Ground improvement the way nature does it - but a million times faster.

Turn sand into rock in one day.

CIPS : A down-to-earth Australian invention.

lithic

Earth Bond Solutions

- CIVIL ENGINEERING - FOUNDATIONS UNDER EXISTING WALLS AND BUILDINGS, LIQUEFACTION PREVENTION, IN SITU CONSTRUCTION OF PILES AND WALLS IN SAND
- OFFSHORE CONSTRUCTION - FOUNDATIONS BENEATH PILES, SCOUR PROTECTION
- MINING - SEDIMENT STABILISATION IN HIGHWALLS, CONTROL ACID ROCK DRAINAGE
- PREVENT BEACH EROSION, RESTORE ERODED BEACHES TO THEIR ORIGINAL STATE
- REDUCE WEATHERING AND EROSION OF HERITAGE STRUCTURES
- DUST PREVENTION

Revolutionary New Ground Improvement Technology

Turn Sand into Rock the Same Way Nature Does – But a Million Times Faster

Are you building a structure on or inside a sandy soil or weak rock? Why not consider a foundation that is Better, Cheaper, Faster and More Environmentally Friendly?

CIPS - Ground Improvement using the **C**alcite **I**n situ **P**recipitation **S**ystem

CIPS transforms loose sand into strong sandstone rock, such as a cylindrical core, sphere or block.

CIPS presents new options for ground support, grouting, construction, protection and safety, often where there are no other viable solutions.

- Excavations in sand for a pool or house.
- Better foundations for brick or masonry walls on sand - tilting or cracking walls.
- Better foundations for offshore piles or piers - increased stability but cheaper, prevent scouring of seafloor sediment.
- Build subsurface columns or walls in sand without excavation.
- Protect sandy beaches from erosion without an unsightly seawall or restore a sandy beach after erosion has occurred.
- Capture fugitive dust from dirt roads and worksites.
- Reduce erosion of historic buildings or monuments built of sandstone, limestone or clay.
- Create passive or reactive subsurface barriers to manage water movement and control Acid Rock Drainage.

"The first truly new technology for Civil Engineering in 50 years."

Professor Peter Vaughan
Imperial College
London 2002

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What is CIPS?

CIPS is a permeation grouting system that delivers 'liquid' calcite into any permeable and porous material, such as sand or porous rock. CIPS begins as a fluid with no solid particles so it easily penetrates long distances under low pumping pressures. Reaction within the fluid precipitates calcite as a cement around grains, binding them into a solid framework with considerable strength.

After treatment pore spaces between grains are only partially filled with calcite - the treated material remains porous and permeable and can be re-treated, each treatment producing a further increase in strength. With multiple treatments any desired strength can be achieved, even up to 50 MPa which is the strength of industrial concrete. Generally 2-3 treatments are sufficient for most applications, creating a strength between 2 MPa and 5 MPa.

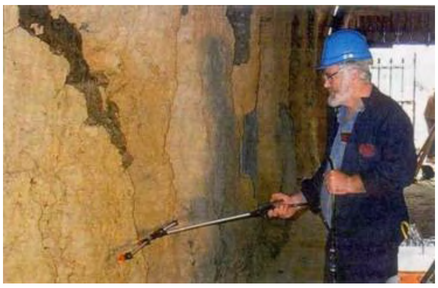
CIPS can be applied above or below the water table into dry or water-saturated materials and is well-suited to in situ application by subsurface injection from boreholes or from pushed or drilled spears from the surface.

When injected into sand CIPS Fluid permeates by displacing all fluids or gasses in the pore spaces between grains and it remains in the pores while the CIPS reaction takes place. Because of the fluid's properties (high density 1.5g/cc, low viscosity 3cP and low surface tension) a sharp boundary is maintained between treated and un-treated areas and consequently it forms a spherical ball of CIPS-Rock around the injection point. By positioning injection spheres adjacent to each other any arbitrary shape of strengthened material can be created.

Application Methods

Subsurface Injection, via a borehole tool or an injection spear, from single injection points at low pumping pressure. A large penetration distance can be achieved. Simultaneous injections from multiple outlet ports is possible.

Soaking from surface flooding and penetration under gravity. Depth of penetration can be variable.



Spraying onto sloping or vertical surfaces is possible so long as the CIPS Fluid actually penetrates the material. Depth of penetration is usually limited.

CIPS-treated sand looks the same as it did before treatment - the same colour and the same texture. The only change is that it is no longer a loose or weak sand - it is a strong rock! Only a small amount of calcite cement is precipitated between the sand grains, not enough to change the sand's appearance. But, that small amount of calcite is very effective as a cement, binding the sand grains into a strong solid framework - just like in natural sandstones. Only after many CIPS treatments does the sand begin to turn white, which is the natural colour of calcite. If required the calcite can be coloured.

Spheres Columns and Walls

When CIPS Fluid is injected into sand at a single point it permeates out in all directions away from that point. For a given flow rate the distance the fluid travels from the injection point depends on the sand's porosity and permeability. So, the size of the injection body is determined by the volume of CIPS fluid injected (length of time that pumping continues) and the porosity and permeability of the sand.

If the sand is homogeneous and isotropic (the same porosity and permeability everywhere and in all directions) then the body of CIPS-treated sand will be spherical in shape. If the sand is inhomogeneous (eg. layered) or anisotropic the body of CIPS-treated sand will be distorted away from spherical to elliptical. If groundwater is moving through the sand the sphere will be displaced slightly from the injection point, but only by a small distance because CIPS Fluid turns into a gel 30 minutes after mixing and injection and this gel is difficult to move.

Columns, walls and 3-D volumes of CIPS-strengthened sand can be formed using multiple overlapping spheres. Several vertically aligned and overlapping spheres, spaced so there are no bulges or constrictions in the regions of overlap, will form a column and several side-by-side columns will form a wall. 3-D volumes can be filled using arrays of overlapping walls.

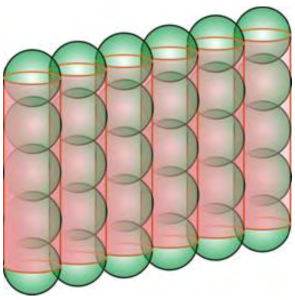
Sphere in homogeneous sand.

Sphere in strongly layered sand.

Column of 3 overlapping spheres.

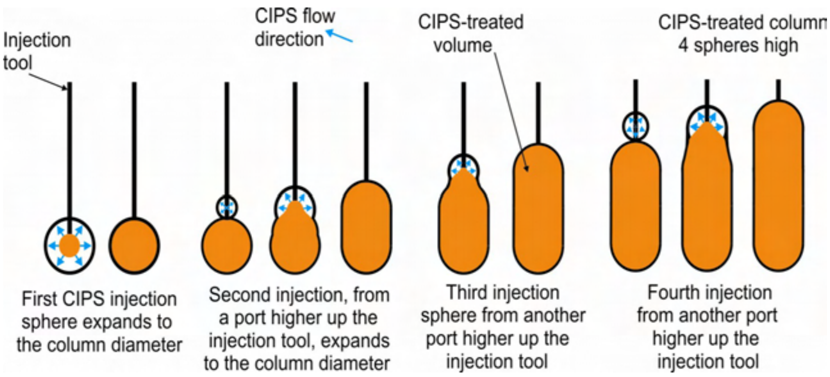
Shallow Injections

Because CIPS can penetrate long distances through sand under very low pumping pressure (it does not contain any solid particles and has low viscosity, similar to that of water), injections can be made at a very shallow depth, even as little as 20cm, without concern that fluid will breakout at the surface.



Wall design of 6 overlapping columns, each composed of five overlapping spheres.

Construction design for a column of CIPS-treated sand made from four vertically aligned and overlapping spheres.



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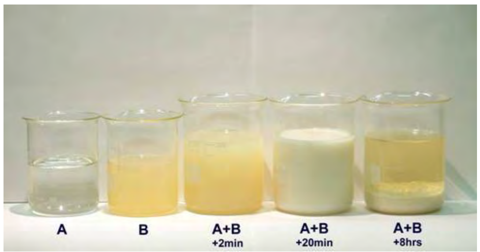
Technical Aspects

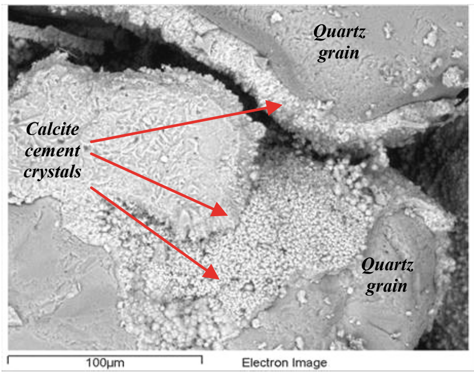
CIPS consists of two water-based, non-toxic, neutral pH, liquids (Solutions A & B) that are mixed together prior to application to make the CIPS Fluid. All necessary chemical ingredients are carried in this fluid, nothing is required from the sand. The reaction starts immediately upon mixing, but little obvious change occurs for the first 10 minutes.

After 15 minutes the fluid slowly turns white as small calcite crystals begin to form. Calcite crystals continue to nucleate and grow and the fluid becomes densely white and viscous and after 30 minutes a thick gel has formed. After 60 minutes this gel begins to break down, larger calcite crystals grow and form rinds on the surfaces of each sand grain.

Calcite rinds on adjacent sand grains lock together forming crystalline bridges between grains. It is this framework of calcite cement around sand grains and calcite bridges between grains that gives the treated sand its strength.

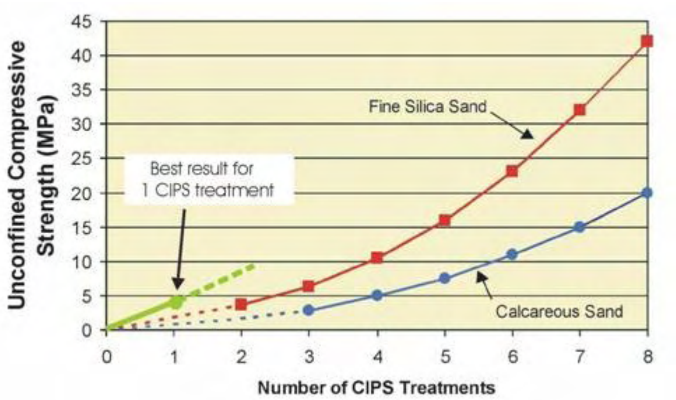


*Beakers **A & B** - Solutions A & B before mixing.*
*Beaker **A+B+2min** - mixture of A & B after 2 minutes.*
*Beaker **A+B+20min** - mixture after 20 minutes.*
*Beaker **A+B+8hrs** - mixture after 8 hours.*



Electron microscope image of CIPS calcite cement on the surfaces of quartz sand grains.

Quartz sand grains cemented with CIPS calcite bridges, some of which is shown by red arrows.



The CIPS reaction takes 8 hours to reach completion, but 90% of the calcite is produced within the first 2 hours.
The reaction is temperature sensitive - faster at higher temperatures and slower at lower temperatures. The CIPS formulation is adjusted to compensate for temperature and to produce greater or lesser amounts of calcite over longer or shorter timeframes. The reaction rate determines the number and size of the calcite crystals, which in turn effects the degree of bonding between grains and this produces strength.

High Strength from Multiple CIPS Treatments

Because calcite cement does not fill pore spaces between grains CIPS treated materials remain porous and permeable. Consequently, CIPS treatment can be repeated after 6-8 hours without any loss of the first-deposited calcite.

Each treatment adds additional calcite, forming larger and stronger crystalline bridges between grains and new bridges where they did not previously exist. Strength increases with each CIPS treatment, up to 50 MPa after 10-12 treatments.

Civil Engineering Applications

An Option for Foundation Design Civil Engineers frequently have to design structures at sites that have inadequate foundation materials. Up until now their options were to excavate the weak materials down to strong rock or install piles to extend foundations down to stronger layers. CIPS presents an alternative by significantly improving the properties of existing in situ material, particularly if they are sands. In situ ground improvement can also be cheaper and quicker than excavation or piling.

CIPS is **complementary** to existing ground improvement technologies, it does not replace them. CIPS strengthens in situ sands, it does not prevent water flow and it does not fill cracks or cavities. It is particularly well-suited to remedial treatment for existing structures where foundation capacity is inadequate, such as with tilting walls or subsiding concrete slabs, or off-shore where sediment scouring has occurred because of waves or water currents.

Vertical Walls and Slopes

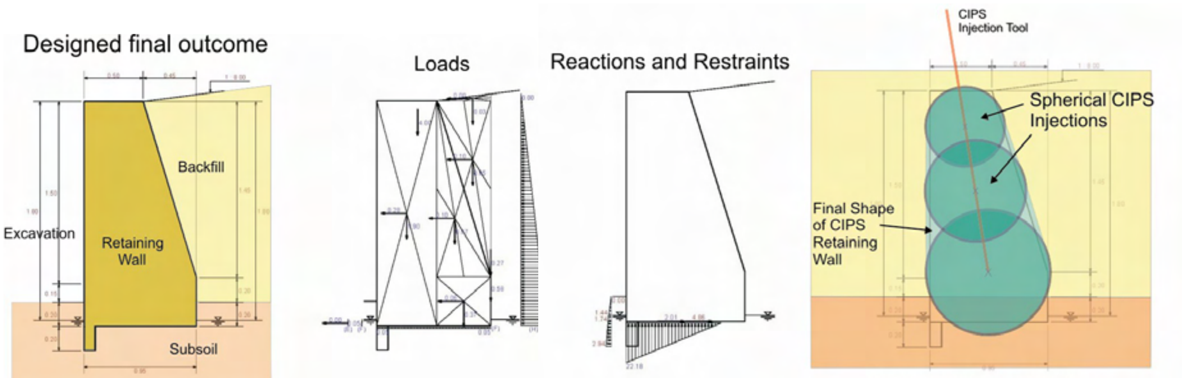
Excavations in sand can easily be stabilized by CIPS, typically by in situ treatment prior to excavation. Normal structural stability design of the CIPS retaining wall (*such as is shown below left and center*) is then followed by CIPS design (*below right*) to achieve optimum positions for the CIPS injection spheres.

5m high face of an excavation at Fremantle, WA. The white material is limestone rock and the brown material is sand strengthened with CIPS by Earth Bond Solutions PL.

Stabilization can be achieved without large equipment, without environmental disturbance (no noise or vibrations) and often at lower cost than other forms of stabilization.

Underpinning

Where an existing structure has inadequate foundation strength, CIPS can provide an easy and comparatively inexpensive method for underpinning without excavating the sand. Access is only needed for the injection tool and several hoses.



CIPS Design for In Situ Construction of Retaining Wall

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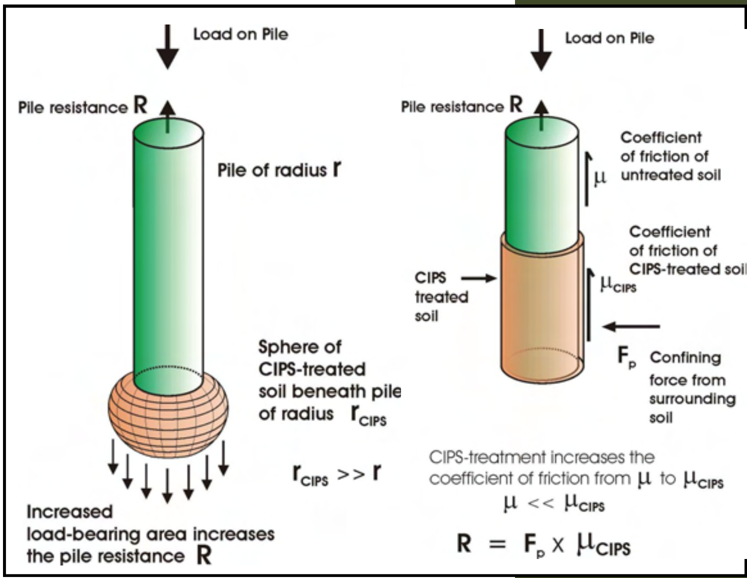
Civil Engineering (Continued)

Piles and Columns - CIPS can be used to construct columns of CIPS-Rock in situ without the need for excavation or for pile driving. In situ construction is usually much cheaper than excavation-casting, particularly if there is limited space for pile driving.

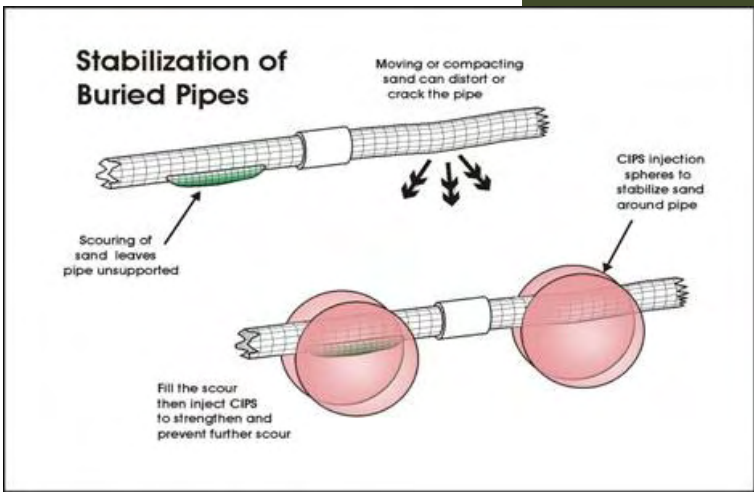
If a pile is already in place (either on-shore or off-shore) its load-bearing capacity can be increased by treating the surrounding sand and converting it into strong CIPS-Rock. Two forms of remedial treatment are possible:

- Increasing a pile's **End-Bearing** capacity by strengthening the sand underneath the pile.
- Increasing **Skin Friction** along the side of the pile by strengthening the surrounding sand.



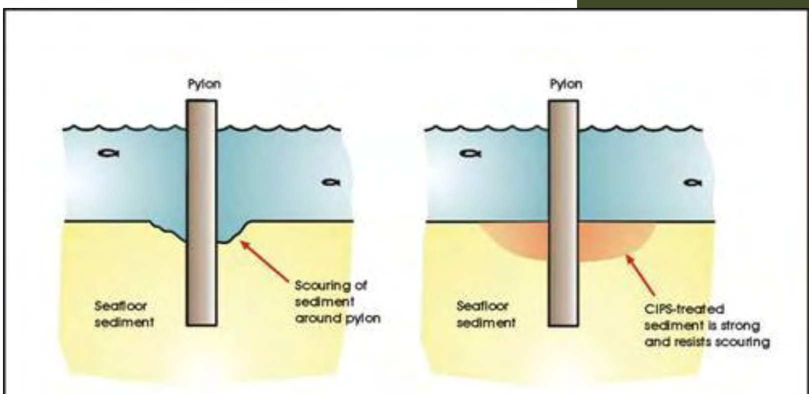
Liquefaction - Subsurface water-saturated sands can be liquefied by shock waves during earthquakes, causing complete loss of foundation capacity for buildings.

Sand can be converted into strong CIPS-Sandstone before the earthquake occurs, thereby preventing liquefaction. Sand grains will be cemented together so they do not bounce about during the earthquake shocks - the foundation will remain solid and strong. Pockets of groundwater will remain isolated inside pore spaces but will still be able to flow slowly, so pore pressures will remain low.



Other Engineering Options

Buildings toppled by soil liquefaction in the 1964 earthquake at Niigata, Japan.



Prevention of Scouring Around Piers.

Coastal Protection

Beaches are dynamic environments that can quickly change in response to many factors, most important being high water level and storm intensity and frequency. With global warming and rising sea levels coastal beaches are at increasing risk of erosion, with consequent loss of beach amenity and property. CIPS can be used to protect beaches by preemptive construction of *'natural barriers'* that are normally invisible and hence do not spoil the beach's appearance.

Gold Coast Beach eroded by storm waves in 1996 and …

… in 2003 replenished naturally in calm weather.

Permanent Offshore Sandbank - Normally, sandbanks stop waves from breaking directly onto a beach. However, during storms sandbanks can be scoured away by strong currents and high water levels (storm surges) exposing the beach to direct wave impact and erosion. CIPS can convert a sandbank into a permanent barrier of strong CIPS-Sandstone (offshore reef) that will not be washed away. It will look the same as a natural sandbank and will allow normal waves to pass over the top, but it will not be seen because it will be below water level. During storms it will act as an offshore reef that prevents large waves from reaching the beach.

Backstop Wall - Public infrastructure or private property close to a beach is at risk of erosion from waves during storms. Some local governments ban heavy construction of protective walls to protect the beach because they are unsightly and change the character of the beach - often causing increased erosion and permanent areas of deep water.

An alternate strategy is to take pre-emptive action and use CIPS to construct a hidden, below-the-sand, backstop wall of CIPS-Sandstone to prevent erosion progressing inland.

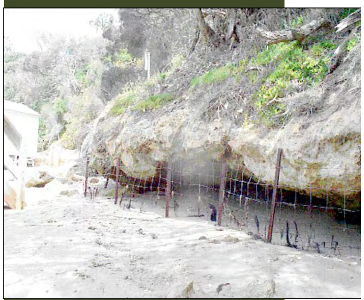
This wall would only be exposed at times of severe beach erosion and would be re-buried during calm weather when sand was again deposited on the beach. A hidden backstop wall is likely to be more acceptable to local authorities and it is cheaper than constructing a rock wall during an emergency, when few options are available.

In 2008 Lithic Australia constructed a 15m long backstop wall on Onetangi Beach, Waiheke Island, NZ, as a trial for Auckland City Council. The wall was build by injecting CIPS deep into the sand while the beach was being used by the public. When the work was finished the injection pipes were removed and the beach returned to its original condition.

Undercutting of Cliffs

Coastal cliffs composed of weakly-cemented carbonate dune sand are often undercut by waves, making them unstable and a danger to the public.

CIPS can strengthen the lower sections of a cliff and prevent undercutting, keeping the cliff stable.



An undercut cliff made of soft calcarenite limestone along the southern boundary of Port Phillip Bay, Melbourne, Australia.

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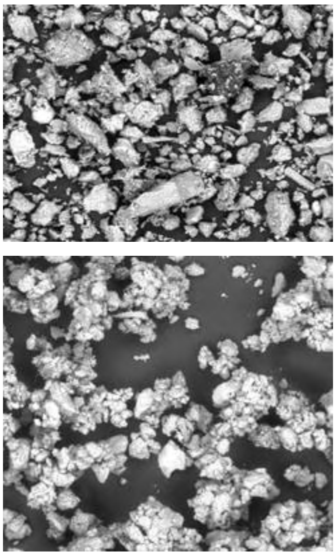
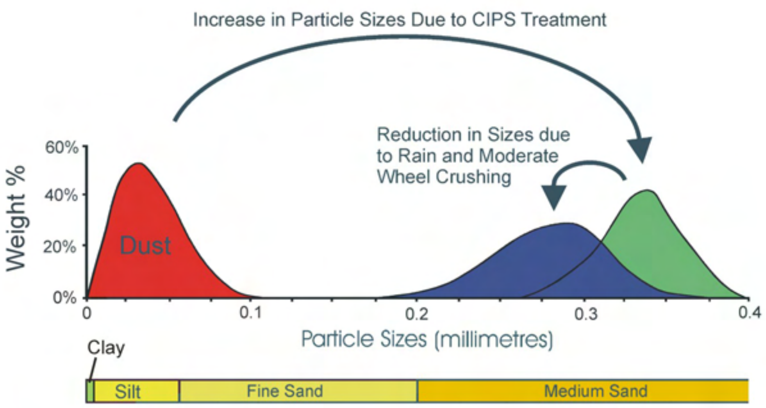
Other Applications

1983 dust storm over Melbourne, Australia.

Dust Suppression - CIPS sprayed onto dirt roads or work areas will capture fugitive dust particles by agglomerating them into larger sand-sized clusters that are less susceptible to wind disturbance. Calcite cementation survives subsequent rain and crushing by traffic so it lasts longer than other dust treatments. Such treatment is quick and easy, the result is durable and the whole job economical.



SEM images of dust particles before (top) and after (bottom) CIPS treatment. Both images are 0.5mm across.



Preservation of Historic Buildings - Historic buildings made of stacked sandstone or limestone blocks covered with clay pisé, or simply made of packed mud, commonly suffer from severe weathering and erosion. CIPS can be used to renew the natural cements between grains in the stones and can stabilize clay particles in the mud, preventing grains from being eroded from the outer surfaces.

It has been demonstrated that CIPS treatment reduces the rate of erosion and can return a structure to close to its original condition.

Remains of two 150 year old miner's huts along Butchers Gully in the Castlemaine Goldfield of Victoria. CIPS treatment arrested weathering and erosion of the packed clay walls and mud pisé covered stone walls. This project was funded by Parks Victoria and the Victorian Heritage Council.

Mining

There are several potential applications for CIPS in the mining industry.

- To strengthen loose sediments in pit walls to allow steeper faces, or in the walls of shafts or boreholes to prevent collapse.
- To strengthen uncemented mine fill without blocking water drainage.
- In situ construction of passive or reactive barriers to control or manage underground water movement and prevent Acid Rock Drainage.

History - How CIPS was Developed

CIPS was conceived and developed in the 1980's by Dr Graham Price in CSIRO, Australia's premier industrial research organization. The idea arose from Dr Price's work with Woodside Energy Ltd on the foundation of the first big offshore oil and gas platforms on the Northwest Shelf of Australia, North Rankin A and Goodwyn.

Lack of foundation strength for the platforms was caused by low skin friction between sub-seafloor carbonate sediments and the platform's 2m diameter steel piles. The key element was the absence of cement between the small hollow seashells of which the sediments are composed. This lack of cementation (strength) in the sediments meant that the piles had to extent down to 125m below the seafloor to rest upon a strong limestone layer.

The North Rankin A Gas Platform.
Photo courtesy of Woodside Energy Ltd.

In 1988 Dr Price won an ARC research grant to employ a chemist and technical staff. Over the next two years they developed CIPS as a permeation grouting system to deliver calcite cement into porous sediments. Extensive laboratory and field testing was carried out in CSIRO and by postgraduate students in the Department of Civil Engineering at The University of Western Australia.

In 1998 Dr Price formed the private company Lithic Technology Pty Ltd to commercialize CIPS through an exclusive licence from CSIRO. Early work concentrated on investigating the fundamentals of CIPS chemistry, securing long-term supply of key chemical ingredients and the development of manufacturing methods and injection grouting systems for different applications. In 2001 the German company CarboTech Fosroc GmbH was licensed to manufacture and sell CIPS throughout Europe. That licence ended when CarboTech was bought out by a retail group and the company's R&D work ceased.

In 2002 Lithic Australia Pty Ltd was formed and licensed to manufacture and commercialize CIPS throughout Australasia. Lithic Australia has a small manufacturing plant at Kogarah in Sydney. In 2005 Earth Bond Solutions Pty Ltd was formed and licensed to manufacture and commercialize CIPS in Western Australia. Earth Bond Solutions regularly carries out CIPS treatment projects around Perth, focusing on underpinning and strengthening foundations beneath buildings and walls and stabilization of sand around excavations for swimming pools and house extensions.

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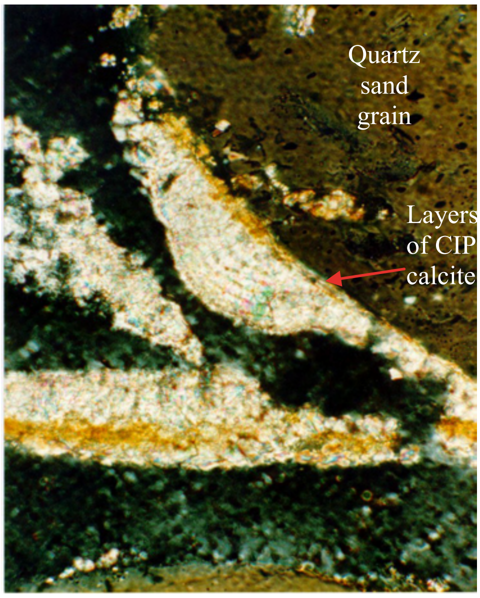
Photographs

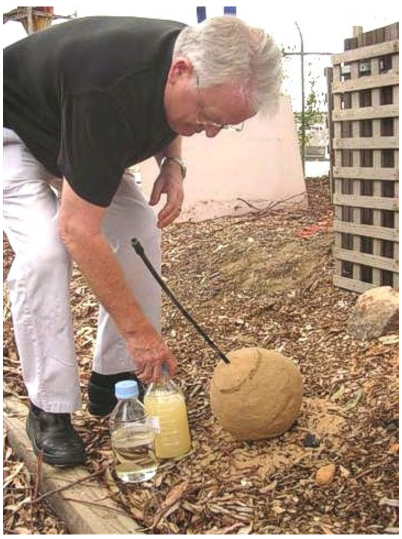
Injection pumps, hoses and CIPS solution tanks during construction of the below-surface backstop wall on Onetangi Beach, Waiheke Island, New Zealand.

1-2mm sand grains (grey, yellow and brown) heavily encrusted with CIPS calcite (white).



Photomicrograph showing seven successive layers of CIPS calcite that were deposited on the margin of a sand

Injecting CIPS beneath the wall of a house in Perth, WA.



A small sphere of CIPS-treated sand around the end of an injection tube. Adjacent are bottles of Solutions A & B used to cement the sand.

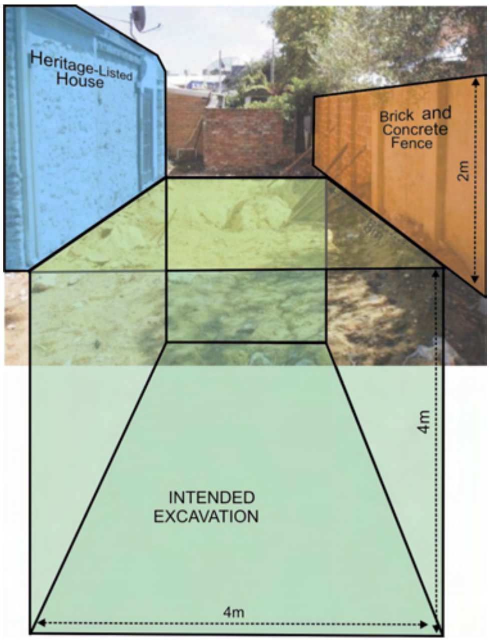
CIPS

CASE STUDY

Excavation Stabilization by CIPS Fremantle, Western Australia

In 2009 the owner of a property in Fremantle, WA, wanted a cellar built beneath the small backyard of his heritage listed brick-quoined limestone house. The design for the cellar was 4m wide by 8m long with a floor 4m below ground level.

One side of the yard was bounded by a brick and concrete fence rising 2m above ground level and founded on a concrete strip footing and stacked limestone blocks sitting on brown sand. On the opposite side was the heritage-listed house founded on natural limestone pinnacles and sand. The first photo below shows the yard between the house and fence and the second image shows the intended excavation.



The builder's task was to excavate the sand and limestone without collapsing the fence or undermining the neighbour's property and without disturbing the house. To do this the brick and concrete fence needed to be supported and to make the cellar as large as possible the supporting structure needed to be as near to vertical as possible.

A conventional engineering design to support the fence consisted of:

- (i) in situ construction of a 1.2m thick retaining wall beneath the fence by permeation injection into the sand of microfine cement grout;
- (ii) a 75mm thick coating of steel-reinforced shotcrete over the exposed face immediately upon excavation; and
- (iii) emplacement of five sets of 3.0m and 4.9m long passive soil nails driven through the shotcrete coating and secured with suitable faceplates.

Because of the high cost of the conventional stabilization design ($60,000) and difficulty in installing the 3.0m and 4.9m long soil nails in the limited space behind the house the owner and builder contracted Earth Bond Solutions Pty Ltd to implement an alternate stabilization scheme. This design consisted of in situ permeation treatment of the sand beneath the fence to form a CIPS-sandstone retaining wall of sufficient strength (5MPa compressive strength) that the shotcrete covering and soil nails would not be required.

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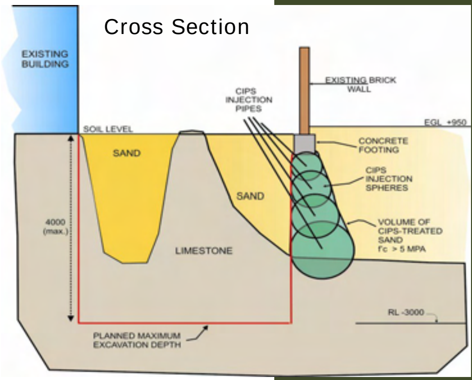
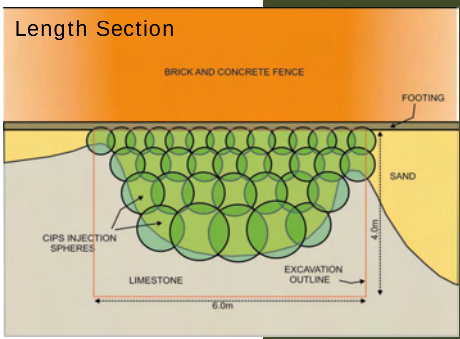
CASE STUDY (continued)

The design for the CIPS-sandstone retaining wall below the fence is shown on the right in both cross- and length-sections. The retaining wall was constructed with overlapping CIPS injection spheres, with each sphere given 3 CIPS treatments to produce a final minimum strength of 5MPa. A total of 3,800 litres of CIPS fluid was injected over a period of 7 days using low pressure and slow flow-rate pumps. Some of the injection lances, angled to reach beneath the wall, are shown in the first photo below.





Injecting CIPS beneath the rear fence using multiple injection lances.

Excavation work began one day after the final CIPS treatment. The CIPS-strengthened sand was described as "hard-as-a-rock" by the workers. The final wall of CIPS-sandstone was cut vertically, with only parts of the limestone pinnacles left protruding into the excavation as visual features in the cellar walls.

The completed excavation. Several white/cream coloured limestone pinnacles stand around the excavation. The CIPS-treated brown sand can be seen in the excavation face on the right.

The strength and stability of the CIPS-sandstone beneath the fence inspired the builder with so much confidence that he extend the excavation to 4.8m depth below the original ground level.

The cost of CIPS treatment was 26% of the cost of the conventional design and it enabled stabilization to be effected in the very limited space between the house and back fence, which would have imposed severe technical risks for other stabilization solutions to the problem.

Several weeks after completion of the excavation a steel-reinforced concrete wall was constructed over the face of the CIPS-sandstone to support a concrete roof over the cellar and connect to a concrete floor.

Material Properties used for the CIPS Design

Limestone: $\Phi=40^{o}$; γ = 20.0 kN/m^3 UCS ~50 MPa

Brown Sand: $\Phi=30^{o}$; γ = 18.0 kN/m^3 UCS = zero

Sand after CIPS treatment (CIPS-sandstone):
$\Phi=40^{o}$; γ = 18.2 kN/m^3; C=170kPa; UCS = 5 MPa

When the project was completed the property owner, K O'Daly, offered the following comment:

"Earth Bond Solutions were a pleasure to work with. Their quote was fully explained, it was much cheaper than others, yet was realistic and reasonable. Their staff were always prompt, pleasant and technically informed. The work they performed justified the outlay, saved my project much delay and avoided other technical difficulties."

Lithic Australia Pty Ltd
Sydney NSW and Melbourne Victoria

Earth Bond Solutions Pty Ltd
Perth Western Australia