Types of Tunnels & Construction Methods

A tunnel is an underground passage through a mountain, beneath a city or under a waterway.

It may be for pedestrians and/or cyclists, general road traffic, motor vehicles , rail traffic, or for a canal. Some tunnels are constructed purely for carrying water (for consumption, hydroelectric purposes or as sewers); others carry services such as telecommunications cables.

- <u>Mountain Tunnel</u>

-- Drilling and blasting (D&B) method

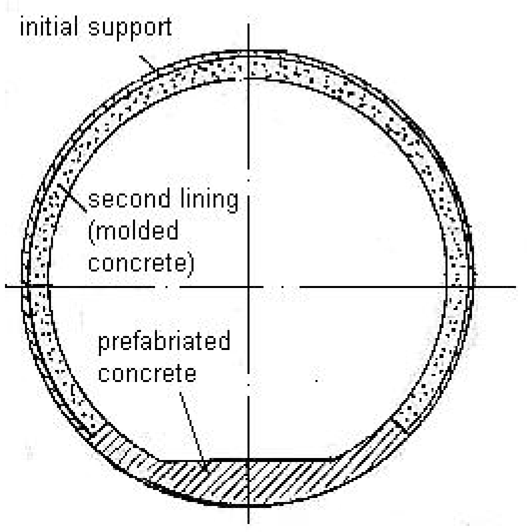
NATM (New Austrian Tunneling Method) is the most common method. It originates in hard rock tunneling and utilizes rockbolts and shotcrete applied immediately after blasting. This is often followed by a cast in-situ concrete lining using formwork.

-- Tunnel Boring Machine (TBM) method

TMB is used as an alternative to drilling and blasting (D&B) methods. TBMs are used to excavate tunnels with a circular cross section through a variety of subterranean matter; hard rock, sand or almost anything in between.

As the TBM moves forward, the round cutter heads cut into the tunnel face and splits off large chunks of rock. The cutter head carves a smooth round hole through the rock -- the exact shape of a tunnel. Conveyor belts carry the rock shavings through the TBM and out the back of the machine to a dumpster.

Tunnel lining is the wall of the tunnel. It consists of precast concrete segments that form rings, cast in-situ concrete lining using formwork or shotcrete lining.



- <u>Shallow-buried Tunnel or Soft Soil Tunnel</u>

Shallow tunnels are of a cut-and-cover type (if under water of the immersed-tube type). Deep tunnels are excavated, often using a tunnelling shield. For intermediate levels, both methods are possible.

-- Cut-and-cover method

Cut-and-cover is a method of tunnel construction where a trench is excavated and roofed over. Strong supporting beams are necessary to avoid the danger of the tunnel collapsing.

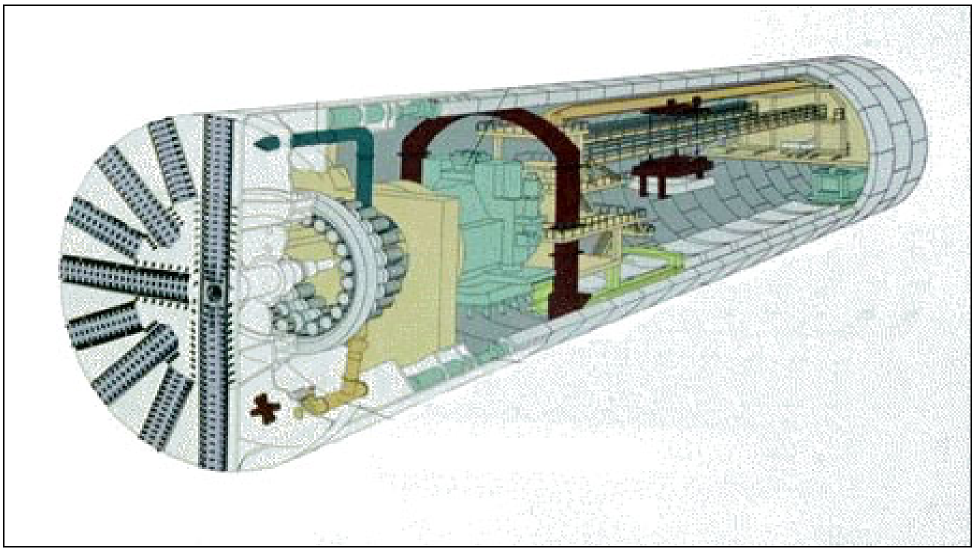
-- Shield method

The Shield method uses one or two shields (large metal cylinder) to cut out a tunnel through the soft ground.

A rotating cutting wheel is located at the front end of the shield. Behind the cutting wheel is a chamber where, depending on the type of the TBM, the excavated soil is either mixed with slurry (called slurry TBM) or left as is (earth pressure balance or EPB shield). Systems for removal of the soil (or the soil mixed with slurry) are also present.

Behind the chamber is a set of hydraulic jacks supported by the finished part of the tunnel which are used to push the TBM forward. Once a certain distance has been excavated (roughly 1.5-2 meters), a new tunnel ring is built using the erector. The erector is a rotating system that picks up pre-cast concrete segments and places them in the desired position.

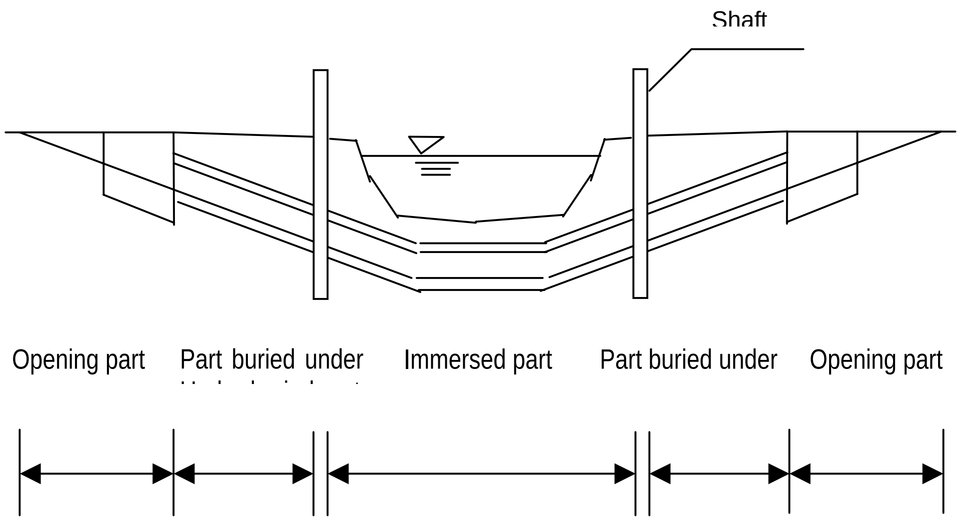
Behind the shield, inside the finished part of the tunnel, several support mechanisms can be found that are part of the TBM: dirt removal, slurry pipelines if applicable, control rooms, and rails for transport of the precast segments, etc.



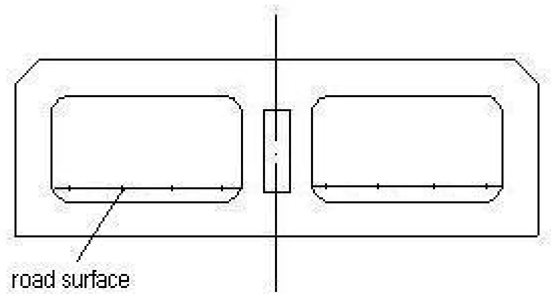
Underwater Tunnel

-- Immersed-tube method

The immersed tube tunnel technique uses hollow box sectioned tunnel elements that have been prefabricated in reinforced concrete. These are floated out into the harbor and placed into a trench that was pre-dredged in the harbor bed. When in position, the elements are joined together to form a tunnel. The trench is then refilled and the harbour bed returned to its original level.



Longitudinal Profile of an Immersed-tube Tunnel



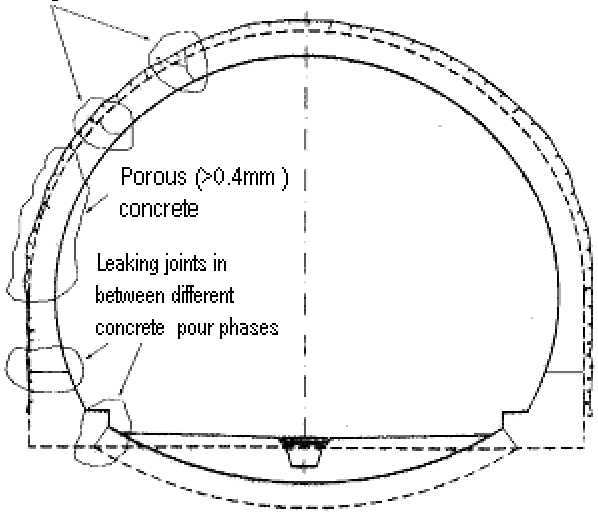
Transversal Profile of a Rectangle Immersed Tube Segment

-- Shield method

As previously stated.

Why Tunnel Structures Deteriorate

Typical Defects in the Impermeability of the Tunnel Lining



Moisture, water and chemical damage to concrete

- Even concrete of high quality is a porous material
  - -- Excess water evaporation during hardening will leave millions of pores and capillaries in concrete
  - -- The zones between cement and aggregates are prone to cracking during hardening due to drying shrinkage, temperature stress and outside forces
- Porosity of concrete
  - -- Allows moisture, water and chemicals to move freely throughout the concrete
  - -- Increases absorption of deleterious chemicals

- **<u>Cracks may develop as tunnel structures are constantly moving and developing strains due to earth loads, stress redistribution and tectonic seismic influences.</u>**

  -- **If not waterproofed, cracks can allow water to pass into the structure and possibly damage utilities, interior finishes and even the structure itself.**

- <u>Moisture, water and chemical intrusion</u>

  -- Results in corrosion of the concrete due to chemicals dissolved in water

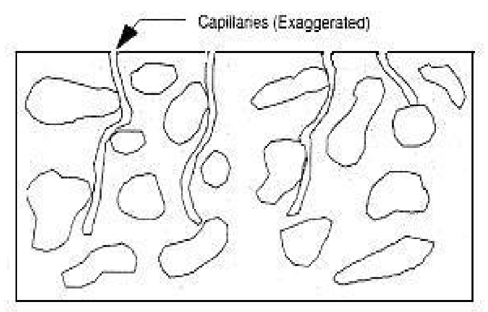
  -- Results in concrete neutralization (carbonization)

  -- Results in alkali-aggregate reaction

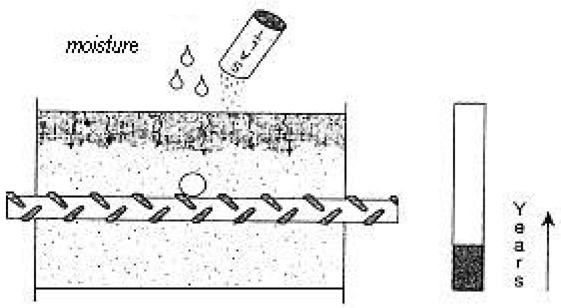
  -- Freeze/thaw cycles can lead to concrete cracking and damage

  -- Reduces structural property

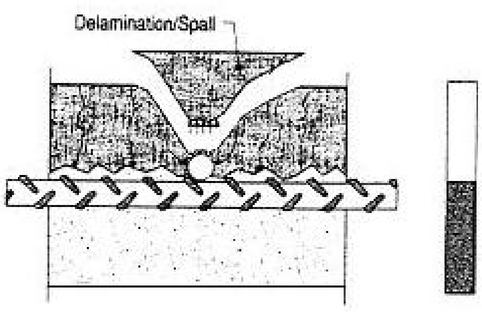
Moisture, water and chemical damage to reinforcing steel



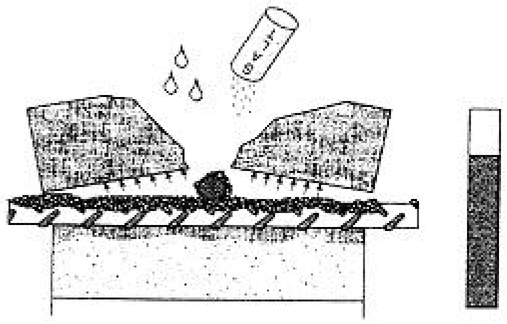
Millions of pores and capillaries are left in untreated hardened concrete



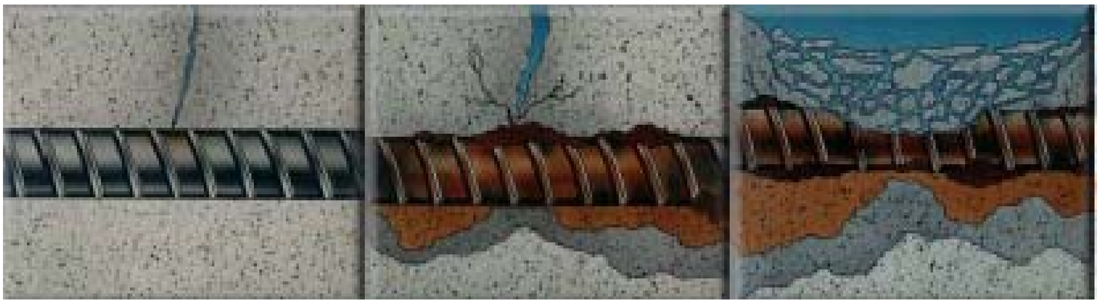
Chlorides penetrate into concrete with the help of surface moisture and water



When chlorides penetrate reinforcing steel, corrosion begins



Further penetration of chlorides results in further corrosion, deterioration and spalling



Over time, any untreated concrete structure will slowly succumb to damage due to the presence of water and chemicals.

What Are Penetron Products?

- Penetron products are cementitious capillary crystalline waterproofing materials

  -- Powders consisting of Portland cement, quartz sand and multiple activating chemicals

  -- A range of activating chemicals in powder form that can be applied to concrete as an admixture, slurry and dry-shake

- Penetron products can effectively stop water and moisture penetration into concrete, providing the best protection by improving the capillary structure and reducing porosity

--	Penetron	Applied by brush or spray on hardened concrete surface
--	Penetron Plus	Dry shake application on horizontal fresh concrete surface
--	Penetron Admix	An additive mixed into new concrete at the time of batching for complete integral waterproofing

- Applications

Water towers & storage tanks	Reservoirs & dams	Swimming pools
Subway & other tunnel systems	Bridge decks	Parking decks
Off-shore & marine structures	Basements	Foundations
Sewage and water treatment plants	Traffic-bearing structures	Elevator shafts

- Company passed ISO 9001 quality system authentication

ISO 9001 : 2000

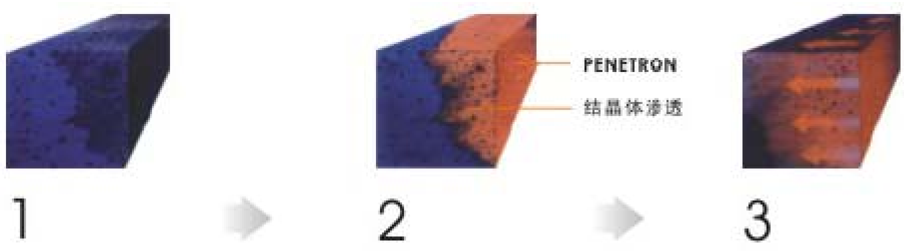
Registered Company

TÜV

TÜV Rheinland of North America, Inc.

How Penetron Products Waterproof & Protect Concrete

- <u>Penetron or Penetron Plus</u>



1: Typical concrete structure with moisture

2: When mixed with water and applied as a coating, the active chemicals in Penetron cause a reaction leading to the formation of nonsoluble crystals within the pores and capillary canals of concrete

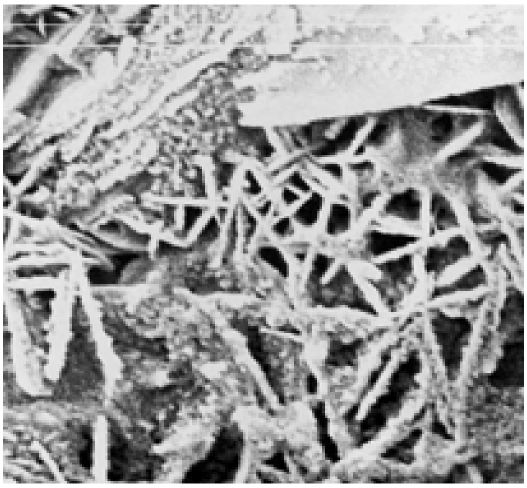
3: The concrete becomes permanently sealed and neither water nor any other liquids are able to penetrate the concrete from any direction

Concrete is saturated with water so that there is an adequate amount of liquid present to allow movement of chemicals into the concrete pores. The chemicals are pushed into the concrete through the action of diffusion. Under the right conditions, the chemicals can also move into the concrete by seeping water, or by the natural wicking action of the concrete.

Once into the concrete, the chemicals react with unhydrated cement particles, and by-products of cement hydration to form needle-like crystals that fill and block the pores and capillaries in the concrete. As water can no longer pass through the concrete it is defined as being “waterproof”.

In the absence of moisture, the activating chemicals remain dormant in concrete for years. If minute cracks recur, at any time, any penetrating moisture will activate the dormant materials, and the chemical reaction and sealing process will repeat itself automatically

- Penetron Admix



Penetron Admix is a unique crystal-forming additive that provides permanent protection for buildings and other structures by waterproofing concrete from the inside out.

Penetron Admix is added to the concrete mix at the time of batching. The activating chemicals of the product react with water, unhydrated cement particles and by-products of cement hydration in concrete to form needle-like crystals. These crystals grow and migrate through the concrete to fill in hairline cracks and microscopic voids that would otherwise serve as passages for harmful moisture.

Penetron Admix enhances the natural hydration process in concrete by intensifying hydration crystal growth, increasing compressive strength and reducing cracking caused by shrinkage.

In absence of moisture, the activating chemicals remain dormant in concrete for years. Should cracks recur at any time, these dormant materials are activated by any penetrating moisture, and the chemical action and sealing process repeats itself automatically.

Features, Advantages & Benefits

- Features and Advantages

-- Penetron Admix

Permanent waterproofing admixture

- Impermeability lasts as long as the concrete
- System becomes an integral part of the concrete
- Does not require re-application

Resists high hydrostatic pressure from either positive or negative surface

- Ideal for below grade application
- Does not need any other form of waterproofing
- Protects against waterborne ground contaminants

Protects reinforcing steel from corrosion

- Highly resistant to waterborne aggressive chemicals
- Stops ingress of water required for AAR
- Allows concrete to breathe, eliminating vapor buildup and leaving the concrete completely dry

Crystal growth years after initial construction

- Will re-activate in the presence of moisture
- Self-heals hairline cracks of up to 0.4mm and stop water ingress that may occur from subsequent damage to the structure
- Continually improves with time

Multifunctional admixture

- Does not contain stearates, sodiums or silicates
- Not a hydrophobic type product
- Not a surface densification product
- Assists concrete in the hydration process, acting as a catalyst to un-hydrated cement particles already existing in the concrete
- Water-reducing, increasing workability of fresh concrete
- Increases compressive strength of hardened concrete
- Non-toxic
- Approved for portable water use

-- Penetron or Penetron Plus

In-depth waterproofing property

- Penetrates deeply, and impermeability lasts as long as the concrete
- System becomes an integral part of the concrete, forming a complete body of strength and durability
- Waterproofing and chemical resistance property remain intact even if the surface is damaged

Completely effective against high hydrostatic pressure

- Ideal for below grade application, reservoirs and pipelines
- Does not require protection during backfilling, placement of steel or wire mesh and other common procedures
- Protects against waterborne ground contaminants

Protects reinforcing steel from corrosion

- Resists chemical attack (PH3-11 constant contact; PH2-12 periodic contact) and provides a wide range of protection from freeze/thaw cycles, aggressive waters, sea water, carbonates, chlorides, sulfates and nitrates
- Stops ingress of water required for AAR
- Allows concrete to breathe, eliminating vapor buildup and leaving the concrete completely dry

Will grow crystals years after initial application

- Will re-activate in the presence of moisture
- Self-heals hairline cracks of up to 0.4mm and stop water ingress that may occur from subsequent damage to the structure
- Continually improves with time

Efficient application method

- Can be applied from either the positive or negative side
- Can be applied to moist or green concrete
- Can be used for new or existing concrete
- Compatible with waterbased glues and surface coatings

High-growth technology

- Zero VOC
- Does not contain stearates, sodiums or silicates
- Not a hydrophobic type product
- Not a surface densification product
- Non-toxic
- Approved for portable water use

- <u>Benefits of Penetron Technology</u>

-- Penetron Admix

Benefits to Property Owners

- Cost effective
- Lowers overall project costs
- Permanent waterproofing system
- Requires no maintenance
- Increases the quality of the concrete for structural performance and integrity
- Increases usage of infrastructure
- Eliminates down-time and costs associated with maintenance and repairs
- Reduces project time requirements
- Long-term manufacturer's warranty
- Manufacturer's history of international success in various climatic & environmental conditions

Benefits to Contractors

- Unmatched technical support
- Reduces application errors associated with installation of other systems
- Improves pouring and placement of concrete
- Eliminates construction delays due to elimination of traditional waiting period to install membranes on cured concrete

-- Penetron or Penetron Plus

Benefits to Property Owners

- Cost effective
- Lowers overall project costs
- Permanent waterproofing system
- Requires no maintenance
- Long-term manufacturer's warranty
- Manufacturer's history of international success in various climatic & environmental conditions

Benefits to Contractors

- Unmatched technical support
- Reduces application errors associated with installation of other systems
- Reduces risk of membrane failure
- Requires no protective cement mortar in comparison with other systems

Comparison of Penetron Products to Other Waterproofing Systems

	Penetron Penetron Plus	Penetron Admix	Membranes (Positive Side)	Other Surface Applied Products
Description	Cementitious material applied on concrete surface to transfer needle-like crystals to infiltrate the concrete mass	Cementitious material added into fresh concrete to form needle-like crystals within the concrete mass	Liquid and sheet applied bitumens and polymers affixed to the concrete surface	Materials applied to concrete surface containing mainly water repellents and sealants
Resistance to hydrostatic water pressure	• Improves with time • Resistance to exceeding 150m head pressure • Withstands 3Mpa in permeability test	• Improves with time • Continuous self-healing ability • Initiates full hydration	• Protection breached by any pinhole or seam • Once leaking, will require replacement	• Reduces initial absorption but will deteriorate with time • Limited penetration leads to poor resistance to hydrostatic pressure
Protection of reinforcing steel	• Prevents corrosion of reinforcing steel by stopping passage of water and chlorides	• Permanent protection • Prevents any permeation of water and chlorides	• No negative side protection • Easily leaks at the joints and seams	• No negative side protection • Limited protection as it slows the water ingress in uncracked areas
Crack self-healing ability	• Will re-activate in the presence of moisture to seal new cracks even years later	• Will re-activate in the presence of moisture to seal new cracks even years later	• No self-healing ability	• No self-healing ability
Crack resistance	• Rigid material, can not bear excessive transformation, but self heals minor cracks of up to 0.4mm	• Reduces cracking in plastic and curing stage • Self heals minor cracks of up to 0.4mm in the presence of moisture	• Can bear excessive transformation • Limited time protection at existing cracks locations	• No crack resistance • Temporarily fills existing cracks
Freeze/thaw durability	• Improves durability by removing water within concrete • Eliminates water penetration at cracks	• Improves durability by removing water within concrete • Eliminates water penetration at cracks	• Slow deteriorating factors initially	• Slow deteriorating factors initially • No durability at crack locations
Repair requirement	• Permanent waterproofing protection, does not need repair	• Easily repaired from positive or negative side • Wide range of options are available • Repairs are cost effective	• Difficult to repair • Difficult to locate pinholes and poor joints • May require total removal & repair • Expensive and sometimes impossible due to accessibility	• Repairs may require removal of previous materials

	Penetron Penetron Plus	Penetron Admix	Membranes (Positive Side)	Other Surface Applied Products
Application	• Applied by brush/ spray to positive or negative side of old/new concrete • Or, dry shake application on horizontal fresh concrete surface	• Mixed at batch plant or on-site • No additional applications required	• Liquids: brush application • Sheets: glued or welded to the concrete surface • Correct joints and seams critical to performance	• Only applied to positive side • Substrate profile critical to performance
Surface preparation	• Needs coarse, water saturated, clean surface for brush or spray • No surface prep for dry shake	• No surface preparation	• Clean surface • Dry surface • Smooth surface	• Needs surface prep depending on products requirements
Construction schedule	• Can be applied during concrete finishing or anytime following	• Added into fresh concrete at the time of batching • Saves 10-50% time and construction costs	• Must be applied at completion of structural work • Require protective cement mortar	• Some require 28 days cured concrete • Similar scheduling as membranes
Effective land usage	• Can be applied to the negative side of concrete allowing construction tight to property lines	• Can build tight with property lines	• Spaces required between property line and concrete for membrane installation	• Spaces required between property line and concrete for surface application
Sub-surface drainage system	• Not required	• Not required	• Require drainage under high hydrostatic pressures	• Require drainage under high hydrostatic pressures
Additional coatings	• Can be finished with coatings, tiles, etc.	• Does not affect coatings • Adhesion excellent for coatings or tiles	• Require protective mortar prior to surface finishes	• May require special preparation prior to surface finishes
Maintenance	• Not only as a surface coating • Maintenance not required	• Maintenance not required for the life of the concrete	• Costly replacement generally required	• Re-application required under hydrostatic conditions
Service life	• Permanent and improves with time	• Life time of concrete	• Become brittle with age resulting in cracks and openings • Surface damage will eliminate protection	• Best when first applied • Deteriorate with time • Vulnerable to surface damage

Penetron Tunnel Treatment

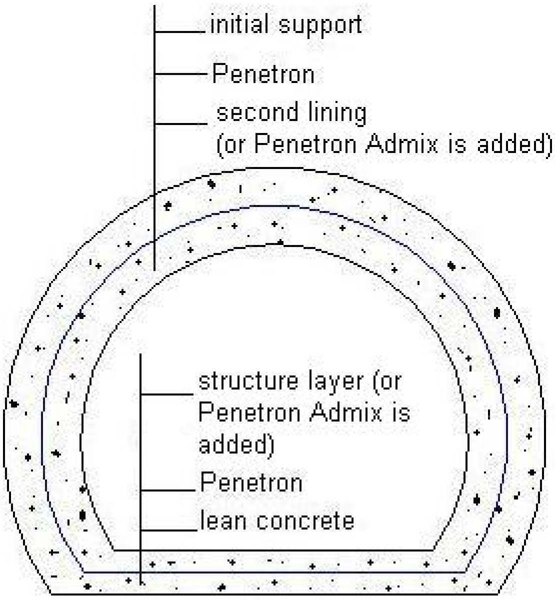
As underground structures are constantly moving and developing strains due to earth loads, stress redistribution and tectonic and seismic influences, cracks may develop in the structure. If not waterproofed, the cracks can allow water to pass into the structure and possibly damage utilities, interior finishes and even the structure itself. Therefore a waterproofinging system must be able to bridge the cracks to keep the structure dry.

There are two types of waterproofing systems: an "open" and a "closed" system. The "open" system utilizes the waterproofing materials to channel the water to sidewall drains that must be cleaned and maintained on a regular basis. For structures below groundwater level, the entire structure is wrapped with the waterproofing system creating a "closed system".

- Penetron Mountain Tunnel Treatment

  -- New Austrian Tunneling Method

  Concrete self-waterproofing treatment or Concrete surface waterproofing treatment



Concrete self-waterproofing treatment

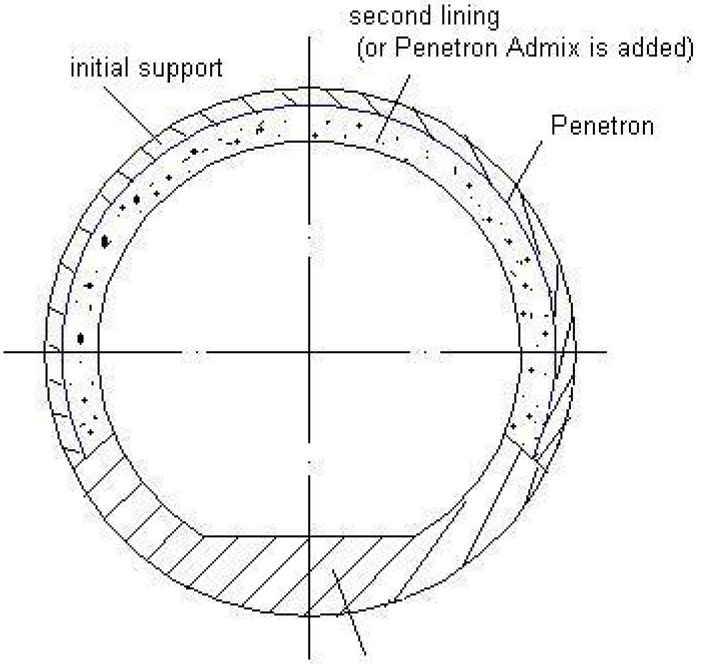
Penetron Admix is added into concrete (cast in-situ concrete as second lining and structure concrete) at the time of batching for complete integral waterproofing.

Concrete surface waterproofing treatment

Penetron is applied on the surface of concrete (lean concrete and shotcrete as initial support) by brush or spray.

-- TBM (Tunnel Boring Machine) method

Concrete self-waterproofing treatment or Concrete surface waterproofing treatment



Concrete self-waterproofing treatment

Penetron Admix is added into concrete (cast in-situ concrete lining or precast concrete lining as second lining and prefabricated concrete) at the time of batching for complete integral waterproofing.

Concrete surface waterproofing treatment + Concrete self-waterproofing treatment

Penetron is applied on the surface of precast concrete lining by brush or spray. At the same time, Penetron Admix can also be added at the time of batching for complete integral waterproofing.

- Penetron Shallow-buried Tunnel or Soft Soil Tunnel Treatment

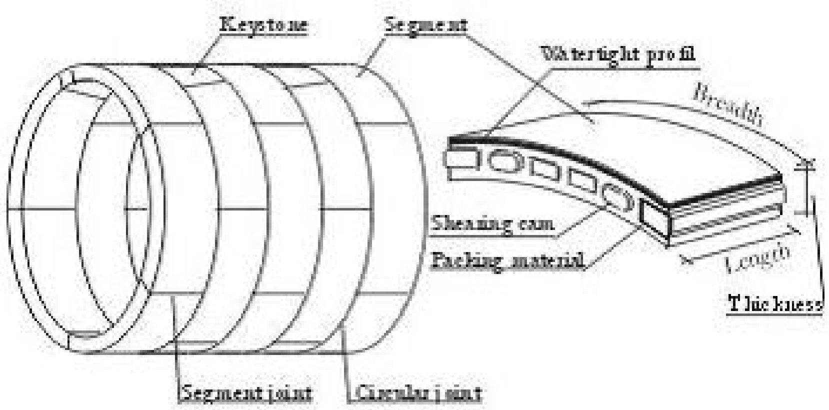
-- Cut-and-cover method

Concrete self-waterproofing treatment

Penetron Admix is added to the concrete mix (cast in-situ concrete lining) at the time of batching.

■ Shield method

Concrete self-waterproofing treatment or Concrete surface waterproofing treatment



Concrete self-waterproofing treatment

Penetron Admix is added into concrete (precast concrete segments) at the time of batching for complete integral waterproofing.

Concrete surface waterproofing treatment

Penetron is applied on the positive surface of hardened concrete segments by brush or spray, or on the positive surface of fresh concrete segments by dry shake.

- <u>Penetron Underwater Tunnel Treatment</u>

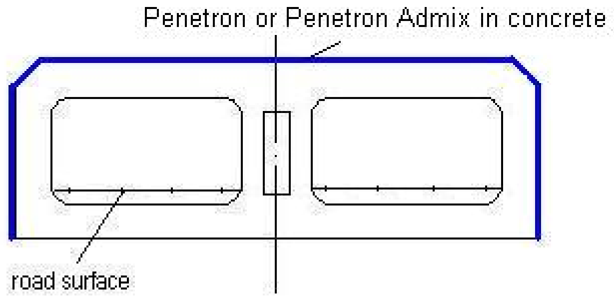
-- Immersed-tube method

Concrete self-waterproofing treatment

Penetron Admix is added into concrete (precast tunnel sections) at the time of batching for complete integral waterproofing;

Concrete surface waterproofing treatment

Penetron is applied on the positive surface of sidewall and top slab by brush or spray.



Application of Penetron Products

- <u>Penetron Application</u>

-- Surface Preparation

The concrete surface must be structurally sound and free of dirt, soil, oil, release agents, laitance or any other foreign materials which may impair the bond, penetration and/or overall performance of Penetron materials.

Extremely smooth concrete surface must be waterblasted or sandblasted to make sure the concrete surface has an open capillary system.

Visible cracks exceeding 0.4mm in size to a depth of 20mm to 25mm must be routed out along with honeycombed pockets and faulty construction joints to sound concrete. Construction joints are routed or provided with a formed 20mm*20mm reglet.

Wet down dry surfaces prior to the application of Penetron materials. Moisture must be present in the concrete strata to ensure maximum chemical penetration. Surfaces must be damp when Penetron products are applied.

-- Mixing

Brush application: 0.8-1.5kg/m^2, 5 parts Penetron to 2 parts water

Spray application: 0.8-1.5kg/m^2, 5 parts Penetron to 2.75-to-3.25 parts water (varies with climate and spray equipment)

Penetron should be mixed to the consistency of thick latex paint. Stir the slurry mixture frequently during the application and prepare only as much as can be applied within a 30-minute period.

-- Application

Apply Penetron coating by masonry-type brush (artificial fibers, if available). For spray application, drop hopper or piston pump type equipment is recommended.

Prior to application of Penetron coatings, fill form tie holes, rout out cracks, honey bombs**,** reglets and seal strips at construction joints with Penecrete Mortar in a laminating layer of 2.5cm to 3cm. Prime concrete surface of these areas with one slurry coat of Penetron prior to applying Penecrete Mortar.

Penetron slurry must be applied to a damp concrete surface. Second coat should be applied when first coat is dry to the touch. A light misting of water may be required between coats in hot/dry climates.

Horizontal concrete surfaces: Apply Penetron slurry in one coat with stiff bristle brush/broom or squeegee.

Dry sprinkle Penetron or Penetron Plus on “still plastic” concrete by broadcasting or with a fine mesh sieve in specified quantities. Work the slab surface with wood flat or power trowel until required finish has been achieved.

-- Coverage

Horizontal concrete surface: Penetron at 1.4 to 1.6kg/m^2. Apply in one slurry coat or powder application when concrete reaches initial set. Trowel or float to specified finish. Penetron Plus powder application at 0.5kg/m^2 when concrete reaches initial set. Trowel or float to specified finish.

Vertical concrete surfaces: Penetron at 1.4 to 1.6kg/m^2. Apply in two coats (0.8kg.per coat).

-- Curing

Except for extremely hot weather and very low humidity, curing of the Penetron system is not required. In these extreme conditions curing, using a light water misting, must begin as soon as the Penetron coating has hardened sufficiently. Under most conditions it is sufficient to mist the areas treated with Penetron three times a day for the first day. In extremely hot climates spraying may be required more frequently and for several days.

Penetron Plus (trowel applied): Follow concrete specifications for curing procedures.

-- Temperature requirement

Penetron system can be applied in a coating or mortar form when the temperature is above 32 degrees Fahrenheit or 0 degrees Centigrade.

Penetron Plus (trowel applied) can be applied in temperatures where concrete can be placed. Follow concrete specifications for protection requirements according to standard concrete procedures.

- Application of Penetron Admix

-- Dosage rate

Penetron Admix: 0.8% by weight of the cementitious materials, including fly ash, silica fume, etc.

Note: Under certain conditions the dosage rate may have to be increased to 2%-3% depending on the project conditions.

-- Application

Ready Mix Plant-Dry Batch Operation: Add Penetron Admix in powder form to the drum of the ready-mix truck. Drive the truck under the batch plant and add 60%-70% of the required water along with 136-227kg of aggregate. Mix the materials for 2-3 minutes to ensure the Admix is distributed evenly throughout the mix water. Add the balance of materials to the ready-mix truck in accordance with standard batch practices.

Ready Mix Plant- Central Mix Operation: Mix Penetron Admix with water to form a very thin slurry (e.g., 18kg of powder mixed with 22.7 liters of water). Pour the required amount of material into the drum of the ready-mix truck. The aggregate, cement and water should be batched and mixed in the plant in accordance with standard practices (taking into account the quantity of water that has already been placed in the ready-mix truck). Pour the concrete into the truck and mix for at least 5 minutes to ensure even distribution of Penetron Admix throughout the concrete.

Precast Batch Plant: Add Penetron Admix to the rock and sand, and then mix thoroughly for 2-3 minutes before adding cement and water. The total concrete mass should be blended using standard practices.

-- Note

Penetron Admix is compatible with other water-reducing admixtures and superplasticizers.

Retardation of set may occur when using Penetron Admix. Trial mixes should be carried out under project conditions to determine setting time. Once the concrete mix design is determined, any adjustment of the dosage rate is prohibited without testing.

QA/QC of Penetron Products

- <u>QA/QC of Penetron</u>

Project: ______________________________

Application Section: ______________________________

Client: ______________________________

Contractor: ______________________________

Date of Inspection: ______________________________

Before-Application Inspection:

Surface Repair:	Crack repair	[ ]
	Spalling repair	[ ]
	Void repair	[ ]
	Construction debris removed	[ ]
Smooth Surface Treatment:	Sandblast	[ ]
	Acid Etch	[ ]
	Waterblast	[ ]
	Scabbling	[ ]
Final Wash-down (High pressure water)		[ ]

Comments on surface preparation: ______________________________

____

During-Application Inspection:

Mixing Product:	Mix water quality	[ ]
	Mix rater	[/]
	Application rate	[kg/m^2]
	Number of coats	1[ ] or 2 [ ]
	Application by brush	[ ]
	Or spray	[ ]

After-Application Inspection:

Observations and comments on consistency of application:

Thickness:____

Coverage:____

Joints:____

Overlap:____

Penetration:____

Curing Program:

Water fogging [ ] times per day, for [ ] days

Volume of product used in this section: [kgs]

Surface area treated [m^2]

Comments: ____

____

____

____

Inspected by:

Date:

- QA/QC of Penetron Admix

Pre Casting

Project: ____

Type of Structure:____

Section Identification:_____________________________________

Date of Inspection: ______________________

Date of Proposed Casting:___________________

Curing Proposed? Yes/No Curing Period_____Days

Curing Type: Water Burlap (Wetted) Plastic

Sand/Water Chemical (Note Brand or Type)

Site Condition Report:

Construction Debris Removed Yes/No

Formwork Clean and Sound Yes/No

Rebar Clean, Secure (well tied) Yes/No

Construction Joints Prepared Yes/No

____

General Site Conditions:____________________________________

Casting Surface- Construction Joint/ Lean Concrete/ Plastic Sheeting/Packed Earth/ Formwork/ Other_______________________________________

Evidence of Ground Water Flow or Seepage?___________________________

Surface Water Runoff or Drainage Points Created?________________________

Waterbar Installed Yes/No Type______________________________

Condition of Waterbar Installation:_______________________________

Nature and location of all defects to be described in detail

____

____

Inspected by:__________________ Witnessed by:______________

Concrete Mix Design

Specification	Specified Characteristic Strength:_______________28 days		
	Target Mean Strength:_______________________________		
	Free-water/Cement Ratio:____________________________		
	Type of concrete:___________________________________		
	Concrete Slump:____________________________________		
Cementitious Materials	Cement	Type:_________________________________	
		Content:_______________________________	
	Silica Fume	Content:_______________________________	
	Fly Ash	Content:_______________________________	
	Other	Type:_________________________________	
		Content:_______________________________	
Aggregates	Type	Coarse:________________________________	
		Fine:__________________________________	
	Relative Density of Aggregates:_______________________		
	Nominal Coarse Aggregate Size:______________________		
	Grading of Fine Aggregate:__________________________		
	Coarse Aggregate Content:__________________________		
	Fine Aggregate Content:_____________________________		
Water	Free Water Content:________________________________		
Admixtures	Type: Penetron Admix		
	Dosage:____________per 100kg cementitious materials		
	Other	Type:_________________________________	
		Dosage:_______________________________	
		Type:_________________________________	
		Dosage:_______________________________	

Inspected by:_________________ Witnessed by:_______________

Date:_________________________

Post Casting

Volume of Concrete:________________________________

Cast Section Identification:____________________________

Date of Inspection: ______________________________

Date of Casting:__________________________________

Date of Formwork Removed:_________________________

Curing Applied?	Yes/No	Curing Period______	Days
Curing Type:	Water	Burlap (Wetted)	Plastic
	Sand/Water	Chemical	Formwork

Condition Report:

Evidence of Honeycombing?		Yes/No/Photo	
Evidence of Cracking?		Yes/No/Photo	
Evidence of water leakage?		Yes/No/Photo	
Exposed rebar	Yes/No/Photo	Tie Bolt Holes	Yes/No/Photo

Finish Surface Condition:____

____

Waterbar Installed Yes/No

Condition of Waterbar Installation:_______________________________________

Is it continuous?____

Re-welding required?______________Cleaning required?______________________

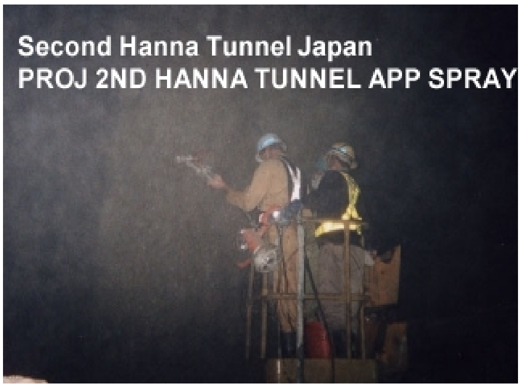
All defects to be described in detail, including location, extent, apparent depth, etc.

____

____

Inspected by:_______________ Witnessed by:______________

Project Case History

<table>
<tr><td>
</td><td>Second Hanna Tunnel, Osaka, Japan
Repairs made to leaking tunnel in 1996.
Penetron products were used to waterproof the shotecrete in this tunnel by applying a lining of Penetron to the shotcrete surface.
Location: National Highway No. 308 Bypass; Second Hanna Toll Road Construction Project; Ventilation Shaft No.27+01 Vicinity</td></tr>
<tr><td></td><td>Washington DC Metro, Washington DC, USA
Repairs made to over 2 miles of tunnels in 1990.</td></tr>
<tr><td>Sao Paulo Subway Sau Paulo, Brazil</td><td>Repairs were made to over 9km of tunnel</td></tr>
<tr><td>Sau Paulo Subway Sau Paulo, Brazil</td><td>Waterproofing new tunnel. Year: 1990-1995</td></tr>
<tr><td>Moscow Metro, Moscow, Russia</td><td>18 km of tunnel were treated.</td></tr>
<tr><td>Saint Petersburg Subway, Russia</td><td>Over 100 tons of materials were used to repair and treated the tunnel (tunnels had severe leaks)</td></tr>
<tr><td>Minsk, Metro, Minsk, Belarus</td><td>Repairs were made to tunnel.</td></tr>
</table>

Second Hanna Tunnel Information

Contents

1. Objective

In case of NATM, a technique used to prevent occurrence of cracking and leakage from the inner lining is that of providing waterproof sheets and nonwoven fabric (cushioning material) between shotcrete and the inner lining. In recent years, however, research has been underway on single-shell lining for integrating tunnel supports and lining to economize on labor. Systems for waterproofing tunnels by making shotcrete impermeable have drawn attention in this research.

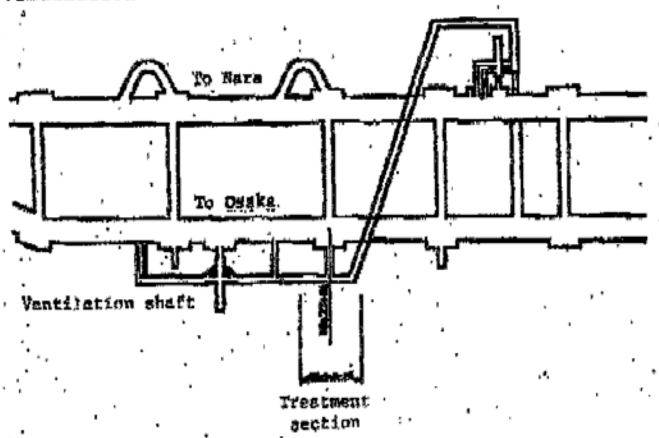
The experiment here proposes a system of pneumatically applying a chemical substance (Penetron) which forms a crystalline compound blocking capillaries in concrete as a system for water cut-off of shotcrete and has the objective of confirming that shotcrete is made impermeable by lining with Penetron and ascertaining the applicability on a tunnel job.

2. Place

National Highway No. 308 Bypass

Second Hanna Toll Road Construction Project

Ventilation Shaft No. 27 + 01 Vicinity



(1)

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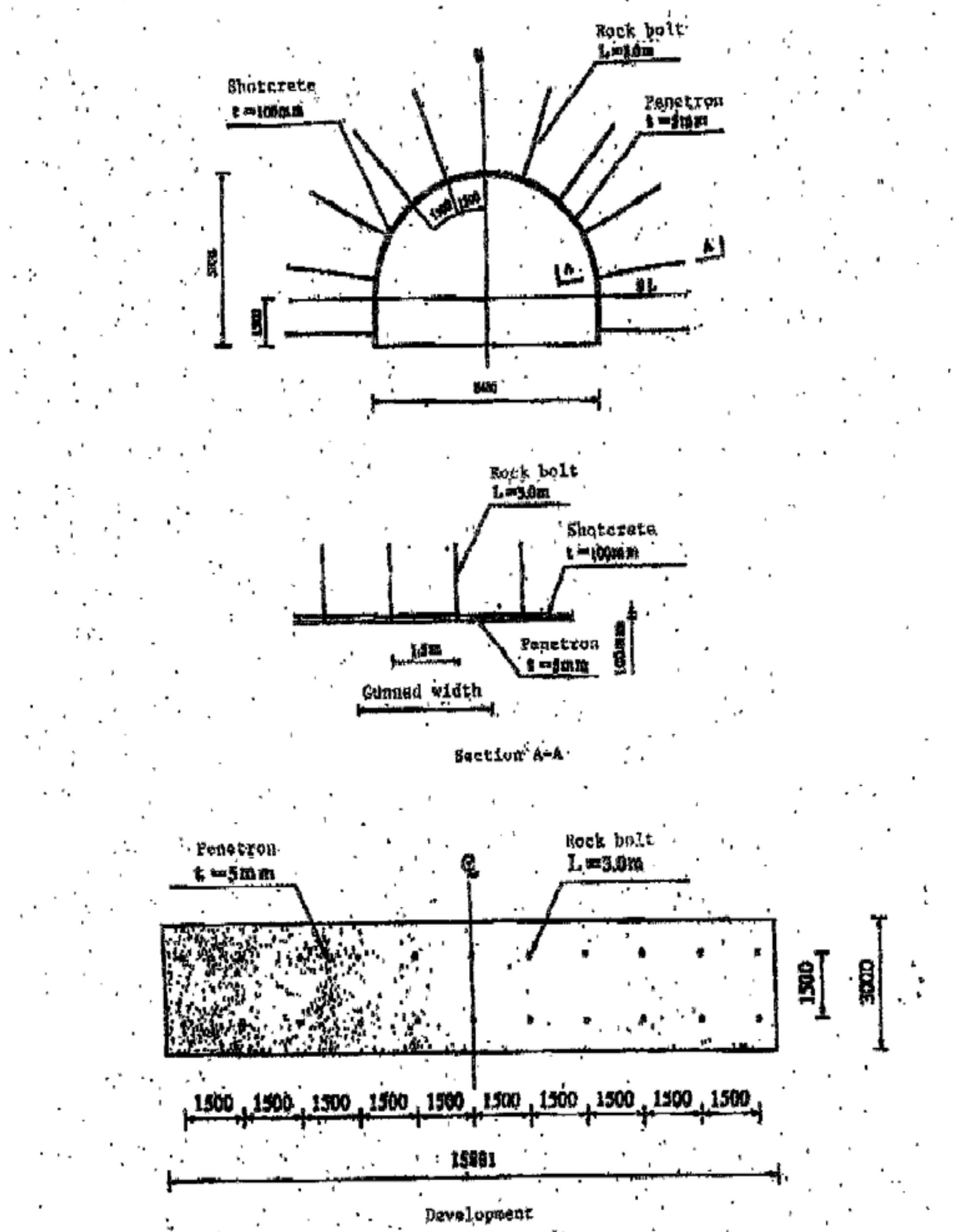
1996年 5月24日 10時01分 NO. 0021 P. 4



(2)

3. Time

(1) Penetron application ..... Mid-June 1996

(2) Follow-up check

4. Experimentation Method

4.1 Materials

1) Features of Penetron

- Various chemical substances contained in Penetron combine with moisture and free lime in capillaries of concrete to form crystals and these crystals close up capillaries and cracks while ejecting moisture.
- Penetron provides protection against sea water, chlorides, carbonates, sulfates, nitrates, etc.
- Penetron can be used on old concrete, green concrete, and fresh concrete.
- Penetron is nontoxic.
- The composition of Premixed Penetron is given below. The components of Penetron itself are presently being investigated at the Technical Research Institute of Obayashi Corporation.

(3)

Premixed Penetron Composition

Cement	Fine Aggregate	Penetron
28%	25%	47%

2) Mix Proportions (Proposed)

Field Mix

Premixed Penetron	Water	P-Funnel Test
1.4 kg	0.7-0.9 kg	sec

3) Work Quantity

Work Quantity

Circumferential Length	Width	Thickness	Application Quantity
15.88 m	3.0 m	1.4 mm	67 liters

4) Application Rate

The application with Premixed Penetron is 1.4 kg per square meter, but 20% extra is estimated taking into account rebound loss.

Application Rate

Premixed Penetron	Water	Quantity Gained
80 kg	46 kg	80 liters

(4)

4.2 Equipment

Item	Specification	Qty	User	Remark
Quality Control				
Stop watch		1		
P-funnel	1725 cc	1		
Work Execution				
Agitator	Hand mixer	1		
Container	About 40 ℓ	1		
Gun	TPS-40 snake type			
Sky Master		1	JV	
High Washer	200 V	1	JV	Shotcrete washing
Other				
Lighting	Eye lamp	6	JV	
Dump truck	2 t	1	JV	Materials and equipment transportation
Coring machine	φ100 mm	1	JV	After Penetron application

(5)

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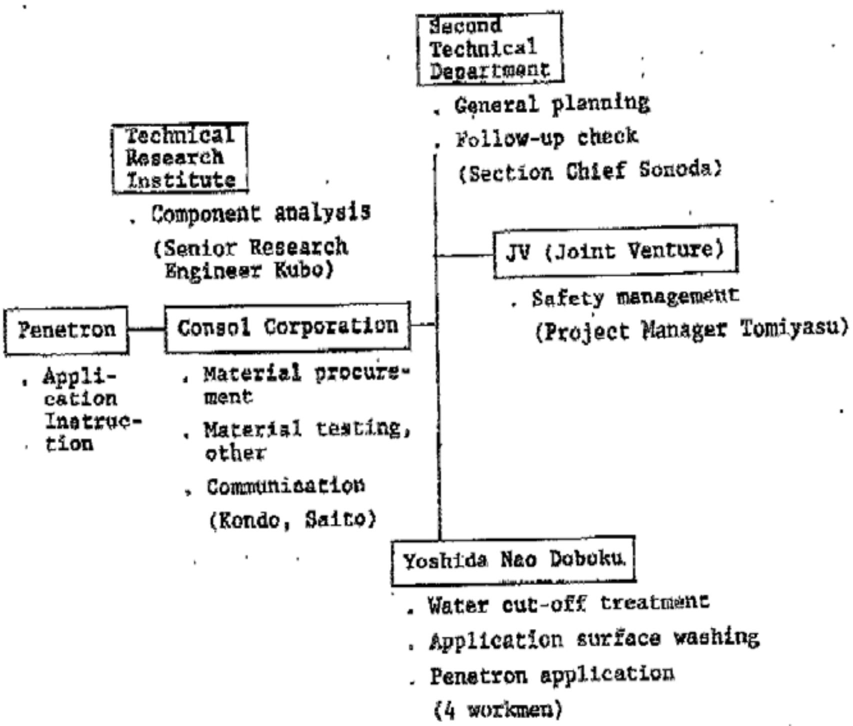
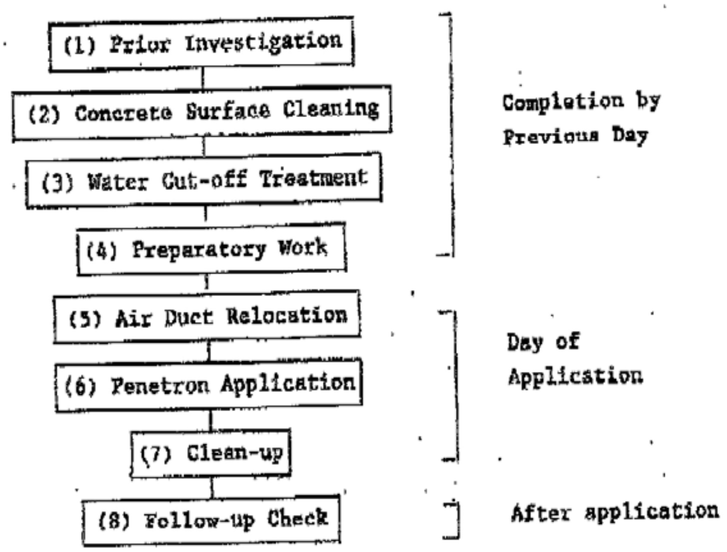
1996年 5月24日 10時02分

4.3 Trial Application Organization



4.4 Application Procedure



(1) Prior Investigation of Section to be Object of Application

Prior investigation of rock bolt washer surroundings, leakage spots in shotcrete.

(2) Cleaning of Application Surface

Cleaning of soiled areas of shotcrete by high-pressure washing.

(3) Water Cut-off Treatment

Water cut-off treatment of rock bolt washer surroundings and leakage spots in shotcrete with

(7)

water cut-off cement or Penetron.

(4) Preparations and Arrangements

Delivery and arrangement of application equipment (gun, others), materials to be used (Penetron, others), lighting equipment, scaffolding (Sky Master, others).

(5) Air Duct Relocation

Relocation of air ducts which would hinder application of Penetron.

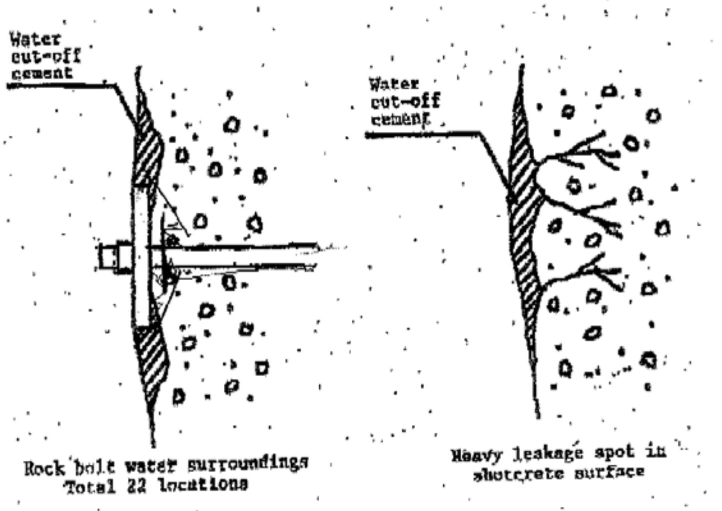
(6) Penetron Application

After sprinkling water on entire circumference of tunnel, gunning of Penetron in 3.0-m width.

(7) Clean-up

Air duct restoration, clean-up.

(8) Follow-up Check



Water Cut-off Treatment

(8)

5. Efficacy Confirmation

1) Visual Inspection

Confirmation whether there is leakage at the wall surface treated.

2) Core Sampling of Treated Concrete

Two to three months after application, cores (diameter 100 mm) of shotcrete treated with Penetron are to be sampled from three locations on each side of the tunnel (locations where leakage had occurred before applying Penetron), crystal growth is to be confirmed, and unconfirmed compression tests performed. To make comparisons between Penetron-treated sections and untreated sections, cores are to be sampled from three locations on each side of untreated sections.

Coring Location	Condition	Number
Penetron-treated location No. 27+01 vicinity	Leakage before Penetron application	6
Untreated location No. 27+01 surroundings	-	6

(9)

PENETRON TRIAL APPLICATION

1. Execution Site

   Second Hanna Tunnel, Ventilation Shaft, C-I Pattern, C-II Pattern

2. Date and Time

   June 23, 1996 (Sunday)

   0830-0900 : Preliminary meeting

   0900-1000 : Materials and equipment delivery, preparations

   1000-1130 : First application C-I Pattern

   1130-1300 : Noon break

   1300-1530 : Moving, first application C-II Pattern, bolt surroundings, test chipping locations water cut-off treatment

   1500-1630 : Moving, second application C-I Pattern

   1630-1700 : Clean-up

3. Work Quantities

   (1) Mix Proportion

   Penetron:water = 5:3 (volumetric)

(2) Work Quantities

Location	Application	Circumference	Width	Area	Penetron
C-I Pattern	1st	15.9 m	3.0 m	47.7 m²	112.5 kg
	2nd	15.9 m	3.0 m	47.7 m²	45.0 kg
C-II Pattern (half face)	1st	9.7 m	2.4 m	23.3 m²	45.0 kg
	2nd	-	-	-	-
Bolt location, test chipping location with leakage				2 spots	Small amount Peneplug

4. Test Results

The results of observations curried out on Wednesday, July 3, 10 days after application, are as follows:

- Places where water cut-off treatment had been done with Peneplug showed no leakage for perfect water cut-off.
- The vicinity of No. 8+73 where springing of water (of the degree of seepage) had been seen before application of the C-I Pattern showed springing (of the degree of seepage) even after Penetron application.
- Before application, at the C-II Pattern in the vicinity of No. 9+23, there was springing of water

of the degree of seepage around bolts provided with water cut-off treatment, while there was also springing of water around H-steel of the degree of water running down the gunned surface. However, after Penetron application, there was no springing of water around bolts and it was felt that the amount of water springing around H-steel had decreased. (Places where Penetron had been applied on top of water cut-off treatment around bolts were dry at their surfaces, while the surface around H-steel was damp.)

. With both patterns, C-I and C-II, there were uneven spots in the applied Penetron due to irregularities of the surfaces gunned, and it cannot be said there had been uniform application over the entire surfaces.

. Surfaces where Penetron had been applied were whitish overall, and it was possible to discern between treated and untreated areas.

(3)

Test Data

- <u>Penetron</u>

-- Laboratory Testing of PENETRON Waterproofing System

Riga Technical University Determination of Waterproofing
RTU Testing Review Nr.64-98 Determination of Waterproofing
Scanning Electron Microscope (SEM) Tests X-Ray Diffraction Analysis
Test Report/Shenzhen, China

-- Compressive Strength

Shimel and Sor 12/21/94
Shimel and Sor 11/22/93
AITA 4/3/85

-- Water Permeability Tests

Shimel and Sor 12/21/94
AITA 8/7/85
AITA 12/10/90

-- Microscopic Examinations

Shimel and Sor 12/21/94

-- Analysis of Concrete for Penetron Content

Shimel and Sor 12/21/94

-- Chemical Resistance

Shimel and Sor 10/19/93
Chemical Resistance/Corrosion Chart

-- Chloride Content

Shimel and Sor 12/21/94

-- Shear and Bond Tests

Shimel and Sor 12/21/94
AITA 3/7/85
AITA 3/8/85
Riga 4/97

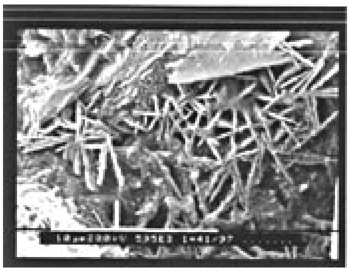
-- Toxicity

Acute Oral Toxicity
Migration of toxic Element
Cytotoxicity Test

- <u>Penetron Admix</u>

SETSCO Singapore-crack bridging report on Terminal 3, Changi Airport
Impermeability, University of Aleppo
Penetron Admix effect on concrete- Helsinki
ACCI-University of NSW, Australia- full examination of Penetron Admix effect on concrete
SETSCO Singapore-microscopic examination of crack bridging effect of Penetron Admix on PBFC concrete
SETSCO Singapore-performance assessment of Penetron Admix

Microscopic examination of concrete at 14 days



Microscopic examination of concrete at 28 days

SETSCO SERVICES PTE LTD

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Website: www.setsco.com

Our Ref: A6127/CHF Date: 25/10/02

TEST REPORT Page 1 of 4

(This Report is issued subject to the terms & conditions set out below)

MICROSCOPIC ANALYSIS ON THE CONCRETE CORES FROM RETAINING WALL AT CHANGI AIRPORT TERMINAL 3

Prepared for:

REVERTON ENGINEERING(S) PTE LTD

605A Macpherson Road #06-02
Citimac Industrial Complex
Singapore 368240
Attn: Mr. Gary Loh

Report prepared by:

Chen Hong Fang
Senior Engineer
Construction Technology Division

Report received and approved by:

Wong Chung Wan
Divisional Director
Construction Technology Department

[illegible]

SETSCO

1. INTRODUCTION

Cracking and seepage of water on the retaining wall at Changi Airport Terminal 3 was reported by Reverton Engineering(s) Pte Ltd (herein refers to as the client). SETSCO has been engaged by the client to carry out laboratory analysis to determine the crack width and crystal growth in the crack on the concrete cores extracted from said structure.

The proposed basement was constructed with three sides of wall, labeled as wall 1-3 in this report (refer to figure 1 in Appendix A). Thickness of the wall was about 600mm. PENETRON waterproofing admixture was said to be used in the concrete. Water leakage was found along the crack line and tie pin after backfill. However, the water leakage has been stopped on wall 1, which was cast somewhere in 2001. Sign of efflorescence was found on all three sides of the walls. Most of the efflorescence emanated from the tie pins, but cracks with some sign of efflorescence were also noted at some areas (Refer to the photographs in Appendix).

A total of three core samples were extracted from wall 1 on 05/10/2002. Samples S1 and S3 were extracted from crack area while sample S2 was taken at the tie pin. During extraction, the cores were drilled to a depth of 400mm but, due to the presence of reinforcement, the length of the core S3 removed was only 240mm.

The concrete mix design furnished by the client is given in Appendix A.

2. MICROSCOPIC ANALYSIS

The microscopic analysis was performed on a ground section using a stereo microscope and metallurgical microscope and on a thin section with a polarizing and fluorescent microscope (PFM) under transmitted and reflected light. For preparation of the ground section, a small block of the sample was cut and ground to attain a smooth finish. For preparation of a thin section, a small concrete block was sawn from the core sample, glued to an object glass and impregnated with an epoxy resin containing a fluorescent dye. After hardening of the epoxy, a thin section with a surface area of approximately 33*63mm and a thickness of 20-30mm was prepared for PFM analysis.

Under transmitted light, the various components (type of cement and aggregates), air voids content, compaction pores and damage phenomena in the samples were identified. Under reflected light, the fluorescent microscopy made it possible to study the homogeneity of the mix and cement paste, capillary porosity, microcracks and other defects in the samples. Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) Analysis technique were also applied for semi-quantitatively analysis of the element composition of the crystals present in the crack and topography of the crystals.

In summary, SEM utilizes a beam of electrons in a vacuum environment to form an image of the surface topography of a sample. Such magnified images are characterized by a high level of resolution and good depth of view. The characteristic X-ray emitted from the sample surface upon being irradiated with the electrons are then analyzed using an EDX accessory/detector that is coupled to the SEM, allowing evaluation of the % elemental content at the irradiated areas/spots on the sample.

3. RESULTS

i) Visual examination

The length of the cores varied from 240mm to 310mm. Crack perpendicular to the surface was noted in samples S1 and S3. The width of the crack ranged from 0.04mm to 0.3mm. The paste matrix appeared light gray in color while the paste matrix was noted to be generally light gray.

Thin sections were prepared at the top of sample S2 and the end of sample S3 for further microscopic analysis. Stereo microscope and SEM-EDX analysis were performed on sample S3 to determined the presence of the crystals in the crack and their elemental composition.

ii) Microscopic analysis

Under stereo microscope, a lot of coarse-grained elongated crystals were seen lining the crack. Thin section of sample S3 showed coarse-grained elongated crystals and fine-grained needle-like crystals in the crack. All these crystals showed low birefringence under crossed polarized microscope.

SETSCO

Further scanning electron microscope and energy dispersive X-ray analysis were performed on the crystals present in the crack. The coarse-grained elongated crystal (BEI image in Appendix) contained mainly *Calcium* (Ca), *Oxygen* (O) and *Silicon* (Si). The fine-grained needle-like crystal was predominantly made up of *Calcium* (Ca), *Silicon* (Si), *Oxygen* (O), *Sulfur* (S), *Aluminum* (Al), which was probably ettringite ($C_6AS_3H_{32}$).

Well-formed $CaCO_3$ crystals were present as laminated texture on the surface of sample S2.

APPENDIX A

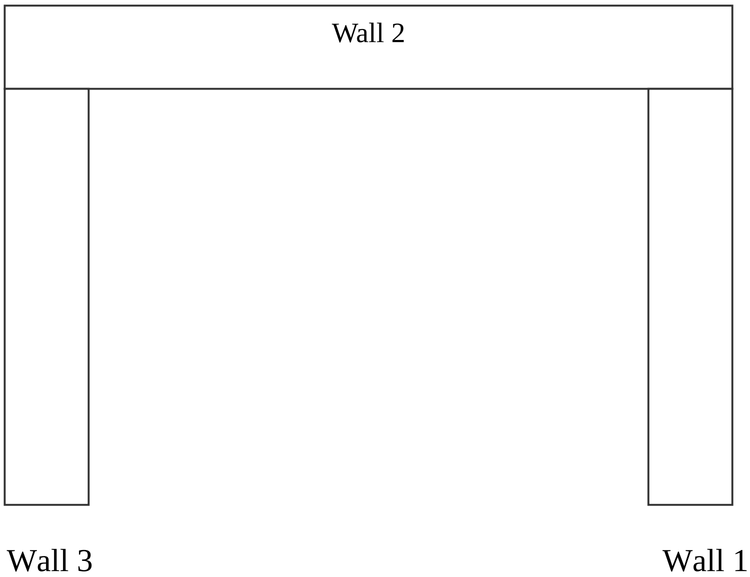

Figure 1: The layout of the retaining wall

Casting date of extracted cores

Sample reference	*Date of cast*
S1	19/12/2001
S2	19/12/2001
S3	06/08/2001

REVERTON
ENGINEERING (S) PTE LTD

CONCRETE MIX DESIGN

Project : Pile Foundation & Basement Construction For Terminal 3
Singapore Changi Airport
Contractor : Sato Kogyo., Ltd
Date : 8th March 2001
Ref : RE/SK/PU/40P/01

Concrete Grade
40
Pump

1	Specification	
	1.1 Specific Characteristic Strength	40N/mm^2 at 28 days in accordance with BS 5328
	1.2 Designed Standard Deviation	4.6 N/mm^2
	1.3 Design Margin	7.5 N/mm^2
	1.4 Target Mean Strength	47.5 N/mm^2
	1.5 Free Water/Cement Ratio	0.46
	1.6 Type of Concrete	Pump Concrete
	1.7 Concrete slump	100±25mm
2	Cement	
	2.1 Cement Type	Ordinary Portland Cement
	2.2 Cement Content	398kg/m^3
3	Aggregates	
	3.1 Aggregate Type Coarse	Crushed Granite
	Fine	Natural Sand/ Manufactured Sand
	3.2 Relative Density of Aggregates	2.60-2.65
	3.3 Normal Aggregate Size	20mm
	3.4 Grading of Fine Aggregate	BS 882 Table 5
	3.5 Coarse Aggregate Content: SSD	1000 Kg/m^3
	3.6 Fine Aggregate Content: SSD	695 Kg/m^3
4	Water	
	4.1 Free Water Content	185 Kg/m^3
5	Admixtures	
	5.1 Admixture Type 1	Penetron (mix design) Admixture
	Dosage	0.8 kg per 100 kg of cement
	5.2 Admixture Type 2	Daratard 88. Water reducing, plasticizing and set retarding
	Dosage	550 ml per 100kg cement
6	Summary	
	(Batch weighs (SSD) Per Cubic Meter of Concrete)	Kg/m^3

Grade	Slump	Cement	Coarse Agg	Fine Agg	Water	Admix Penetron	A/C	W/C	Density
40	100±25mm	398	1000	695	185	3.18	4.26	0.46	2281.18

603A, MacPherson Road, Citimac Industrial Complex, #06-02, Singapore 368240
Tel : (65) 858 0660 Fax : (65) 858 0377

APPENDIX B PHOTOGRAPHS

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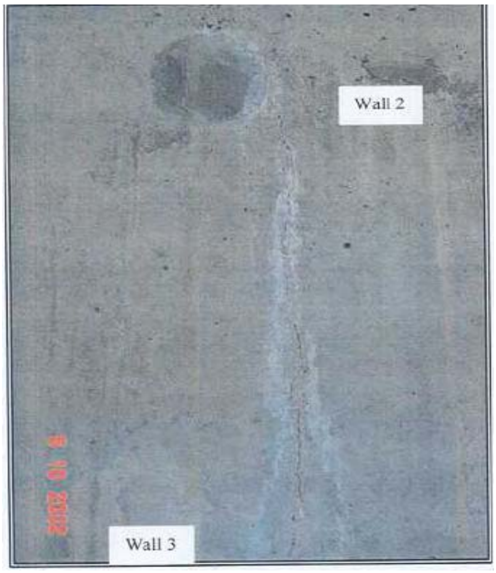
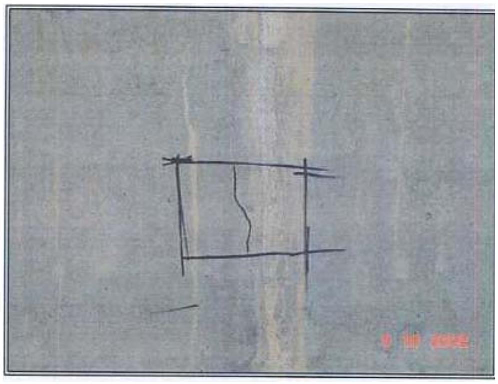


A crack connecting with tie pin with sign of Efflorescence was observed on wall 1

Sign of efflorescence was found along the crack line on wall 1.



The location of sample S1 extracted at the cracked area on wall.

A 75mm diameter core containing a crack at Wall 1 was extracted for laboratory analysis.

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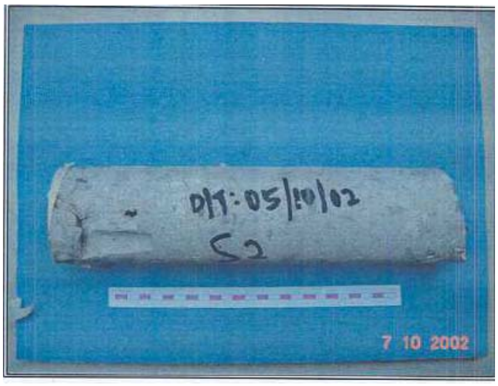
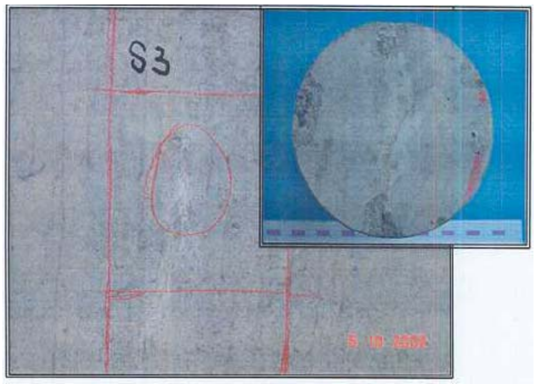
A crack perpendicular to the exposed surface was seen in core S1.

Core S2 was extracted at the tie pin on wall 1.



Relative thick whitish substance was on the surface of core S2.



Sign of efflorescence was found along the crack line where core S3 was taken on wall 1.

A crack perpendicular to the exposed surface was seen in core S3.

A crack perpendicular to the exposed surface was seen in core S3.

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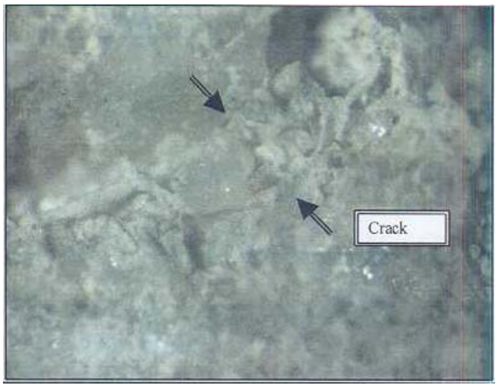
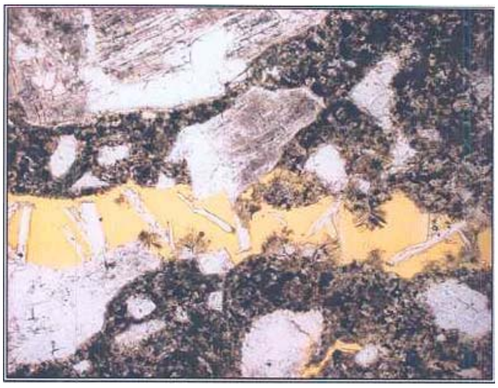


Sample S3: Some crystals grew in the crack.

Sample S3: Abundant coarse-grained crystals in the crack.

Sample S2: Laminated CaCO3 crystals on the surface of the concrete. The width of the field is 3.88mm under plane light.

Sample S2: Laminated CaCO3 crystals on the surface of the concrete. The width of the field is 3.88mm under crossed polarized light.



Sample S3: Coarse-grained elongated crystals and fine-grained needle-like crystals were lining the crack. The width of the field is 3.88mm under plane light.

Sample S3: Backscattered electron image (BEI) showed some crystals was in the crack.

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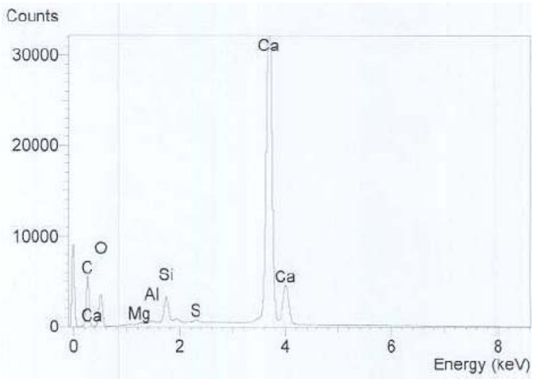
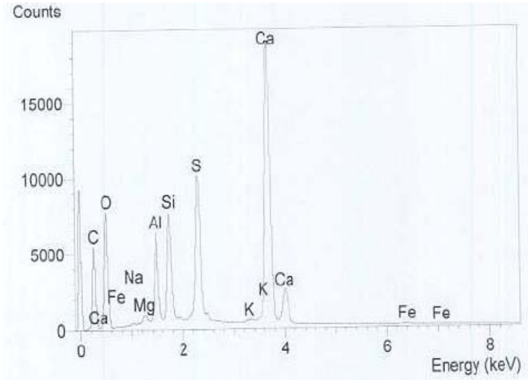
Sample S3: Backscattered electron image (BEI) showed elongated crystals and fine needle-like crystals in the crack.

Sample S3: High magnified view of needle-like crystals in the crack.

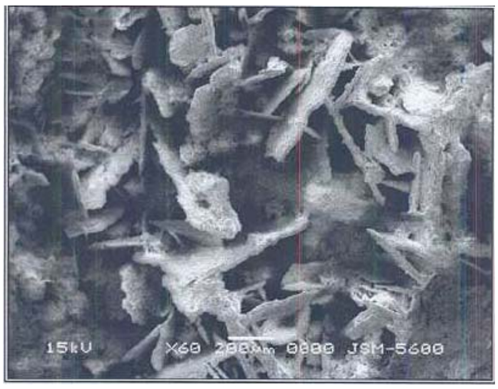
Sample S3: Secondary electron image (SEI)



EDX spectrum of elongated crystals in the crack.



EDX spectrum of needle-like crystals in the crack.



Sample S3: Secondary electron image (SEI) showed coarse-grained flaky crystals in the crack.

Sample S3: SEI image showed the crystals in the Crack.

SHIMEL and SOR TESTING LABORATORIES, INC.
Testing - Inspection - Consultation
98 Sand Park Road, Cedar Grove, N.J. 07009
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Kamil Sor, Ph.D.
Charles Shimel, P.E.

Client ICS/Penetron International Ltd., 45 Research Way, Suite 203, East Setauket, NY 11733

Project Information of Client

Subject Laboratory Testing of Penetron Waterproofing System

Report No.: 95-387 Date: 01/24/95

Reference is made to our report No. 94-6175, dated December 21, 1994. In that report, effects of Penetron coating on the properties of concrete were reported. As indicated in that report, the depth of penetration of some of the components of Penetron were as deep as 50 mm, although most penetrations were down to 10 mm depths of the concrete surface.

At the Client's request, additional studies were performed to determine and photograph the type of materials penetration or diffusing into the concrete from the Penetron coating. In order to perform these tests, the test techniques used were scanning electron microscopy and energy dispersive x-ray diffraction methods.

TEST RESULTS

1. Scanning Electron Microscope (SEM) Tests

The concrete core section tested, was coated with a minimum of gold in order to provide a surface which could be studied by light microscopy and compared to the SEM images.

The photographs taken under SEM are presented on Attachment I.

2. X-Ray Diffraction Analysis

According to the attached four spectrums of x-ray diffraction, there is a calcium accumulation in the concrete below the Penetron coating to 25 to 50 mm depths. Calcium appears to be in the form of Ca(OH)2 and calcium-silicate gel. Obviously, these crystalline growths are the diffusion products of the components of the Penetron coating on the concrete surface. Below 50 mm depths Ca(OH)2 is less while the silica content (from the cement) becomes dominant.

CONCLUSIONS

Based on these test results, it is our opinions that Penetron coated concrete surfaces develop improved concrete microstructure and waterproofing properties.

SHIMEL AND SOR TESTING LABORATORIES, INC

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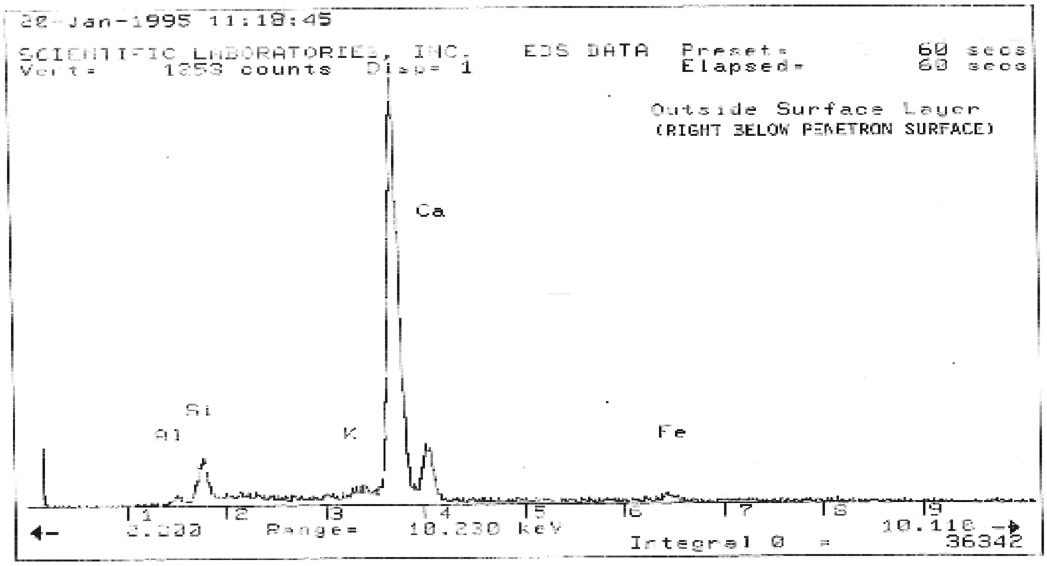
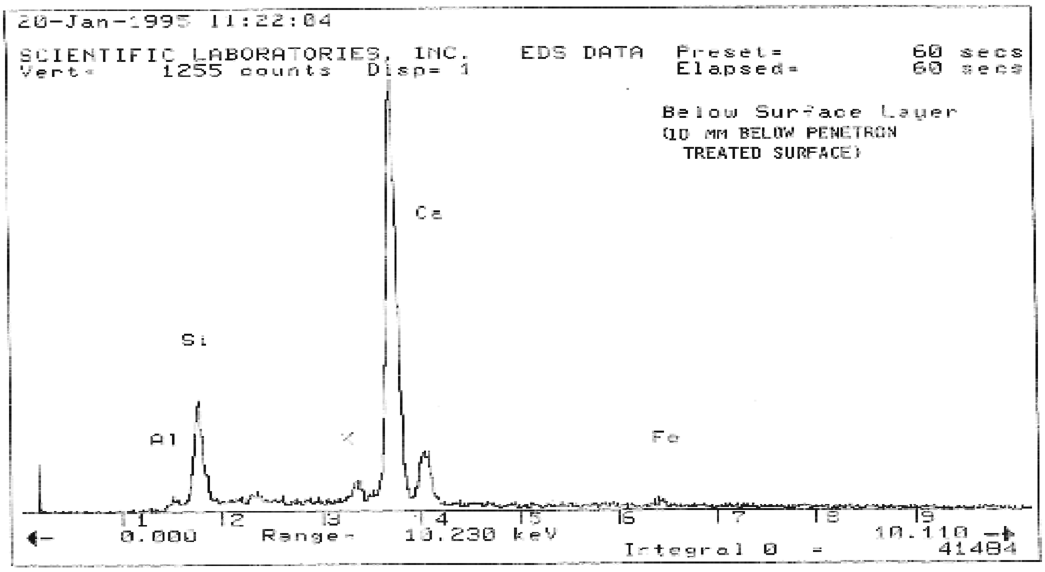
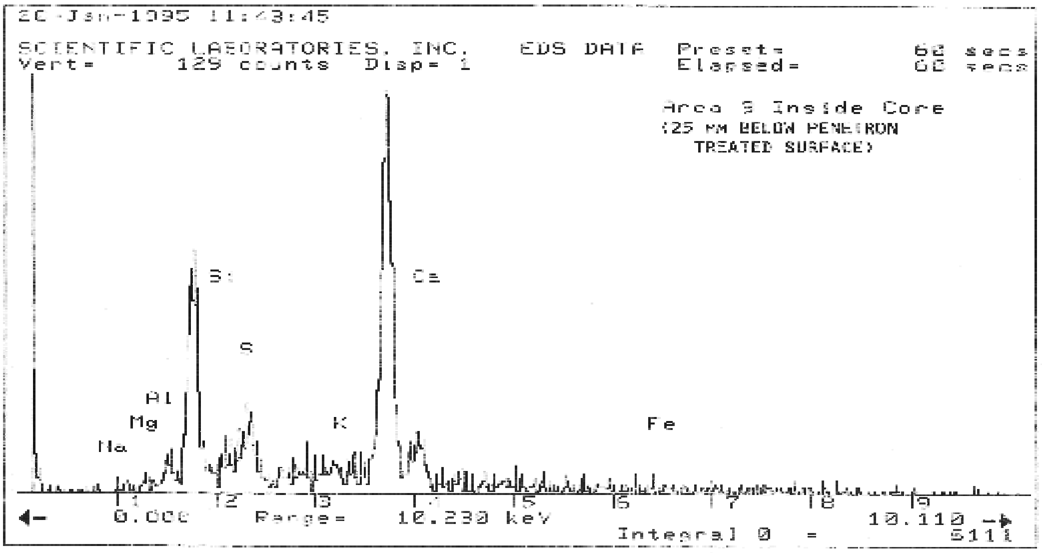
cc: (1) Client
Robert Revera



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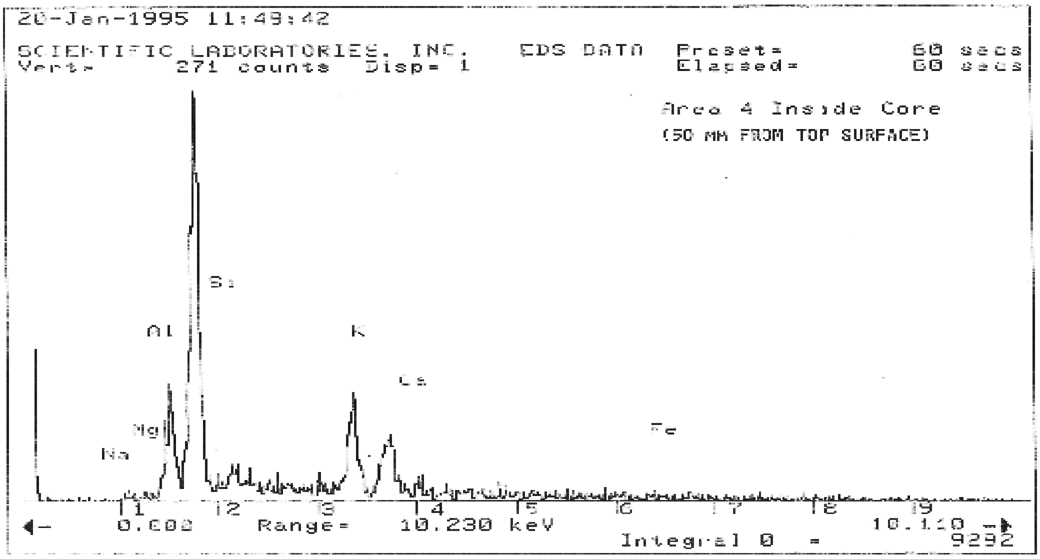
Vert= 129 counts Disp= 1 Elapsed= 60 secs
Area 3 Inside Core
(25 MM BELOW PENETRON
TREATED SURFACE)
Si
Ca
S
Al
Mg
K
Fe
Na
0.000 Range= 10.230 keV 10.110
Integral 0 = 5111


20-Jan-1995 11:48:42
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Area 4 Inside Core
(50 MM FROM TOP SURFACE)
Si
Al
K
Ca
Mg
Na
Fe
0.000 Range= 10.230 keV 10.110
Integral 0 = 9292

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Client: ICS/Penetron International Ltd., C/o All Island Testing Labs.

Project: Information of Client

Subject: Laboratory Testing of Penetron Material for Chemical Resistance

Report No. **93-3981** Date **10/19/93**

At the request of the Client, laboratory tests were performed to determine the chemical resistance of Penetron treated concrete.

Experimental Design

The concrete used for the study had a design strength f"c = 4000 psi. The concrete mix proportions are presented on Attachment 1.

The concrete specimens used were saw-cut from 6 x 12 inch concrete cylinders. The specimens were 2 inches thick and 6 inches in diameter. At the time of the study, the concrete was 28 days old.

The Penetron material (which was received in powder form in a sealed bag) was mixed with water into a slurry. The ratios were:

- 2 parts Penetron
- 0.8 parts water

The slurry was then applied on all surfaces of the concrete specimens by brushing. After the final setting of Penetron the surfaces of the specimens were moistened and placed in a regular concrete curing room for 14 days at 73 ^{o}F and 100% relative humidity.

At the end of 14 days, the specimens were removed from the curing room and placed in various chemical solutions which provided a wide range of pH levels and corrosive conditions.

Test Results

SAMPLE NO.	SAMPLE TYPE	TYPE OF TREATMENT	PH	OBSERVATIONS	
				7 day	28 day
1A	Penetron Treated	Dilute Hcl	3	No Effect	No Effect
1B	No Penetron	Dilute Hcl	3	No Effect	Surface Weathered
2A	Penetron Treated	Dilute H2SO4	3	No Effect	No Effect
2B	No Penetron	Dilute H2SO4	3	No Effect	Surface Weathered
3A	Penetron Treated	Rain Water	4	No Effect	No Effect
3B	No Penetron	Rain Water	4	No Effect	Surface Weathered
4A	Penetron Treated	$CaCl_2$	7	No Effect	No Effect
4B	No Penetron	$CaCl_2$	7	No Effect	Slight Effect
5A	Penetron Treated	NaOH	11	No Effect	No Effect
5B	No Penetron	NaOH	11	No Effect	No Effect

CONCLUSIONS

Based on these test results, the following conclusions were drawn:
1. The Penetron treated concrete was found to be resistant to acidic and alkaline conditions ranging between pH values of 3 to 11. Also, chloride containing solutions did not have any measurable effect on the Penetron concrete.
2. The untreated concrete (control samples) had surface weathering when exposed to pH of 3, rain water chlorides and sulfate solutions.

SHIMEL AND SOR TESTING LABORATORIES, INC

Kamil Sor, Ph.D.
President

KS/smdcc: (1) Client

Doug Quick

ATTACHMENT I

CONCRETE MIX DESIGN USED

FOR THE PENETRON TREATMENT TESTS

MATERIALS	AMOUNTS PER CUBIC YARD
Portland Cement, Sacks	6.0
Portland Cement, Lbs	564
*Sand, Lbs	1450
*Coarse Aggregate	1860
Water, Ga	36.3
Water, Lbs	302.4
W/C Ratio	0.54
Slump	4.0
Entrapped Air, %	1.8

(*) SSD basis