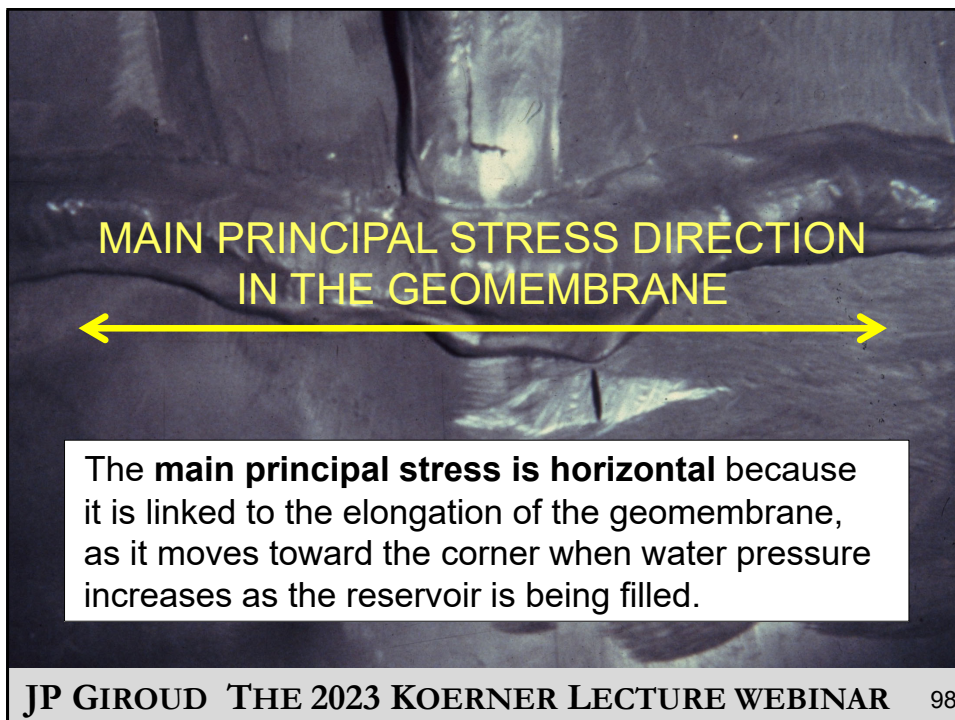


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From zero leak at end of geomembrane installation to zero leakage in service

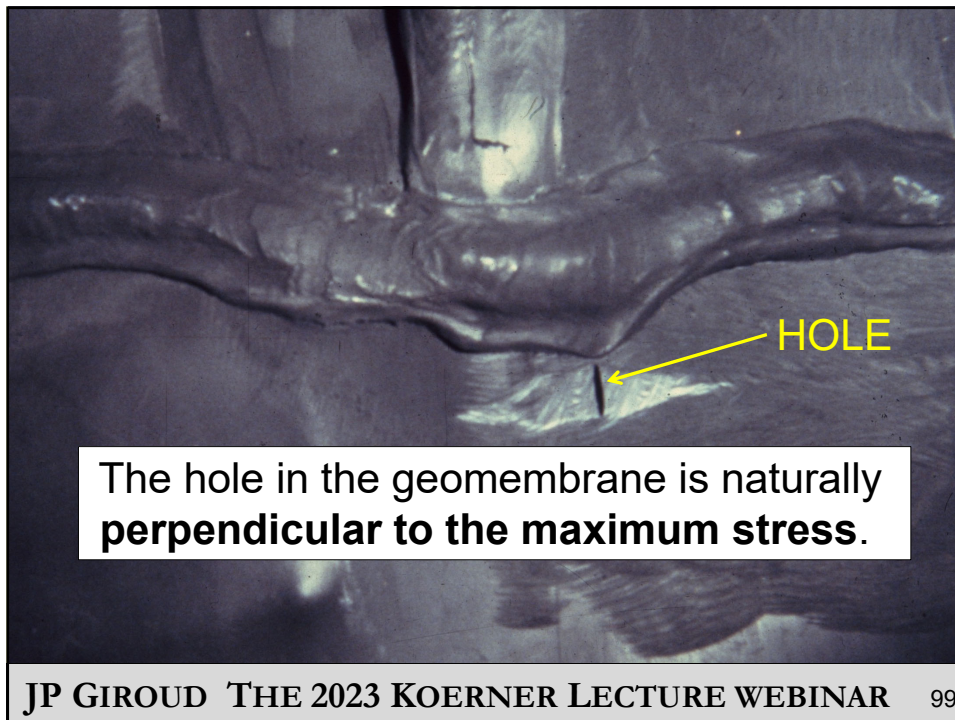


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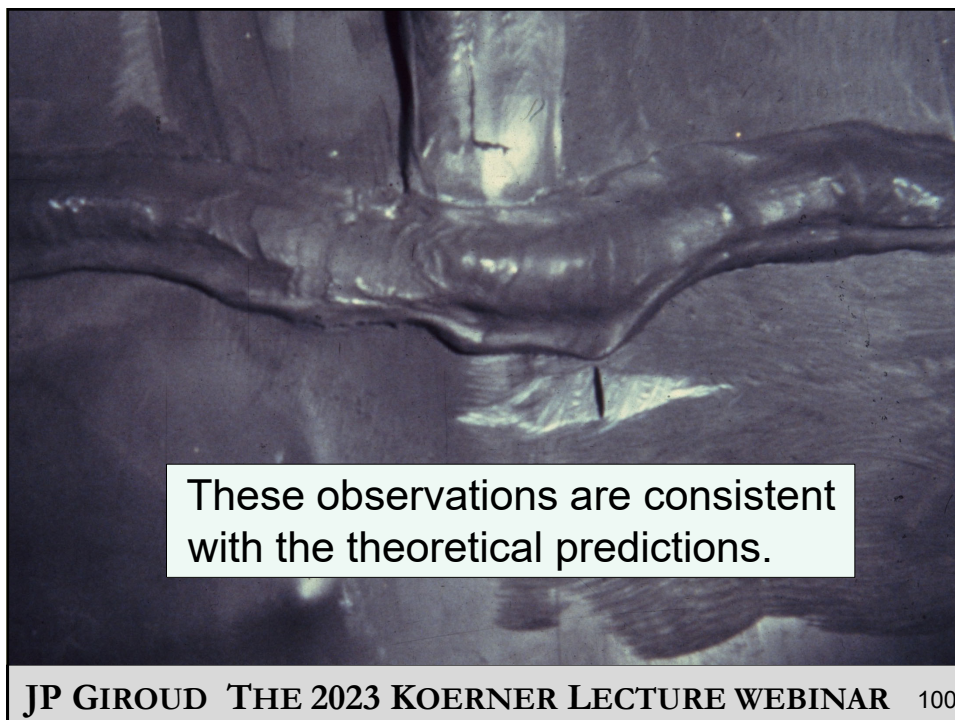


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From zero leak at end of geomembrane installation to zero leakage in service



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From zero leak at end of geomembrane installation to zero leakage in service

REMEDIATION

The **remediation** consisted in constructing the **chamfers** that had been initially recommended.

The physicists had an excellent idea for **constructing the chamfers** in the corners of the reservoir **without removing the liners.**

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REMEDIATION

- Lightweight **concrete** was slowly poured **in the corners** between the rock-salt wall and the secondary geomembrane, thereby *using the geomembrane as a form*, **while water was progressively added** in the reservoir, as needed to balance the fresh concrete pressure.
- The reservoir was thus successfully repaired and filled with water at the same time.

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From zero leak at end of geomembrane installation to zero leakage in service

The following lesson was learned:

We **must believe**
our theoretical analyses
because the **theories** we use
in geotechnical engineering
and in geosynthetics engineering
are **generally correct**.

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The next **CASE HISTORY** shows that

**IT IS IMPORTANT
TO UNDERSTAND THE FUNCTION
OF THE RESERVOIR.**

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From zero leak at end of geomembrane
installation to zero leakage in service

CASE HISTORY

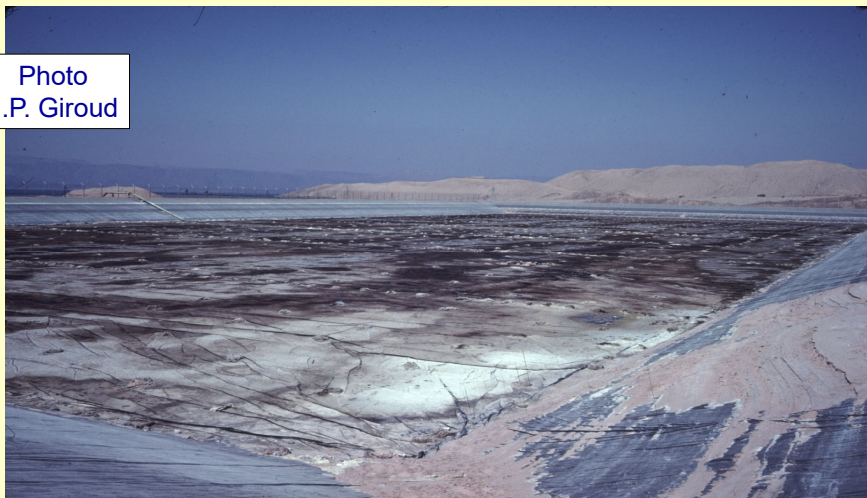
- A large reservoir containing **acid** was constructed on a soil with a high **calcium carbonate** content.
- It was lined with a geomembrane installed **without construction quality assurance**.
- **Acid leaked** through the **many holes** in the geomembrane and attacked the calcium carbonate, thereby creating **cavities**.

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The reservoir emptied after the geomembrane **burst** over several **large cavities**.

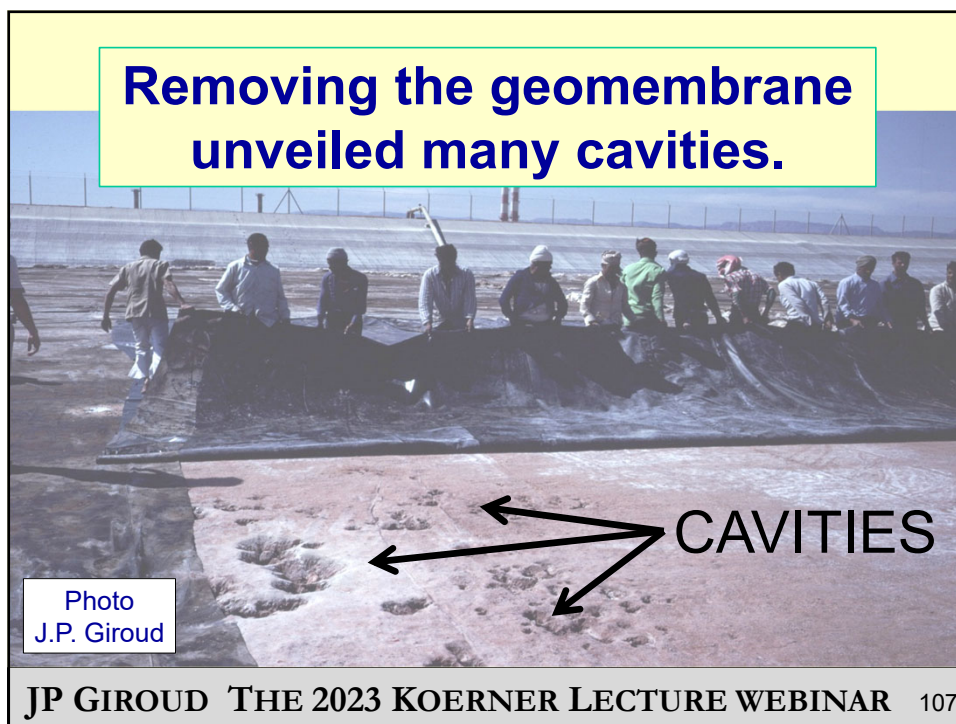
Photo
J.P. Giroud



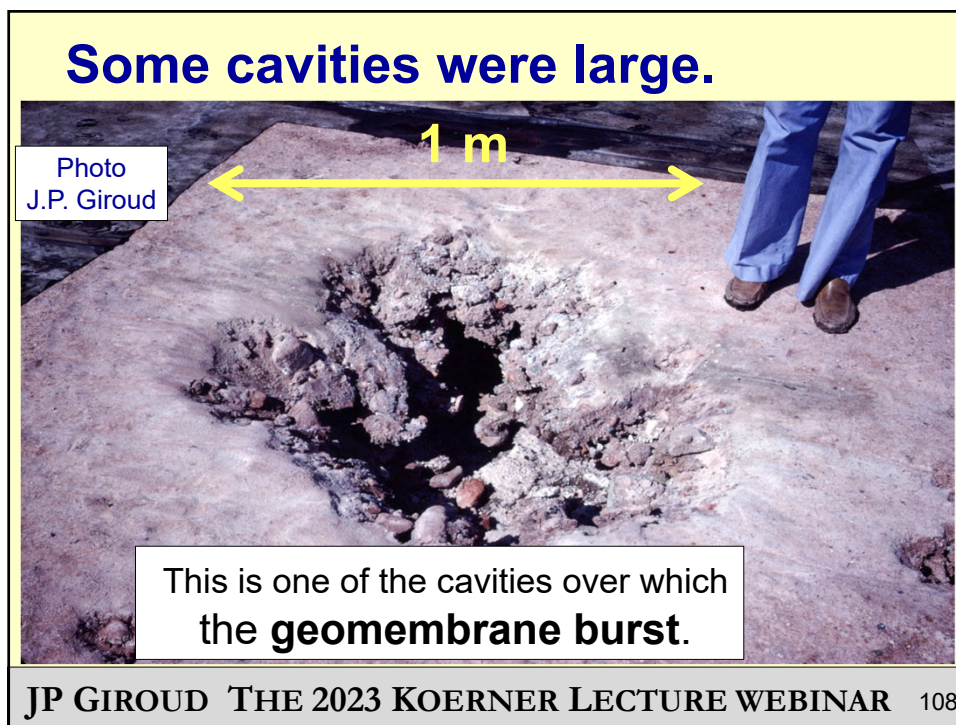
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From zero leak at end of geomembrane
installation to zero leakage in service



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From zero leak at end of geomembrane installation to zero leakage in service

CONDITION OF THE GEOMEMBRANE

The geomembrane had **many holes** (open seams, punctures, tears) due to **careless installation**.

It was clear that the geomembrane had to be **discarded** and that **a new geomembrane had to be installed**.

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STRATEGY FOR REPAIR

The **installer** of the original geomembrane had **guaranteed in writing** that the geomembrane was “**absolutely impermeable**” and that there would be “**zero leakage**”.

Accordingly, the **owner of the reservoir** demanded a *new geomembrane* “**with zero leakage**”.

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From zero leak at end of geomembrane installation to zero leakage in service

STRATEGY FOR REPAIR

After a long discussion,
I convinced the owner
that it is impossible
to install a geomembrane liner
without holes,
and that the **same problem**
would happen again,
unless the project is redesigned.

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From the **discussion with the owner**,
I understood that the reservoir
had **two functions**:

- **Evaporation pond;**
- and
- **Storage reservoir.**

I concluded that the **solution**
was to **separate the two functions.**

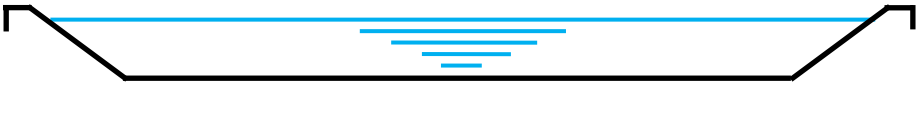
I recommended replacing the reservoir
by **three smaller reservoirs.**

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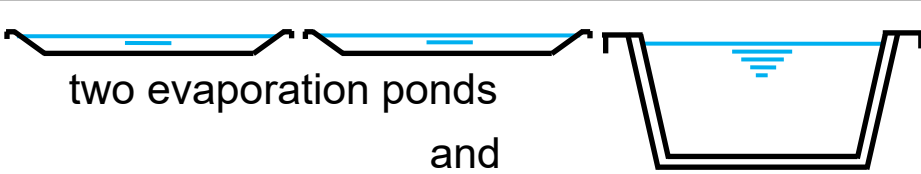
112

From zero leak at end of geomembrane
installation to zero leakage in service

The large and deep reservoir with two functions (evaporation and storage)



was replaced by three reservoirs:


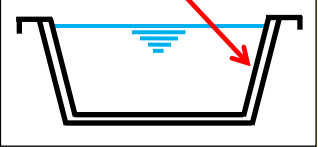


two evaporation ponds and one storage reservoir

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The storage reservoir was designed with a **double liner** to prevent leakage of acid into the ground.



But why two evaporation ponds ?

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From zero leak at end of geomembrane installation to zero leakage in service

Why two evaporation ponds ?

- To promote evaporation, these two ponds were **shallow** (0.5 m of acid).
- As a result, the **risk of leakage was limited** and a single liner was appropriate.
- However, **leakage could still happen**.
- But leakage would unlikely happen in the **two** evaporating ponds at the **same time**.
- If leakage happens in **one** evaporation pond, **repair can be done without interrupting the operation** of the facility.

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The lessons learned from this case are:

- Claims such as “**zero leakage**” or “**absolutely impermeable liner**” should not be believed.
- **Demanding zero leakage is pointless**.
- The **consequences of leakage** should be evaluated.
- The design engineer should meet with the owner to **understand the needs** of the project.
- The conceptual design should be **adapted to the needs**.

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From zero leak at end of geomembrane installation to zero leakage in service

The next **CASE HISTORY** is also related to deterioration of the supporting soil.

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CASE HISTORY

- A large reservoir (30 ha), containing **sea water**, was constructed on a **soil** containing **gypsum**.
- It was lined with an exposed geomembrane (2 mm thick HDPE) installed **directly on the soil**.
- During the **first filling** of the reservoir, when the water depth was 7 m, the water level suddenly decreased.

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From zero leak at end of geomembrane installation to zero leakage in service

The rate of **leakage** was **huge**:
of the order of 120 m³ per minute.

Flooding of a residential area was avoided
by the site manager and his team
who breached a dike during the night
to redirect the flood toward an empty area.

The failure mechanism is discussed on the next slide.

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A **large cavity**, 20 m³, had slowly developed
at the bottom of the reservoir due to **leakage**
through a **small hole** in the geomembrane.



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From zero leak at end of geomembrane
installation to zero leakage in service

The cavity developed because the soil was **highly soluble** in water, especially salt water.

The **high solubility** and **erodability** of the soil was evidenced by deep gullies seen at the site.




Photo
J.P. Giroud

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The geomembrane **burst over the cavity**.

Here is a photo of the geomembrane ruptured **over the cavity**.



Photo
I.D. Peggs

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From zero leak at end of geomembrane installation to zero leakage in service

The geomembrane burst into the **20 m³** cavity
35 days after leakage started.

These 35 days are **consistent** with
leakage rate **calculations**,
and with the **calculated time** required
for the leaking water to dissolve **20 m³** of that soil.

Also, **calculations** showed that the **bursting**
of the geomembrane under 7 m of water was
consistent with the **geomembrane strength**.

It is important in forensic analyses
to present quantitative explanations.

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*What about
the design?*

The soil had a **low permeability**,
and the **design engineer** expected
that the geomembrane on this soil
would form a **composite liner**.

However, this so-called “composite liner”
could not work for two reasons:

- **Intimate contact** is required in a composite liner
between the geomembrane and the soil,
but there was **no load** to keep
the geomembrane and the soil in contact.
- Furthermore, a leak would **dissolve** this soil.

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From zero leak at end of geomembrane
installation to zero leakage in service

The high **solubility** of the soil was **known** by the design engineer and, at the time of the design (2004), it was **known**, in particular by the design engineer, that the possible presence of **holes** in geomembrane liners **should always be considered** at the design stage.

Therefore, the possible **consequences of leakage** **should have been identified** and **evaluated**.

This was not done, and, therefore, the **failure** was **inevitable**.

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Against my recommendation, after the 2011 failure, the **repair** was done with the **same design**.

In 2013, I wrote in a court document:

*“The reservoir, with a single geomembrane liner, on a material highly sensitive to water, is a **failure-prone reservoir** where it is logical to **expect** that the mode of failure observed in June 2011 **will happen again**.”*

As predicted, **the liner failed again** in 2021.

This time, **300 homes were evacuated**.

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From zero leak at end of geomembrane installation to zero leakage in service

An important **lesson learned**
from this case history is that
site-specific data should not be ignored,
for example,
the solubility of the soil.

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The last CASE HISTORY
shows that
**PLACING A LINER
DIRECTLY ON TOP OF
ANOTHER LINER
IS RISKY
IN A LIQUID RESERVOIR.**

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From zero leak at end of geomembrane
installation to zero leakage in service

Two almost identical reservoirs
were constructed on the same site,
at the same time.

This case is remarkable
because the **two reservoirs**
experienced the **same problems**.

Only the problems
of **one of the two** reservoirs
will be described.

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A reservoir of **brine** for a **pumping station**
was lined
with an **old bituminous roofing membrane**.

This old membrane
was in **relatively good condition**,
but there was **some leakage**,
which contaminated groundwater.

The environmental agency required
that the leakage be fixed.

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From zero leak at end of geomembrane
installation to zero leakage in service

The owner asked an **installer** to place a geomembrane **directly on top of the old membrane** to solve the leakage problem.

The environmental agency liked this solution.

No design engineer was involved, *but I was informed of this project* by the installer.

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I told the installer that installing a **liner on a liner** was **risky** because liquid may accumulate between the two liners and uplift the top liner.

Both the installer and the owner ignored my warning.

I sent a letter to the installer to make sure it was clear that I did not support the adopted solution.

Then, I did not hear about this project for a year.

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From zero leak at end of geomembrane installation to zero leakage in service

I eventually learned that the owner and the installer had ignored my warning because they considered that I was driven by **theoretical considerations**

(and, I agree, they were right)

and they had concluded that I lack **common sense**

(and, I agree, they were right).

Indeed, it was obvious to them that **common sense** dictates that *two liners are better than one* (which, I know, can be wrong).

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As decided by the owner, a 1 mm thick PVC geomembrane was installed on a geotextile **cushion** placed on the old bituminous roofing membrane.

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From zero leak at end of geomembrane installation to zero leakage in service

The **pumping station** reservoir was used for several months with the **brine level fluctuating daily** between full and half full.

The geomembrane could not be seen through the brine, but the pumping station operator suspected that the **geomembrane liner was moving**.

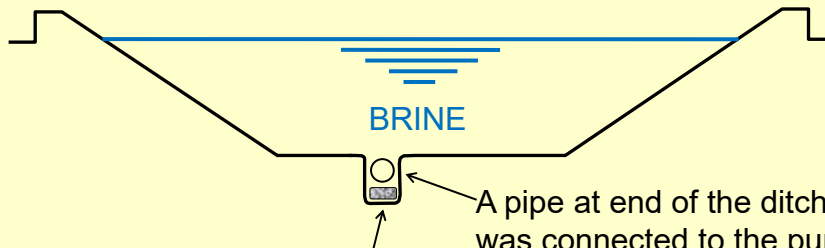
And, I was asked to visit the site *to investigate problems with the liner*.

To understand the problems, a cross section is needed.

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A long ditch was used as a sump to pump the brine.



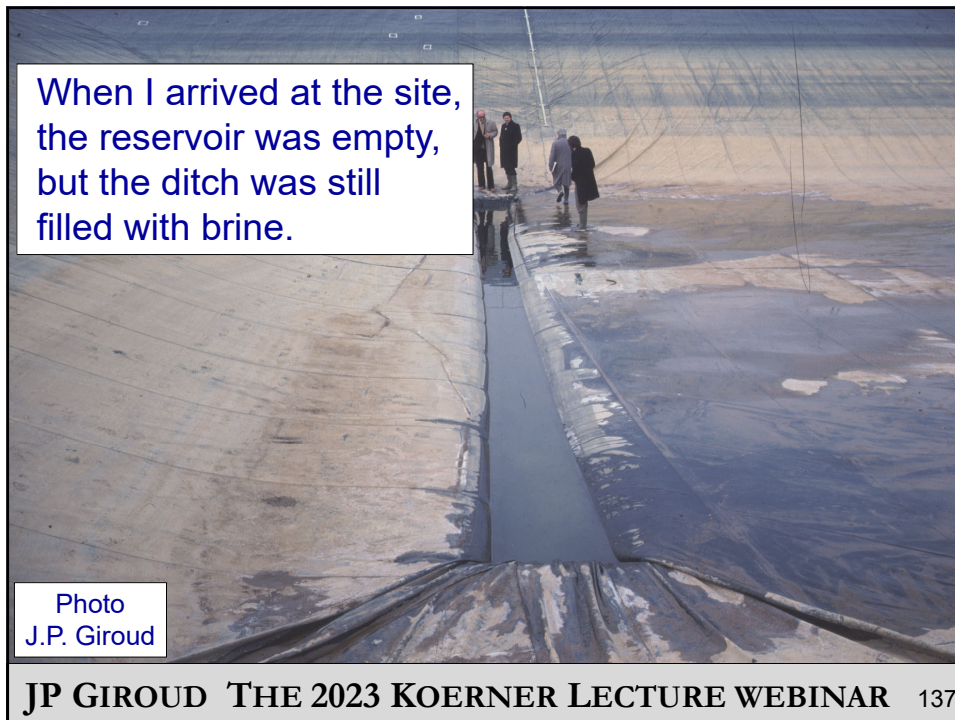
The geomembrane was ballasted at the bottom of the ditch.

Therefore, the geomembrane could not move at the bottom of the ditch, but could move elsewhere since it was not covered.

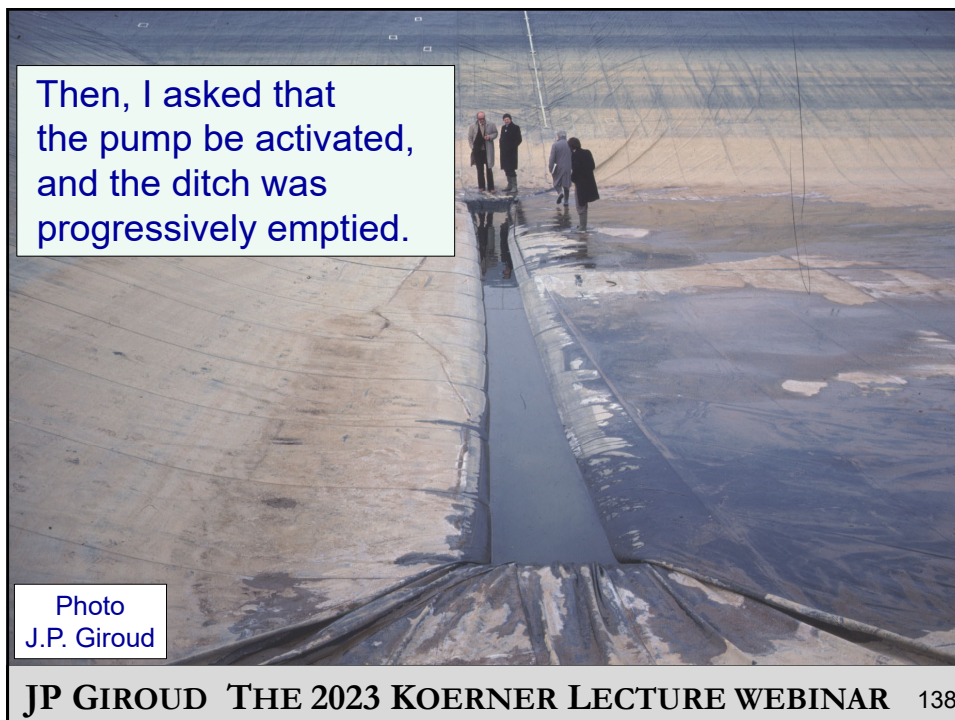
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From zero leak at end of geomembrane installation to zero leakage in service

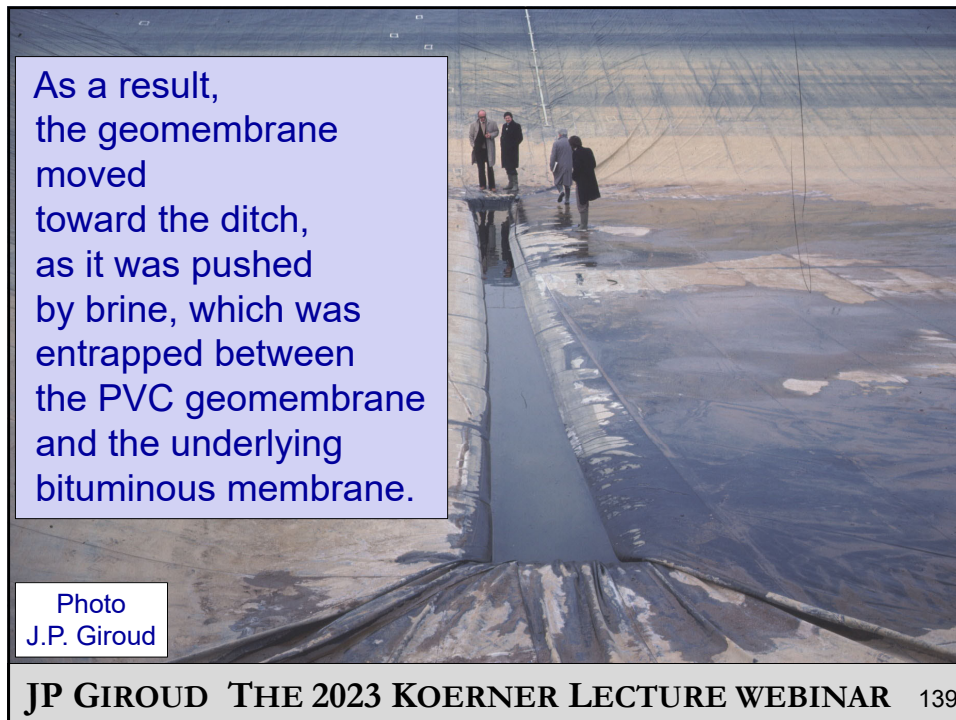


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From zero leak at end of geomembrane installation to zero leakage in service



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From zero leak at end of geomembrane installation to zero leakage in service

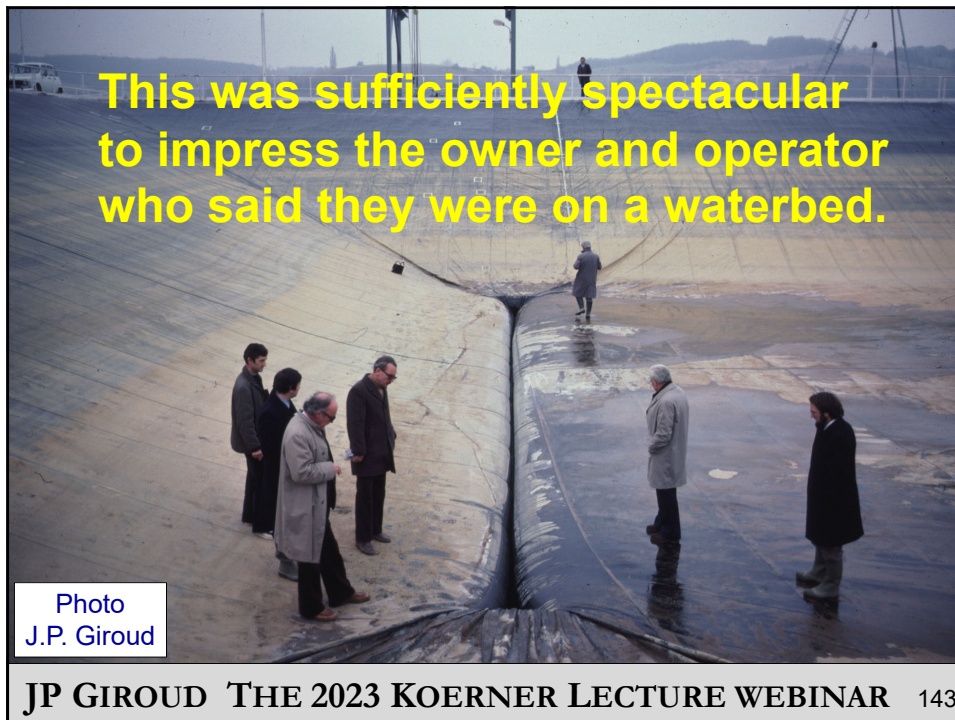


141

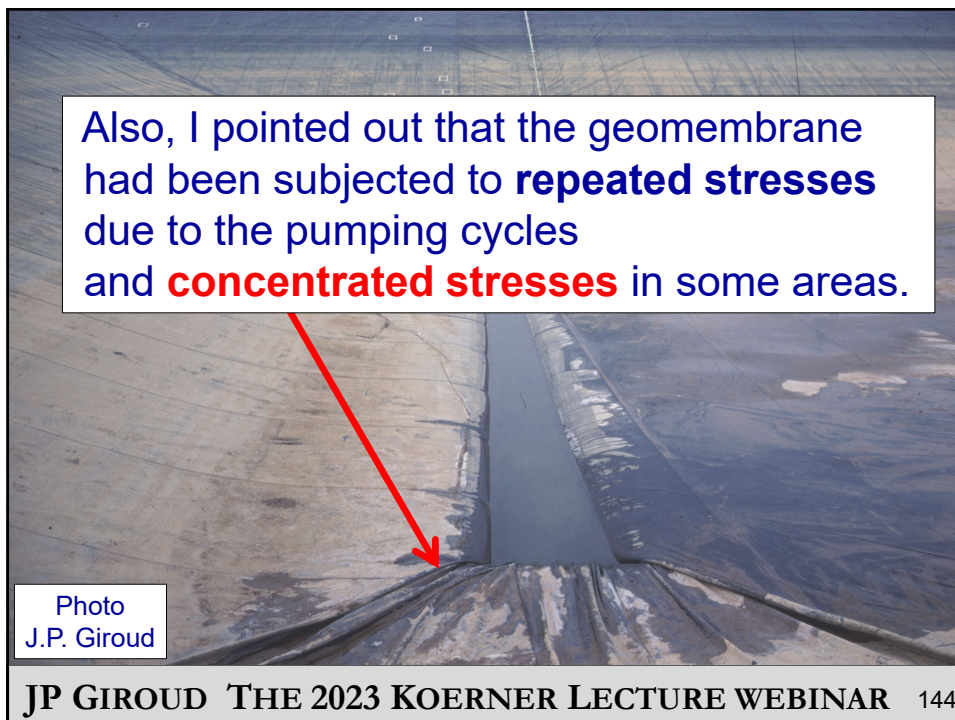


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From zero leak at end of geomembrane
installation to zero leakage in service

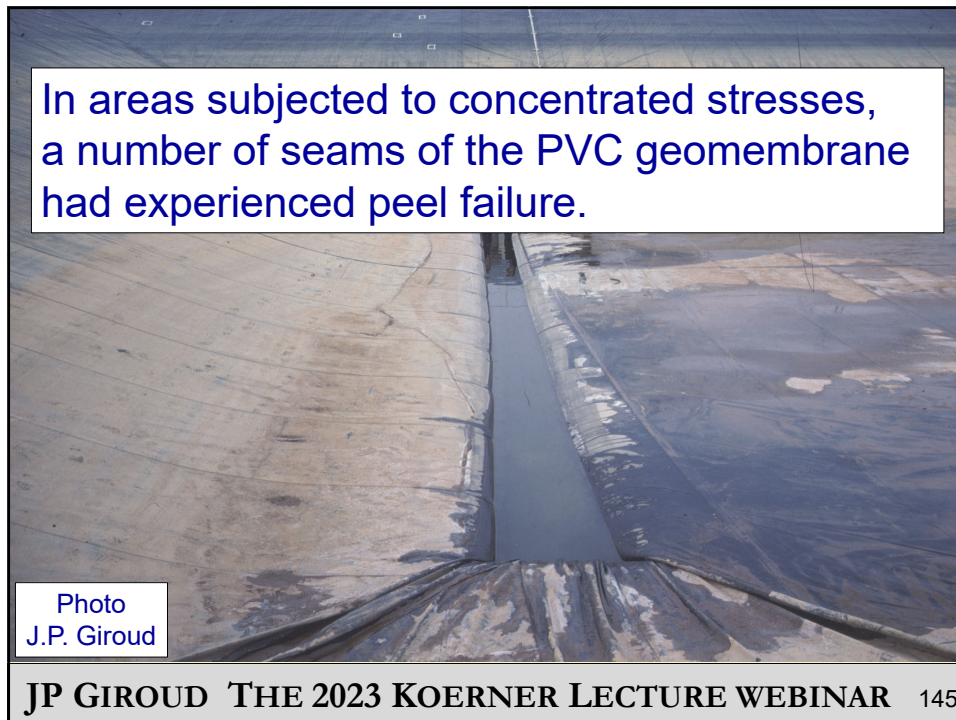


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From zero leak at end of geomembrane installation to zero leakage in service



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Also, during my visit, I learned **interesting facts**.

During six months in service, the reservoir had been **emptied twice**.

Each time, the geomembrane was **displaced** toward the ditch by **liquid entrapped under the geomembrane**.

Each time, the geomembrane was *intentionally* cut to discharge the entrapped liquid into the ditch, and *salinity measurements* indicated that the **entrapped liquid was brine**.

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From zero leak at end of geomembrane installation to zero leakage in service

I also learned that, **shortly after installation**, and *before any brine was stored in the reservoir*, the geomembrane had moved toward the ditch, pushed by **liquid under the geomembrane**.

Based on the bulging, the volume of liquid entrapped was estimated to be between 2 and 4 m³.

The geomembrane was *intentionally* cut, and **fresh water** was discharged into the ditch.

This water was attributed to **intensive rainfall** during geotextile and geomembrane installation.

I checked this assumption as shown on the next slide.

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During geotextile and geomembrane **installation**, the 50 m³ ditch was filled with rainwater; therefore, more than 50 m³ of rain fell on the reservoir (*which is consistent with rainfall records*).

I calculated that the 300 g/m² **geotextile** could **contain** approximately **6 m³ of water**, and that it would take **only several days** for this water flowing downslope **to reach the ditch**.

These numbers, *volume and time*, indicate that, indeed, **rainwater** explained the 2 to 4 m³ bulging, which occurred shortly after installation.

Quantitative explanations are important in forensic analyses.

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From zero leak at end of geomembrane installation to zero leakage in service

After this investigation, it was clear to me that a **new design was needed** because of the following **facts**:

- The **fact** that geomembrane displacement by entrapped liquid had happened **every time** the reservoir was empty.
- The **fact** that the **same problems** happened at the **other reservoir at the same site** constructed with the **same design**.
- The **fact** that the geomembrane displacement was **rationally explained and predicted**.

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The repair consisted in creating a **double liner**:

- The damaged PVC geomembrane was discarded.
- The old bituminous roofing membrane was kept as a **secondary liner**.
- A thick geotextile (600 g/m²) was placed on top of the existing geotextile (300 g/m²) to serve as **leakage detection layer** (*today a geonet would be used*).
- The ditch was *filled with gravel* to become a sump for the leakage detection layer.
- The **primary liner** was a new PVC geomembrane.

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Many lessons were learned from this case history:

- **Installers** who agree to install a geomembrane **without a design engineer** should be careful, because a failure is possible.
- **Common sense** is wrong as often as it is right. It is a *random process*, not a design guide.
- **Theoretical analyses** are a reliable guide.
- Two liners are better than one **only if engineering principles** are respected, for example, by *ballasting* or by creating a *double liner* with drainage between the two liners.

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CONCLUSION

I could present more cases,
but it is time to conclude.

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First, I want to reassure you.

Most geomembrane projects are **successful** thanks to designers, manufacturers, installers, laboratories, and providers of **essential services**, *construction quality assurance* and *electrical leak location surveys*.

In most cases, **leakage is controlled** (*but, generally, it is not zero*).

However, there are still too many failures, and **we must learn from failures**.

If we do not learn from failures caused by others, **we will learn from our own failures**.

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Clearly, the **zero-leak** and **zero-leakage goals** cannot be achieved if the liner **design is flawed**.

The **zero-leak goal** cannot be achieved **at end of geomembrane installation** if the design of the containment facility *ignores the properties* of geomembranes and *the requirements of geomembrane installation*.

The **zero-leakage goal** cannot be achieved **in service** if the design of the containment facility *ignores the mechanisms* that may cause leakage.

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In conclusion,
quasi-zero leakage in service could be envisioned only under *ideal conditions*, including :

- perfect design for installation and performance;
- reservoir with no appurtenances;
- double geomembrane liner;
- perfect earthwork and ground preparation;
- geomembrane installation under ideal conditions;
- first-class installing crew;
- strict construction quality assurance;
- electrical leak location survey of both liners;
- **Zero leak at end of installation;**
- well-planed and careful operation and maintenance;
- no filling-emptying cycles; etc.

**Zero leak at end of installation
is only one of the conditions.**

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Considering that these ideal conditions are rarely met, and considering that **specifying zero leakage** or an *excessively small leakage rate*, may lead to extensive investigations and repairs that could cause defects generating **more leakage**, the rational approach consists in specifying an **acceptable leakage rate** based on:

- an *evaluation of the consequences* of leakage that is specific to the project being designed; and
- *published guidelines, studies and recommendations* on acceptable leakage rates.

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I hope that this lecture will promote progress
in the design of liquid containment reservoirs.

Controlling leakage is **essential**
for the **protection of the environment**
not only
by **preventing migration of contaminants**
into the ground
but, also, by reducing waste of water.

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Saving water will be a major
economic and environmental **challenge**
for the coming decades.

Geomembranes
and other geosynthetics
will be at the forefront of the efforts
to meet this **challenge**,
and, therefore,
our industry should play a **major role**
in the 21st century.

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CLOSURE

I want to close this lecture
by sharing with Bob Koerner
the thoughts I presented today
on engineering, on geosynthetics,
on our discipline, on our industry.

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And thank you, Bob, for being together once again.

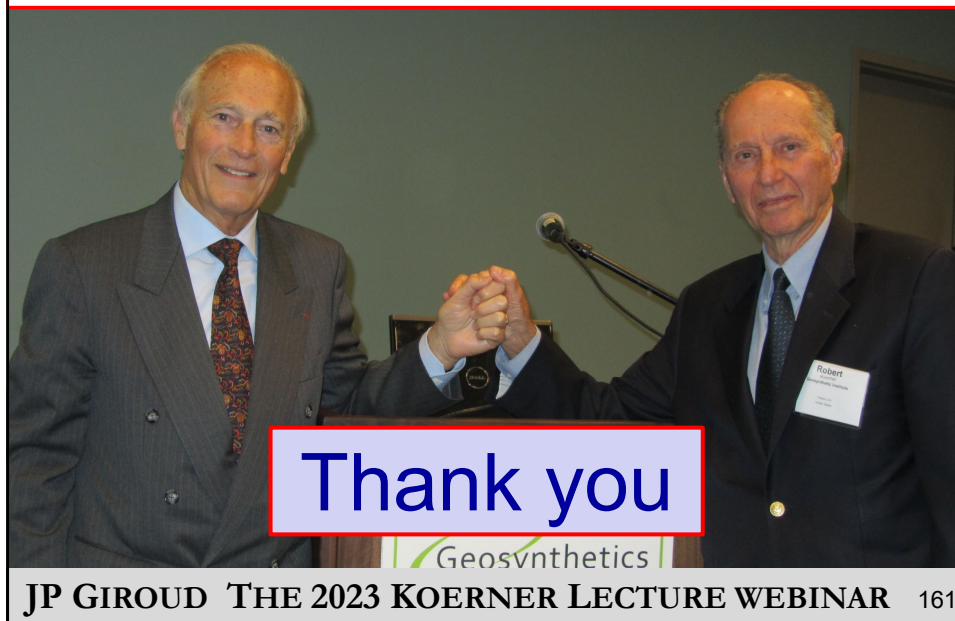


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And thank you all for attending.



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ACKNOWLEDGEMENTS

I am grateful to Eric Blond, Richard Thiel and Robert Wallace who reviewed this lecture and provided valuable comments.

I want to thank Fred Chuck and the Geosynthetic Materials Association (GMA) for their invitation to present the Koerner Lecture, as well as Barbara Connett and Rick Collins for their assistance.

I also want to thank Tim Stark and Jen Miller of the Fabricated Geomembrane Institute (FGI) for the organization of the webinar, which made this lecture available to an international audience.

A handwritten signature in black ink that reads 'JP Giroud'.

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References of papers on acceptable leakage rate (see Slide 156)

Peggs, I.D. & Giroud, J.P., 2014, "Action leakage rate for reservoir geomembrane liners", *Proceedings of the 10th International Conference on Geosynthetics*, Berlin, 10 p.

Giroud, J.P., 2016, "Leakage Control using Geomembrane Liners", The Victor de Mello Lecture, *Soils and Rocks*, São Paulo, Brazil, Vol. 39, No. 3 September-December 2016, pp. 213-235.

These two papers can be downloaded from
<https://geosyntheticconference.com/proceedings-archive/>

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ABOUT THE LECTURER

Dr. J.P. Giroud, civil engineer Ecole Centrale Paris and PhD University of Grenoble, is: a consulting engineer; a former professor of geotechnical engineering; co-founder and Chairman Emeritus of Geosyntec Consultants; past president of the International Geosynthetic Society (IGS); co-founder and former chairman of the Editorial Board of the IGS journals, *Geotextiles and Geomembranes* and *Geosynthetics International*; and a member of the U.S. National Academy of Engineering.

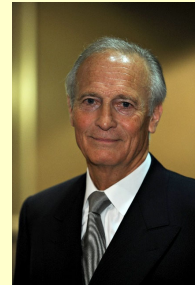
Dr. Giroud coined the terms "geotextile" and "geomembranes". He has developed numerous design methods used in geosynthetic engineering, for example, methods for leakage evaluation, liner stability on slopes and voids, filters, unpaved roads.

Dr. Giroud originated several geosynthetic applications: first use of a geotextile filter in a dam, first use of geotextiles to protect geomembranes, first double geomembrane liner, first use of a geonet between two geomembranes to form an entirely geosynthetic double liner, and his design method for geomembrane wind uplift made it possible to construct landfills with exposed geomembrane cover. Also, he co-pioneered construction quality assurance of geomembrane liner installation.

Dr. Giroud is author of more than 450 publications, and he has presented several prestigious lectures, such as: the Vienna Terzaghi Lecture, the ASCE Terzaghi Lecture, the Victor de Mello Lecture, the Széchy Lecture, the Mercer Lecture, the Jack Hilf Lecture, the Raoul Dutron Lecture, and now the Koerner Lecture.

Dr. Giroud has been appointed Honorary Member of the IGS with the mention "Dr. Giroud is truly the father of the International Geosynthetic Society and the geosynthetic discipline." The IGS has named his highest award "The Giroud Lecture" with the mention "in recognition of the invaluable contributions of Dr. J.P. Giroud to the technical advancement of the geosynthetic discipline".

Dr. Giroud is Doctor *Honoris Causa* of the Technical University of Bucharest, he has been named Hero of the Geo-Institute of the American Society of Civil Engineers, he received the Felix Leader Award of Ecole Centrale Paris for 2013, and he is Chevalier in the Order of the Legion d'Honneur.



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