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ELECTRO-OSMOSIS USING MULTI PULSE SEQUENCING FOR REMOVING AND REPELLING WATER OUT OF BUILDINGS AND OTHER STRUCTURES

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Abstract

Water ingress into sub-surface concrete structures takes place by capillary action, even through dense and un-cracked concrete. The water ingress problem can also be amplified by inflow through cracks in the concrete. Therefore the permanent drying of concrete structures cannot easily be achieved by using traditional waterproofing solutions as these do not easily prevent ingress through the body of the concrete due to capillary action.

Research over the past 20 years has resulted in the development of the Multi Pulse Sequencing (MPS) system which applies the technology of electro-osmosis to arrest the capillary ingress of the ground water and cause it to move in the opposite direction, to such an extent that it can repel water against a hydraulic pressure of 60bar. The MPS system ionizes the water molecules by applying low voltage DC pulses at a very low current level.

The system utilizes high grade materials and is virtually maintenance free.

Installation costs are competitive with traditional methods and on-going maintenance costs have been shown to be negligible for drying out leaking walls, basements, and tunnel linings for a range of applications over the last 8-10 years. These include the MTRC's Hong Kong Station pedestrian subway, a number of deep basements for major commercial buildings in Hong Kong, electrical cable tunnels in China and concrete dams in Norway amongst other projects.

A recent application for the London Underground's Walthamstow station has overcome water ingress problems that could not be successfully treated by traditional methods and has achieved their dryness certification standards and electro-magnetic compliance standards. Calibration of the electric current levels in the individual electrode circuits provides an effective means of monitoring the ongoing relative humidity levels in structural elements including those that are not readily accessible for inspection. Current levels will increase in response to any further ingress of water thus providing a unique self-control and performance monitoring system.

Introduction

In many parts of the world, structures that have been built below ground level, such as basements or tunnels, are prone to problems of moisture ingress from the adjacent ground, especially where there is a high water table such as where the structure is close to a river or the seashore. The damage associated with such moisture ingress costs billions of dollars per year, both in damage to the contents and in remedial repair work.

The traditional methods of keeping water out of concrete include the addition of integral waterproofing admixtures to the fresh concrete mix; the use of sheet or spray applied membranes to the hardened concrete, or the application of spray on penetrating chemicals such as silanes. Very often such systems are compromised during the construction period, and the defects only become apparent later in the life of the structure, when most forms of remedial work have difficulty in rectifying the problem.

It is well known that water penetrates concrete through defects such as cracks, tie-bolt holes, and badly formed construction joints. What is not generally known is that water often passes through the concrete via small capillaries. During the mixing process more water is added to the concrete than is actually needed to physically hydrate the cement. This additional water, which is added to the concrete in order to enable it to be fully compacted into the formwork in which it is placed, slowly dries out leaving very small passages known as capillaries. These are too small to be seen by eye but are present in all concrete. And if water can get out of concrete it follows that it can also get back in.

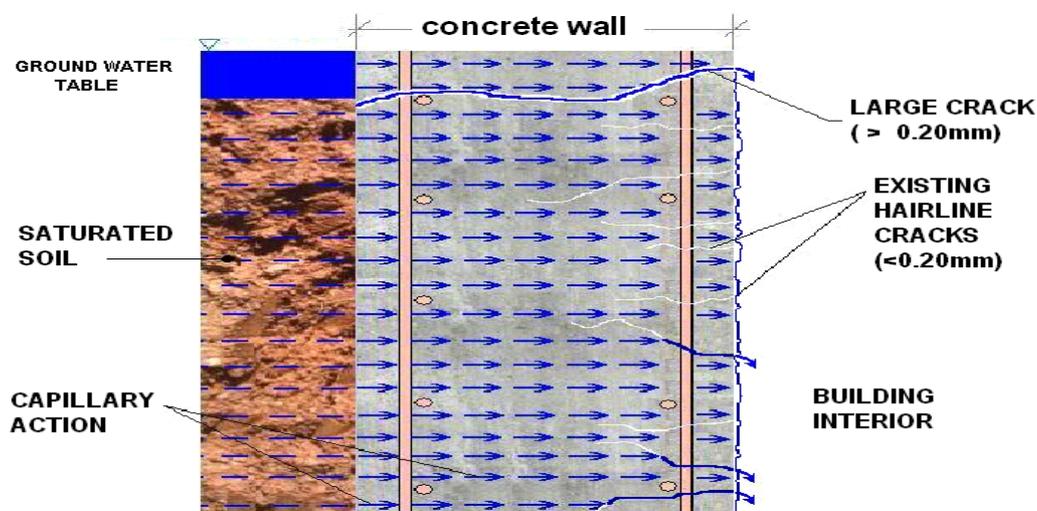


Plate 1 – Horizontal movement of water through capillary pores in a wall structure.

If one side of a concrete wall or floor is wet relative to the other, as for example happens in a basement, tunnel, or underpass, the water can migrate through the concrete, especially if there is a temperature or water pressure difference from one side of the concrete to the other. The water is drawn through the fine capillaries, in much the same way as tea will climb up a sugar cube if it is placed in contact with the surface of the tea. Even more important, the finer the capillaries, the greater is the water or vapour suction within them. Water will therefore pass through the body of the concrete as well as through defects such as cracks. This will cause any painted surfaces to bubble or blister as well as surface dampness on the interior of the

concrete wall, leading to the formation of mould and algal growths, in addition to providing breeding grounds for the growth of potentially harmful bacteria.



Plate 2 - Typical example of the problem caused by water ingress into the roof of a pedestrian subway

Air quality effects of damp concrete structures

Moisture and humidity in below ground structures give rise to breeding grounds for bacteria to flourish as well as the formation of mould growth.

The table below shows the results of air quality monitoring of the Shenzhen Metro where the air quality is severely affected by dampness. Many underground structures have similar problems but often the seriousness is not realised. Damp basements and subways can pose a serious health risk unless steps are taken to keep the wall surfaces dry.

Table 1: Results from testing air quality in Shenzhen Metro

Proportion	Micro organisms
100%	Mycete (a form of mould)
99.20%	Bacteria
11 no.	Haemolytic Streptococcus (Dangerous Bacteria)

- Notes:**
- 1. Total no. of air samples tested: 9,460**
 - 2. Source: Chinese Electronic Periodical Services (Dec. 2007)**

One of the ways to draw water out of concrete and keep it dry is by the use of electro-osmosis. This is an evolutionary technology, built on well proven scientific theory. It can give new life

to existing structures and is also very useful when applied to new build projects. It can offer an economic and permanent solution to all groundwater ingress problems which are very common in many parts of Singapore and South East Asia.

Electro-osmosis

Electro-osmosis has been around for many years in the geotechnical field as a system for the removal of water from fine grained soils and clays but has only been used in concrete in more recent years. The system works by applying a very low electric charge which is passed through conductive electrodes in the form of probes or wires which are strategically placed within portions of concrete walls, ceilings or floors that are either wet, or from which the water needs to be excluded. By passing a low voltage pulsating charge between the positive and negative electrodes the water is ionized and drawn towards the negative electrode which is placed in damp soil on the outside of the structure. When the electric power is turned on the water starts to be expelled from the concrete. Once in operation this system will permanently prevent water from intruding back into the structure, ie it is an active rather than a passive system. The wet areas of the concrete are eradicated and will remain dry for the life of the structure. It can prevent water even with a head of 600metres (60 bar) from penetrating the concrete as long as the electric power is switched on.

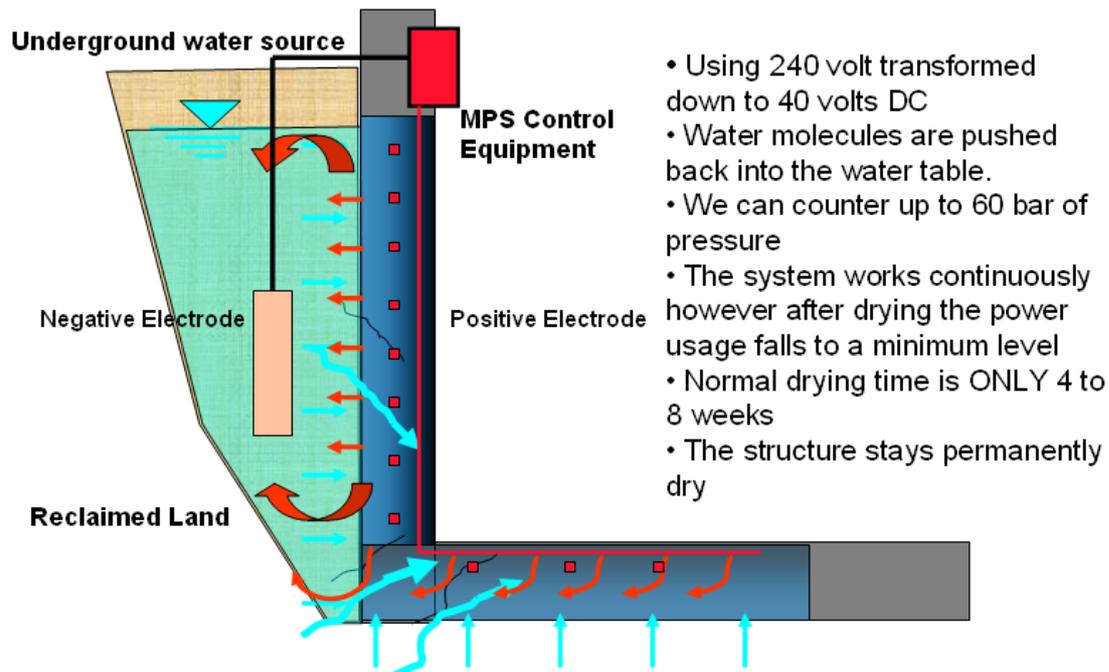


Plate 3 – The MPS System in action

The normal installation procedure is to place small diameter titanium wires into sawn or pre-formed grooves in the concrete 23mm deep and to encase them into a special conductive grout. These are the positive electrodes and they are placed between about 800mm to 1200mm apart depending on the thickness and properties of the concrete. The negative electrode is placed in the ground outside the building and the two sets of electrodes are connected through a junction box to the main control unit. In new build projects it may be possible to cast the titanium electrodes into the concrete, which would represent a considerable cost saving compared with positioning the electrodes in sawn or pre-formed grooves. When the grout has hardened and the power is switched on, it takes about 4-6 weeks on average to dry out the concrete. Once the concrete is dry, it will remain in a dry condition

providing the power is not switched off. In the event of a power cut, it will take at least as long for the water to get back into the concrete, as it did to dry it out in the first instance, and since it is unlikely that the power will be off for more than a few hours under normal conditions, the concrete will therefore still be protected from the problems of water ingress. The system costs no more to install than a conventional waterproof membrane system and the power consumption is minimal at about 10 watts per 1000m² of concrete area, and the concrete is touch safe.



Plate 4A – Measuring the moisture content of the floor prior to installing the system



Plate 4B – Marking out the position of the electrodes in the concrete floor.

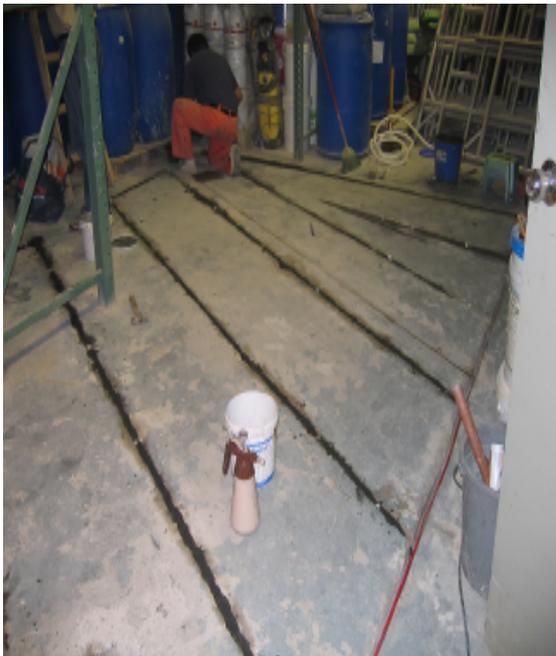


Plate 4C - Grouting up the electrodes in the concrete floor



Plate 4D – Installing the MPS control unit

Electro-osmotic control of water is not a new concept. Over 60 years ago a Geotechnical Engineer, Casegrande, experimented with the technology and used it to stabilize soil slopes, and in 1967 a Scandinavian engineer, Lauritis Bjerrum described a project in which electro-osmosis was successfully used to dewater an excavation in very soft, weak Norwegian clay. It is therefore surprising that the technology has not been more widely employed in the construction industry. One of the main reasons for the previous lack of take-up of this technology probably relates to the crude nature of the control systems that were used in the past, where constant rather than pulsed voltage systems were applied. The new technology also utilises very low voltages and a control system which can adapt to varying concretes and moisture states within the structure. As long as certain conditions exist, such as the existence of a relatively continuous source of groundwater, and a concrete with a series of interconnected capillaries, the system will successfully drive the water out of the concrete. If the concrete contains cracks in excess of 0.2mm wide these may have to be sealed using conventional crack repair methods. The cracks are only a problem if they pass through the full thickness of the concrete. Surface cracks can be ignored. In order to establish whether the cracks need to be repaired, the system can be activated following its installation, and any cracks that are in need of rectification will remain damp and are therefore easier to identify. This saves the effort in needlessly repairing inert surface cracks.

There are no deleterious effects on any adjacent buried services within the concrete. This has been confirmed following extensive tests carried out for electromagnetic compliance by York EMC Services Ltd, following which the technology has been granted a full European EMC compliance certificate. It has also satisfied all the stringent requirements for London Underground and Metronet in the UK in connection with EMC compliance for railway system. In addition it has been shown not to induce any stray currents in the steel reinforcement following independent tests undertaken by CAPSIS.

The system is essentially self-regulating, since as the concrete structure dries out, the electrical resistance of the concrete rises proportionally, resulting in less current being drawn and a rapid decrease in the corresponding rate of moisture movement. If the relative humidity of the concrete increases, perhaps in response to prolonged heavy rainfall or a broken pipe, the system responds immediately to counter the moisture ingress. The increasing relative humidity will reduce the concrete resistivity resulting in an increase in the current flow which will drive any moisture away from affecting the inside face of the structure.

The installation of the MPS osmotic system requires careful quality control which is achieved using trained supervisors. Once installed apart from periodic checking there is no obvious need for ongoing maintenance of the installation and it should continue operating for many years without requiring any intervention.

Project references

The system has been used on a number of significant projects in Asia as well as other parts of the world.

An interesting application was in the Central Subway of the MTRC underground railway in Hong Kong. The subway has artwork on the walls and it was important to protect the artwork so that it did not become damaged by possible water ingress problems. Eight years ago the system was installed and it is still functioning perfectly. The adjacent section of subway was not installed with the system. This provides an excellent control for monitoring the benefits of the system. Plate 5 shows the area behind the wall where the system was installed. On the

left it can be seen that the supports are still in good condition but on the right in the untreated area the supports can be seen to be beginning to corrode.



Plate 5 – Area behind the wall where the artwork was installed. On the left the supports are still in good condition, whereas on the right in the untreated area the supports are beginning to show signs of corrosion.

In the basement of the Hong Kong International Finance Centre there was severe salt water ingress through the walls, which resulted in the lift machine room being extensively flooded. Following the installation of the MPS system in 2000 the water ingress has completely ceased and the machine room has completely dried out.



Plate 6 – IFC below carpark area, machine room was flooded out, now completely dried out after MPS installation

In the loading bay in the basement of City Plaza 4 in Tai Koo Shing, the Diaphragm wall was completely saturated from ground water ingress. One section of the loading bay was treated and this was subsequently extended to include two further bays. The wall has remained bone dry for over 10 years. Plate 7 shows how the moisture content in the walls has dropped to a value of 82% which is 10% lower than the 92% paint dry standard specification of BS 6150. As the wall dried out, the current dropped from an initial value of 200mA down to a value below 10mA.

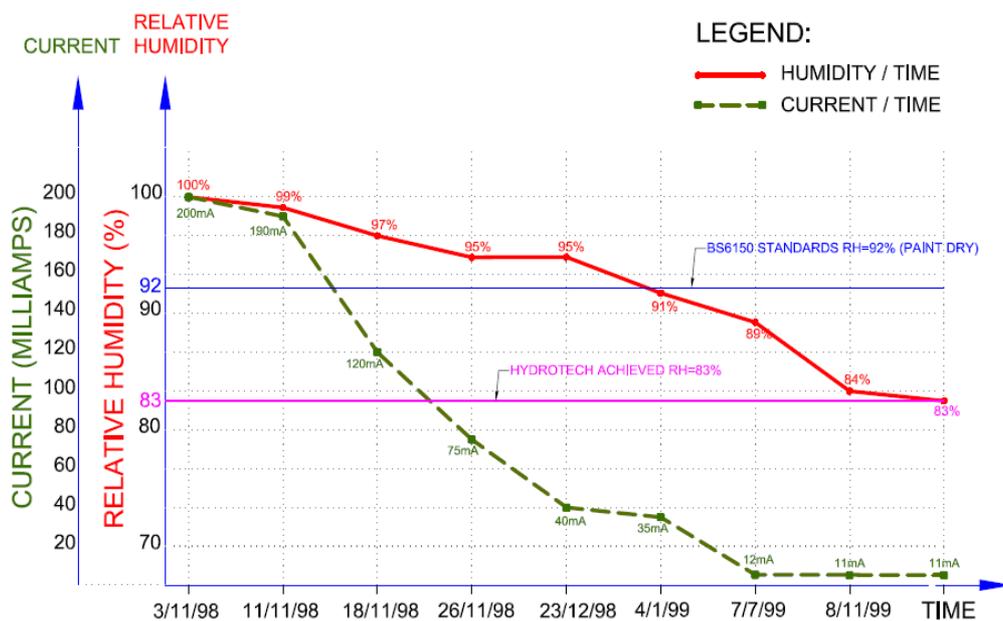


Plate 7 – MPS Intelligent System, Control and Performance Monitoring

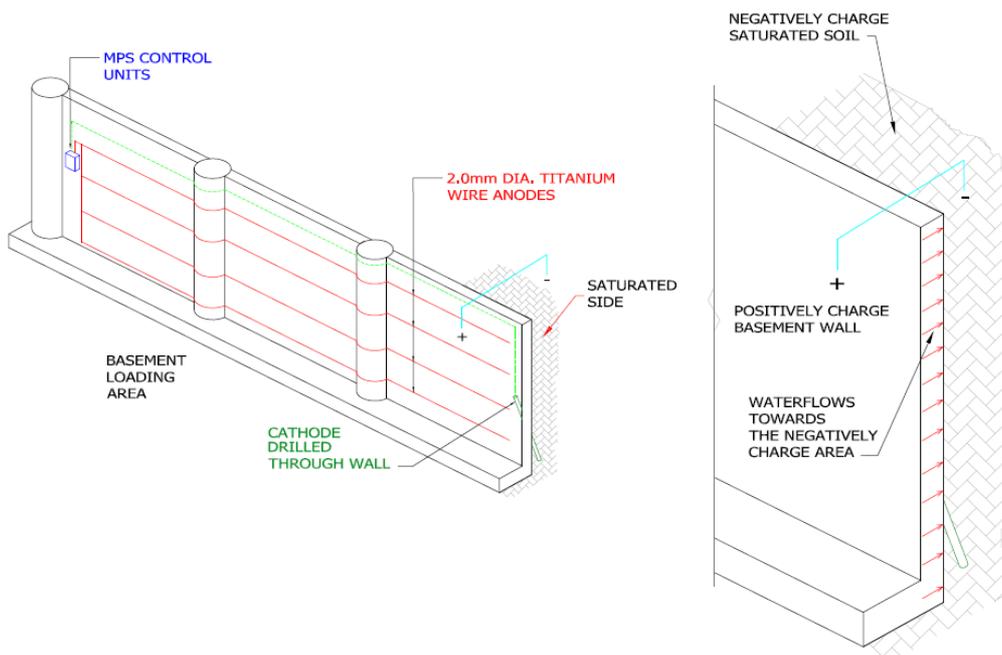


Plate 8 – Electrode Placement in City Plaza 4

The London Underground Walthamstow station subway was two years late opening because of the water ingress problems encountered. Following the installation of the MPS system it completely dried out and is now in daily use.



Plate 9 - Jebel Ali.



Plate 10 - Walthamstow Subway dried out and now in use.
More than 22,000m³ of concrete were cast in a single continuous pour lasting 35 hours.

The system has also been installed in structures such as Dams. The Tafjord Dam in Norway is the second highest dam in Europe and has been successfully repaired using the MPS system. In the 1990's it was thought that the dam could not be repaired and it was scheduled for demolition but since the installation of the MPS system it is now in good condition since the leakage has successfully been stopped.



Plate 11 - Tafjord Dam is Europe's second highest at 96meters. Electro-osmotic technology was employed to address the defects and the leakage was stopped

Many other buildings and structures worldwide now benefit from the installation of an MPS system to keep them dry and in a good condition.

Conclusions

Electro-osmosis is a well proven method of driving moisture out of concrete. The power consumption for its ongoing operation is minimal, at about 10 watts per 1000m² of the concrete area. Its use will help to prevent steel corrosion and the occurrence of alkali-aggregate reaction. Because it reduces the moisture in basements it reduces the corrosive environment for plant and equipment. It also prevents the occurrence of mould and bacteria formation on damp wall surfaces. In addition some of the other benefits are listed below.

It provides a permanent solution for waterproofing suitable structures and can be retro-fitted to existing buildings and structures. It is also cost effective and easy to install. It can also be installed from the inside face of the structure, eliminating the need for expensive exterior work. It is environmentally friendly with no harmful emissions or waste and has no damaging effects on the structure or its material composition.

TABLE 2: WATER INGRESS PROTECTION BY MPS

OBJECTIVES	SYSTEM PERFORMANCE
Reducing / preventing capillary absorption	●
Minimise ingress through cracking <0.2mm	●
Minimise ingress through cracking >0.2mm	n/a
Prevention of Corrosion of steel rebar	●
Prevention of cracking from expansion of corroding steel	●
Long Term Humidity, Mould and Bacteria and Odour Control	●
Heating/Vent/A-C Savings	●
Performance Monitoring	●

● - Effective n/a - Not Applicable

In addition it prevents peeling paint, and mould formation, and its dehumidifying effect improves the thermal insulation of the structure, thereby reducing both heating and air conditioning costs.

It also reduces or eliminates the need for drained cavities in dry-wall construction with a corresponding space saving and reduction in cost.

Once the benefits of the system are more fully appreciated it is a technology that will find wide scale use in both new build projects and in eliminating moisture ingress in existing

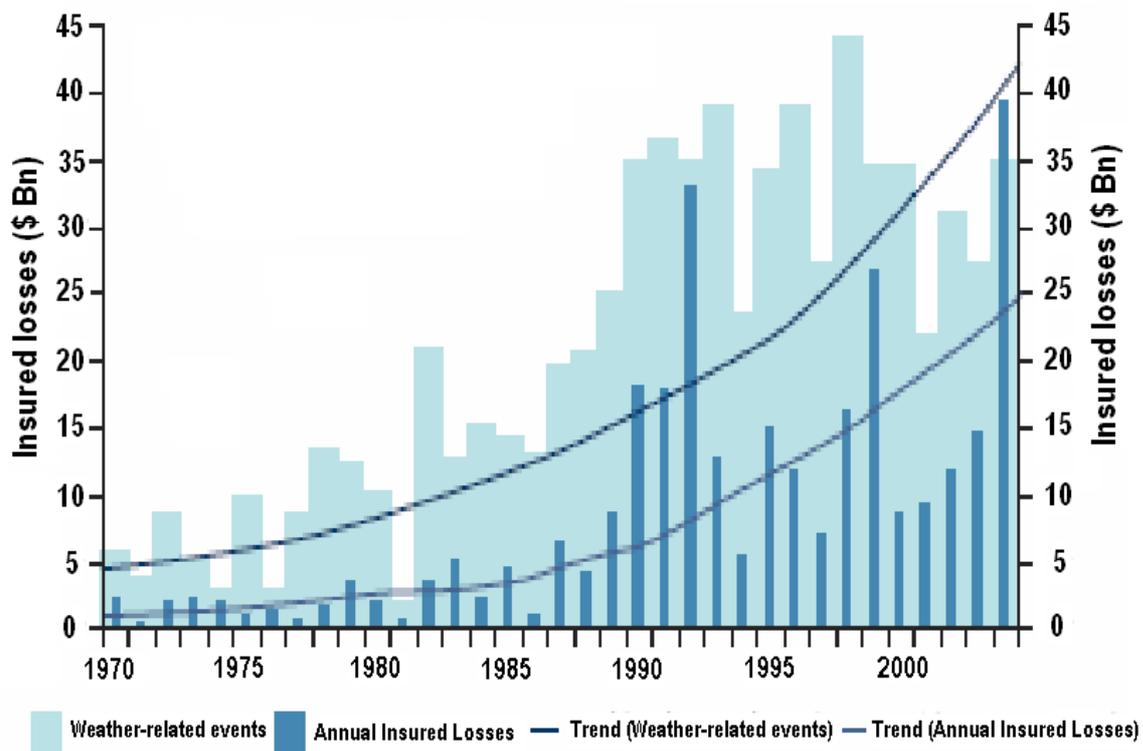
buildings and structures, especially those where traditional repair methods have not been able to solve the problem. The technology can also be applied to brick and masonry structures, bridge abutments and arches and underground car parks.

In concrete buildings, especially those constructed with geologically older rock types, the concrete tends to emit Radon gas which is highly carcinogenic. In above ground situations most of the gas can simply be dispersed by opening the windows, but in below ground situations the gas can build up to a high concentration and is normally difficult to disperse. Additionally, if the structure is founded on older rock substrates such as Granites, additional Radon gas can permeate the structure from concentrations in the rock. The MPS electro-osmotic system will help to drive the gas back out of the structure and minimise the risk in below ground applications.

Global Warming Effects

This chart shows the ever increasing trend towards weather related insurance losses (quoted in US Dollars). Many of these problems are related to damage caused by water ingress to buildings and structures. Much of this damage can be minimised through the installation of Electro-osmosis system in buildings and structures that are prone to flooding such as those constructed on the flood plains associated with rivers.

Global cost of extreme weather



Source: Swiss Re Sigma Database

List of References

1. Bao-Ying Ye, Yan-Min Quin, Ran Zhang., 2001 Detection Results of Microorganisms in the air of Shenzhen Metro. Chinese Electronic Periodical Services 21/12/2007/
2. Swiss Re Sigma Database., Global Cost of Extreme Weather, 2008