do.co.mo.mo

international working party for
documentation and conservation
of buildings, sites and neighbourhoods of the
modern movement

The Fair Face of Concrete

Conservation and Repair of Exposed Concrete

preservation technology
dossier 2
april 1997

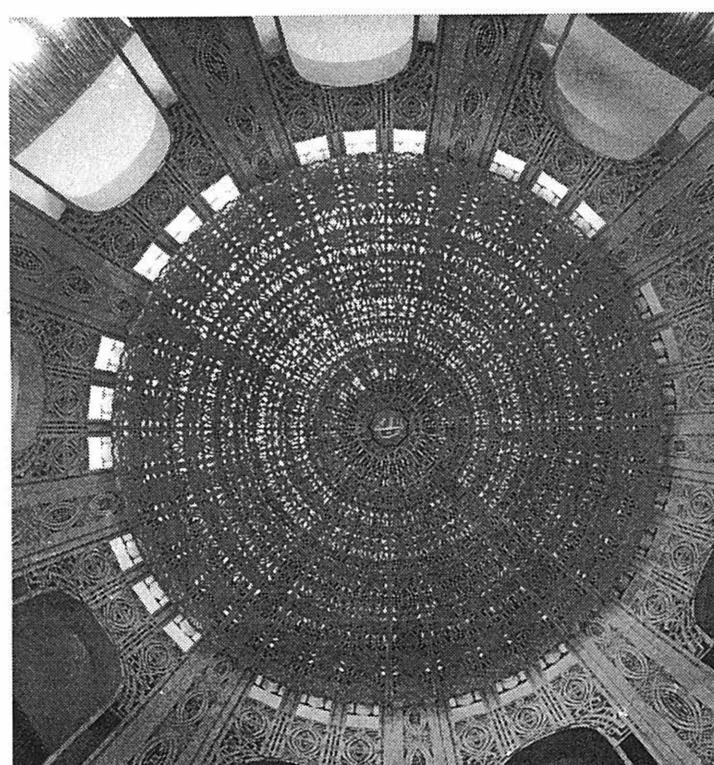
Technische Universiteit tu/e Eindhoven
abt
VNC
FOSROC

do_co_mo_mo_

international working party for
documentation and conservation
of buidings, sites and neighbourhoods of the
modern movement

The Fair Face of Concrete

Conservation and Repair of Exposed Concrete



Interior of the dome of the Bahá'i House of Worship.
Photo: R. Armbruster 1991.

The Fair Face of Concrete
Conservation and Repair of Exposed Concrete
Proceedings International DOCOMOMO Seminar, April 8, 1997, at the Eindhoven University of Technology, the Netherlands

Editors
Wessel de Jonge
Arjan Doolaar

Production
Birgitta van Swinderen

Printing
Eindhoven University of Technology printshop

ISBN
90-6814-076-0

Eindhoven University of Technology
BPU Postvak 8
P.O. Box 513
5600 MB Eindhoven
The Netherlands
tel. +31-40-2472433
fax +31-40-2459741
e-mail docomomo@bwk.tue.nl
internet www.ooo.nl/docomomo

Cover photographs
Repair of textured concrete makes high demands upon the mixture, colour and texture of the materials, as well as the workmanship in application (photo: W. de Jonge). The entrance of the Highpoint building (1938) in London by Berthold Lubetkin, expresses the great architectural potential of exposed concrete (photo: P. Cook, London).

Committee of Recommendation
- Drs. A.L.L.M. Asselbergs, Director, Rijksdienst voor de Monumentenzorg
- Dr. W. van Loo, President, Vereniging Nederlandse Cementindustrie VNC
- Prof.Ir. H.A.J. Henket, Professor, Eindhoven University of Technology

Sponsors
This seminar enjoyed financial support from:
- Eindhoven University of Technology, Faculty of Architecture
- Vereniging Nederlandse Cementindustrie VNC
- Adviesbureau voor Bouwtechniek ABT
- FOSROC NCT a.s.

In cooperation with:
- DOCOMOMO Specialist Committee on Technology
- Section Renovation Technology, Eindhoven University of Technology

The editors have tried to verify all photo credits. If a photo credit is incorrect or incomplete, please contact the DOCOMOMO International Secretariat.

CONTENTS

* Additional paper, not presented at the Concrete Seminar on April 8, 1997

Preface

The Fair Face of Concrete seminar of April 8, 1997, has been a very interesting event, and DOCOMOMO deserves to be complimented for this initiative.

The event was interesting for two reasons. In the first place, because the repair of concrete constructions in 'modern' architectural heritage is a relevant but often difficult task. The pioneers of modern architecture discovered the expressive possibilities of concrete at a very early stage and, when applying this new material, created buildings that are sometimes of a breathtaking beauty. Through their pioneering spirit and vision, the development of concrete as a construction material, with its particular aesthetics, received an unprecedented stimulus.
To be a pioneer means: to learn through discovery. The importance of quality control and careful work, even in details, was gradually recognized. Now, decades later, it seems that the elegance of their creations is incidentally being effected by corrosion of the reinforcements and drastic repairs are sometimes needed. The pioneer's best buildings are nevertheless well worth preserving.

This brings us to the second aspect of our appreciation. An effort has been made to create an international and professional platform where practical knowledge and experience about non-destructive repair methods could be exchanged. It has been demonstrated that these non-destructive techniques have developed to a point where concrete repairs can be carried out without disturbing the architectural character.

The Vereniging Nederlandse Cementindustrie (VNC, the Association of the Dutch Cement Industry) attaches great value to such professional exchanges of information and has therefore willingly supported this DOCOMOMO initiative. Reading through the information brought together in this publication is highly recommended.

Mr. W. van Loo
Vereniging Nederlandse Cementindustrie VNC

Introduction

The fair face of concrete: critical authenticity

The architectural heritage of the Modern Movement is today more at risk than that of any other period, due to its age, the functions it was designed to perform, and the present cultural climate, but most of all because of the involvement of often innovative technology. The employment of new materials and construction types, and the development of industrial building methods with standardized components has been instrumental in materializing modernity in architecture. Constructions and envelopes were pushed to their physical limits, and were often designed with a limited lifespan. Their technical and architectural characteristics present enormous preservation problems today.

DOCOMOMO International aims to foster the development of appropriate techniques and methods of conservation for Modern Movement structures, and to disseminate this knowledge throughout the professions. Yearly international seminars on modern conservation technology are organized with the aim to produce a series of professional Preservation Technology Dossiers. The seminars focus on the preservation challenges posed by such emblematic modern features as structural frames, light envelopes and curtain walls, steel windows, glass, and exposed architectural concrete. The first seminar 'Curtain Wall Refurbishment, A Challenge to Manage' took place in January 1996. The present publication is the result of the second seminar of the series in April 1997, and a third meeting is scheduled for May 1998 on modern windows and glass.

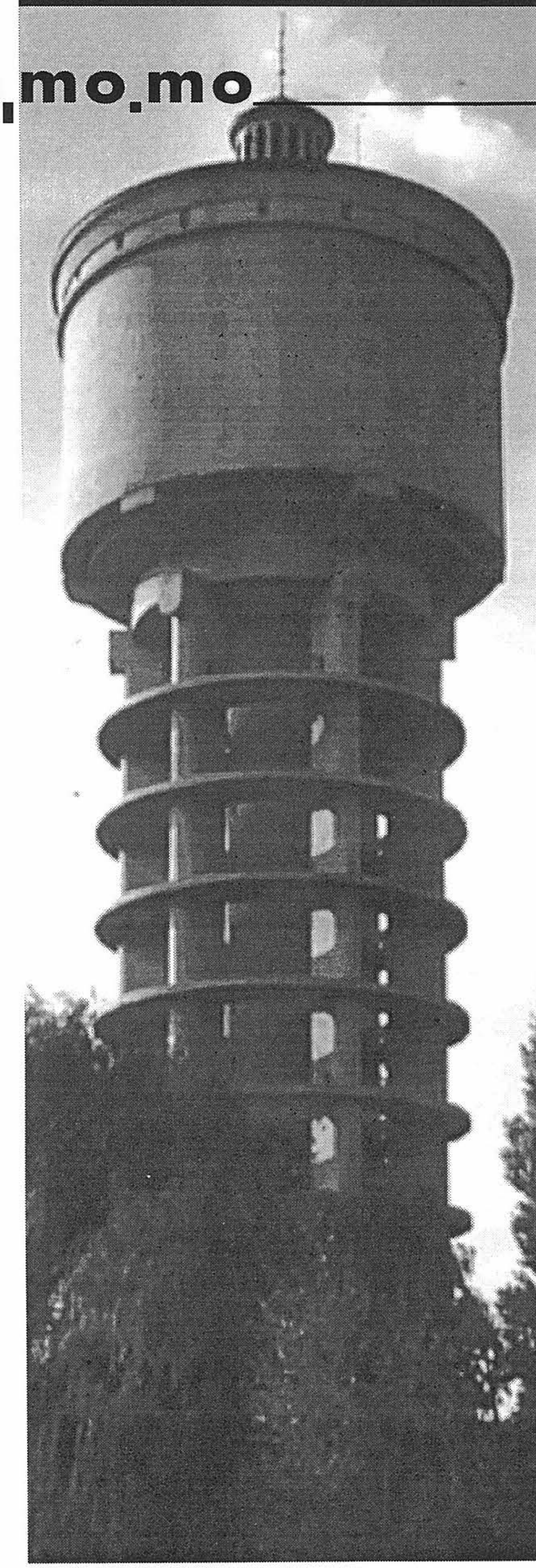
Among the numerous challenges that must be addressed in the conservation of modern heritage, the remedial treatment of exposed concrete raises conceptual and technical questions about longstanding conservation principles.
The introduction of reinforced concrete dates mostly from the 19th Century when this modern material was primarily used in civil engineering. When introduced in architecture by the end of the century, concrete was mostly clad with traditional materials. It was not until the 1920s that architects became interested in the design potential of concrete itself. Their interest mainly concerned the plastic qualities of reinforced concrete rather than the tectonic qualities of the material itself, and most concrete work in early Modern Movement structures is rendered or painted. Although the use of reinforced concrete was initially limited to structural applications, the material found a wider use after World War II in panels and cladding. The aesthetic qualities of concrete itself met wider appreciation, and exposed concrete was introduced as an architectural material.
The term exposed concrete has been used in this publication to describe concrete left as a visible surface including integral decorative finishes such as board marking, bush hammering, acid etching, profiling, and so on, to both *in situ* and precast concrete.

With the appreciation of recent architectural heritage on the rise the need for appropriate remediation and conservation techniques has become critical. As the mechanisms of failure, distress or deterioration of concrete through poor workmanship, carbonation and chloride attack are well known, traditional repair methods are aimed at restoring the structural integrity of the concrete.
These techniques rely on the replacement of defective concrete patches and are not primarily respectful to the architectural and historic qualities of the concrete face. With great care in the design of the concrete mix, the selection of aggregates and colour, as well as placement and texturing of the patches, it is possible to make repairs more discreet, as is demonstrated in several of the papers in the present volume. Today, even protective coats are available that are virtually unobtrusive when applied on particular concrete surfaces.
Electro-chemical treatments are a relatively new but promising approach to concrete repair at historic structures, especially in cases where damage is latent rather than patent. Case studies and an analysis of these techniques examine their viability for repairing the exposed concrete of Modern Movement structures when material and design authenticity are critical. It is essential to understand that both the electro-chemical methods and traditional repair techniques are complementary rather than mutually exclusive. The use of any remediation or conservation technique should be based on a full understanding of its advantages and disadvantages. The quality of any conservation strategy lies in making the right architectural judgements on the basis of an informed diagnose in each case. The intention of the present publication is to provide some key data to assist other professionals to make such a judgement, and to share some essential considerations to benefit the conservation community.

Wessel de Jonge, seminar organizer
DOCOMOMO International Specialist Committee on Technology

HISTORY AND DEVELOPMENT

do_co_mo_mo_



Opening

by Hubert-Jan Henket

Whereas the importance of concrete as a building material is historically different from country to country, it was variably used either as a substitute material, as a structural material, or for its independent architectural expression. As Berthold Lubetkin, protagonist of the Modern Movement in Britain in the 1930s, is quoted by John Allan: 'we wanted to give a face to our time'. Yet the creation of that face not only has left us today with beautiful buildings but also with many different conservation problems. Susan Macdonald points out that these problems differ considerably from period to period. The late 19th and early 20th Century concrete buildings tended to be carefully crafted, with limited but conservative regulations. In Europe, with the emergence of the Modern Movement and structural engineering, lobbying of regulatory bodies resulted in the relaxation of some of the strictest regulations and greater freedom of expression. Concrete in this period was virtually always rendered and painted. As a consequence, the level of durability is considerably less than with its predecessors.
In this respect it is interesting to note that many prewar concrete structures in Argentina for example, contrary to their European counterparts, excel in excellent condition still today. This is mainly attributed to the German contractors, still trained and experienced in the conservative way, who immigrated to Latin America at the beginning of the century.

After World War II the use of concrete became widespread and, influenced by Le Corbusier's examples of *beton brût*, architects all over the globe started to try rough concrete surfaces for aesthetic purposes. Many of these experiments today are in dire condition, as is shown clearly by Philippe Oudin with Royan Cathedral. The evolution of concrete as a building material is very much tied into the development of conservation techniques, to respond to structural and aesthetic demands and their philosophical acceptance.
Theodore Prudon presents some clear examples of the structural dilemmas of older and obsolete structures, due to the increase in contemporary building codes or functional requirements, in a society that is highly sensitive to legal liability.
Particularly the conservation problems of the aesthetic authenticity of postwar concrete surfaces is touched on by many speakers. The honest expression of concrete forms the crux of the problem in terms of authenticity, because the surface expresses not only the conceptual and structural intention but also the detail. Here, as Susan Macdonald says, material authenticity and aesthetic authenticity are inseparable. Repair options for both latent and patent decay of postwar concrete do not readily accommodate the general aims of conservation. Patch repairs too often result in a blotchy appearance, in contrast with the monolithic nature of concrete; shotcrete or protective coats cover the authentic texture and colour; and even electro-chemical repair will leave its marks. Whereas all these intervention options have the potential to retain the authentic material as much as possible, none specifically attempts to preserve the original aesthetic as yet.

To date the industry, the repair contractors and the building owners clearly concentrate on the economic advantage of retaining concrete structures, rather than on the cultural value of the authentic architectural expression. Also more care is required from architects and consultants to match repairs with existing work in design, colour and texture.
In their twin-lecture, Heide Hinterthür and Koos van der Zanden clearly demonstrate the importance of dedication by owner, craftsman and conservation officers alike. Patience and perseverance continue to be vital for satisfactory solutions. John Allan draws our attention to the importance to tailor different materials and techniques to suit different conditions and specific characteristics. He also points at the importance to respond a client's concern to reduce future running cost, even if this implies the alteration and technical improvement of original details. He has a point here, particularly for conservation officers and agencies.
Surely the intention of conservation is not only to restore an object as much as possible to its original state, but also to safeguard its future. If sensible exploitation is not properly guaranteed, the true purpose of conservation is missed. This goes particularly for Modern Movement buildings where the detailing and the use of materials were never intended to last a long life in the first place.
Berthold Burkhardt asks attention for the history of concrete construction in order to arrive at a better understanding of the current use and future development of concrete technology, both for the design of new structures and for the development of better conservation techniques and methods. Long-term monitoring of applied conservation interventions and repair work *in situ* is an important source of empirical knowledge.

The lectures presented at The Fair Face of Concrete seminar clearly indicate there is a lot of work to do for all concerned with the preservation of concrete architecture of the recent past. Concrete repair and conservation is still in its infant stage.

Hubert-Jan Henket is an architect, professor of architecture at the Eindhoven University of Technology and the chairman of DOCOMOMO International. He chaired The Fair Face of Concrete seminar.

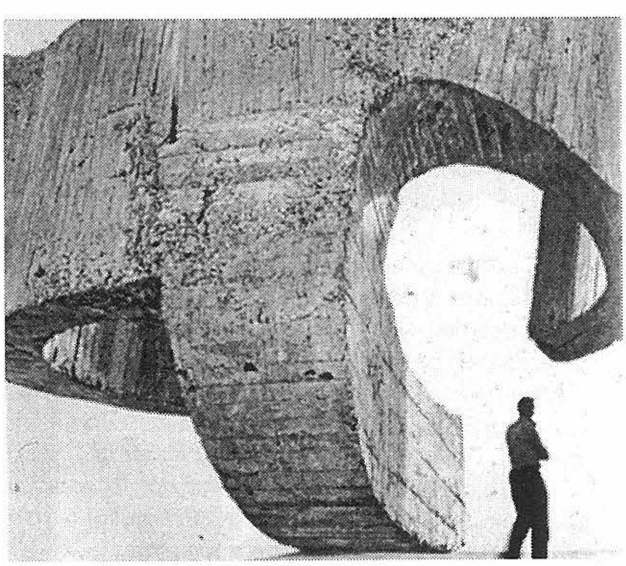
Concrete is Art
The design potential of concrete

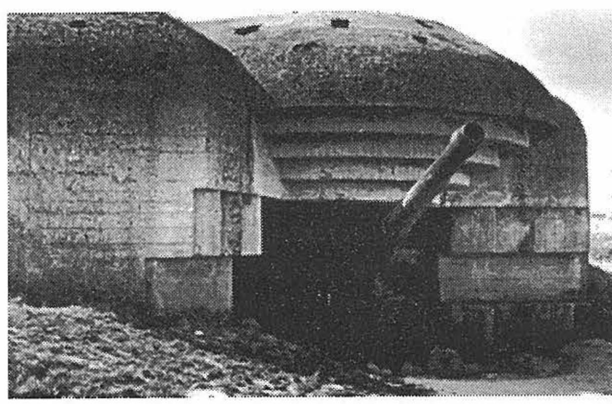
The tectonic and aesthetic qualities of concrete have fully been recognized only since the 1950s. The sculptural potential of reinforced concrete as a structural material in architecture today inspires architects to create unprecedented forms. Textures, colours and finishings have an impact on the weathering of concrete and lend an architectural expression to the fair face of a *noble* material.

by Peter Thole

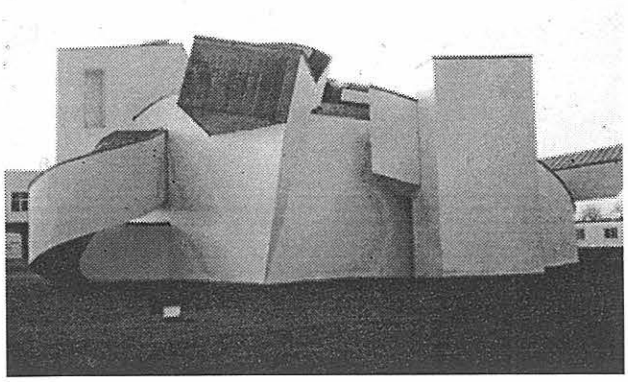
The fascination that concrete holds for us stems from the fact that it is cast. In principle, a unique and authentic product is created every time. Even in case of prefabrication and production in larger numbers, purpose made components still lend a specific character to buildings. Casting concrete is moulding, the art of carpentry, indirect design and therefore a complex process. In a way it can be compared with the work of a sculptor. Cast concrete is art, is 'real', in a sense that it is authentic, one-off, primal, timeless yet of the present, heavy, solid, voluminous, in-your-face, tough and sober. It is difficult to change, it lasts for eternity, is highly valued and costly.

Image
Set against all these superlatives, concrete remains 'commonplace'; it can look so simple, even coarse, rough, patchy, and not smooth. It does not pretend to exert any particular aesthetic effect, witness the objects by the Spanish sculptor Chillida, or the bunkers designed by German engineers during the last war. Commonly, not even the huge and impressive, white and smooth civil works in rural Holland, perfectly engineered and carried out, are recognized as real works of art.
At the same this represents the weakness of concrete. The colour and the imperfect surface are generally regarded as not being very attractive. People don't like concrete and that's it! To their mind, concrete is not top quality but a second-class material. This negative image makes the public to have a fear of concrete.
Most architects, on the other hand, love concrete and dream about it. Otherwise, Perret, Le Corbusier, Böhm, Coenen, Snozzi, Hadid, Gehry, Hertzberger, and Van Eyck could never have made such beautiful buildings.


A monumental object by the Spanish sculptor Eduardo Chillida. All photos courtesy of P. Thole.


Bunkers designed by German engineers.

Material
Concrete is a beautiful material. What really makes it very special is that objects, structures and buildings can be made in one piece. Top and bottom, roof and exterior wall, space is literally flowing everywhere, in organic and crystalline forms. This type of architecture is strong, indestructible and monumental, but can be elegant and dynamic at the same time. More than steel, with its members and sheets,

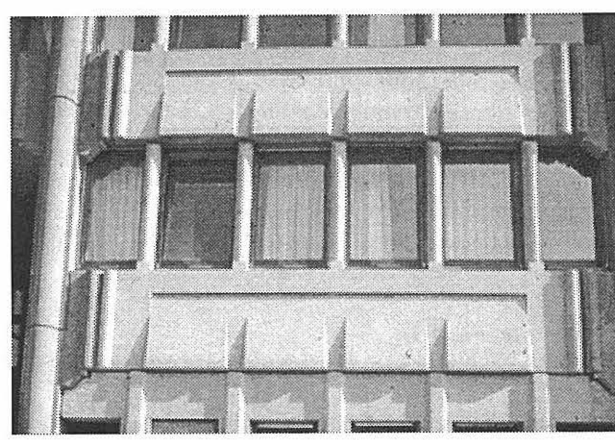


Vitra Museum by Frank Gehry, Weil-am-Rhein.

concrete is in fact *the* material for the future. Reinforced concrete suits the unlimitedness of open-plan cybernetic architecture, which is almost too far out to imagine, let alone to depict, except with 3-D systems. Still the construction of formwork has not come that far and constricts such versatile employment of concrete.
Thanks to reinforced concrete large spans and cantilevers are possible, which suggest that concrete can 'float'. Spatial shapes can be designed so as to combine the functions of load bearing (structure) and separation (exterior wall) within one single concept. This is virtually impossible with constructions in brick, steel or glass, which depend on the assemblage of components. It is not by coincidence that the most particular buildings in our society today are designed in concrete... monuments, memorials, public buildings, churches, bridges, viaducts, bunkers, and water towers. You can't turn your back on concrete.

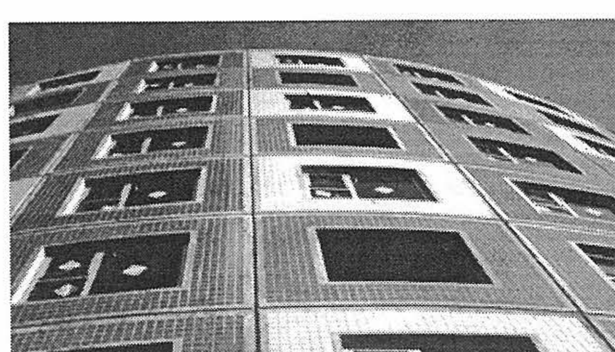
Prefabricated concrete
Nearly a hundred years ago architects like Perret and Garnier discovered the potential of concrete. Their interest regarded not just concrete cast *in situ* but also in its prefabricated form for applications like claddings and decorative grills. Prefabricated components lend scale to buildings through joints or chase lines. Structural and decorative elements can more easily be distinguished, which supports the definition of the architectural concept and expression.
The typically French, classical idiom of Auguste Perret is recognizable in the Palais Iena (1937) in Paris - not only in the shape and the symmetry of its design, but primarily in what has been dubbed the 'Perret' column and the construction of the facade. Another example of architectural impact through small prefabricated components is Charles van den Hove's Hoogfrankrijk project for Maastricht (1992-93). Here, the architect limited himself to a differentiation in a classical, post-modern style, perfect in detail and workmanship, though somewhat detached from the casual observer's perception.
On a big scale, large buildings can be segmented through the use of storey-high exterior wall elements. This can sometimes be very expressive and strong, such as in the 1980s residential complex for the

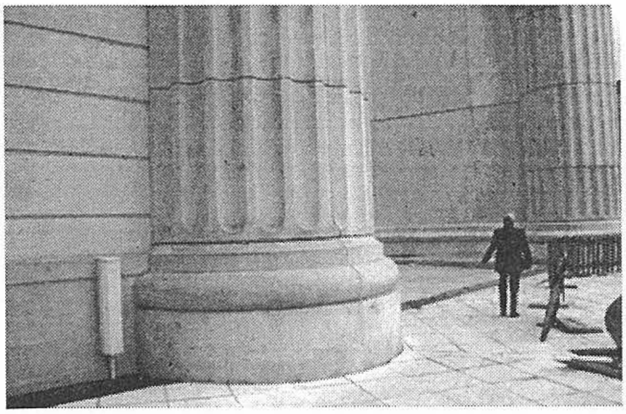
Load bearing facade of the Villa Cassarate with white ribs in Lugano, designed by Aurelio Galfetti and Antonio Antorini.



The Züblin Haus in Stuttgart by Gottfried Böhm.

Detail of housing block 'De Peperklip' in Rotterdam by Carel Weeber, 1978-82.





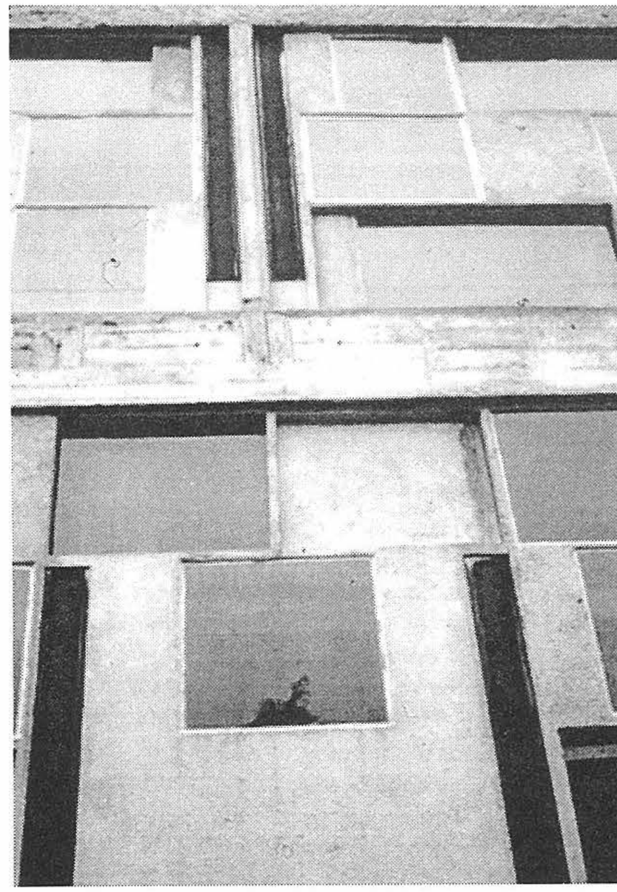
Classic beauty in concrete. Logements Montparnasse by Bofill.

elderly in Lugano by Durish, and sometimes as subtle as in the ribbed white facade of the Villa Cassarata, designed by Galfetti for Santorini in 1987. In 1985, Gottfried Böhm, in his design for the Zublin Haus in Stuttgart, segmented the front into load bearing prefab uprights with suspended facade elements between them, which again support the floors. An ingenious example is also Abel Cahen's stacking of 'blocks and columns' for a contemporary canal house in Amsterdam (1964-70). Carel Weeber was one of the first architects in the Netherlands to use brightly coloured tile-clad exterior panels on a large scale, in his 'De Peperklip' housing scheme in Rotterdam (1978-82). The prefabricated concrete panels are pitiless in repetition, uncompromising in design, consistent and sober, refined in the curved concept of this residential building. In France such things are often done differently, and there is more room and need for classical monumentality and decor. Bofills work in Marne La Vallée represents the classical beauty of concrete, the proof that anything is possible, and that any shape and any colour can be copied: grandeur for the man in the street, concrete for every dwelling, and in every family.

Concrete cast *in situ*

Prefabricated concrete has become an indispensable element in our construction industry. Anything is possible, and in terms of technology the product is becoming ever more perfect and high quality, durable

Mondadori building by Oscar Niemeyer in Milan, Italy.



Facade detail of Le Corbusier's monastery 'La Tourette' (1957-60) in Eveux-sur-Arbresle, near Lyon.

and strong, aesthetically pleasing and monumental. Unfortunately, it is too complex and too expensive for smaller structures. However, concrete cast *in situ* continues to fascinate and remains a dream of every architect who acknowledges its design potential. There are sufficient examples, such as the striking 1970s tower blocks by Emile Aillaud in Nanterre/Paris, with the stunning tile colours and drop-shaped window openings, or the beautiful forms of Oscar Niemeyer's office building in Milan of around 1985 that could never have been built in Europe but by Brazilians.

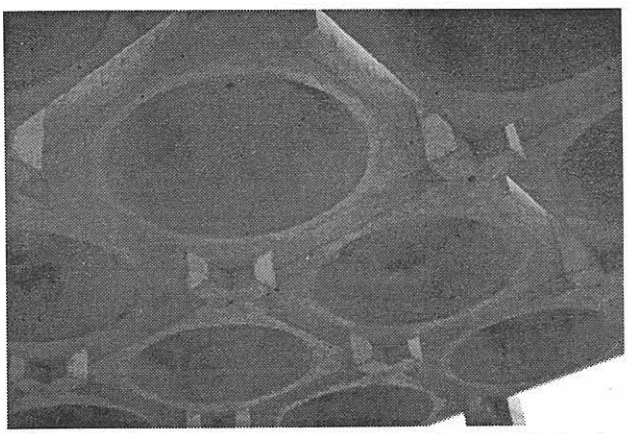
But we, Europeans, also have our laboratories where experiments can be conducted with concrete in all its facets. Churches, cloisters and graveyards, in particular, appear to be extremely suitable for architectonic research. Sacral areas apparently inspire architects to exceptional design in order to attract God's attention as well as that of the visitor, who can easily loose himself in such supernatural structures and spaces. Aalto, Portoghesi, Le Corbusier and Van Eyck are examples. The monastery of La Tourette (1957-60) near Lyon is *the* undisputed Mecca for architects rather than the faithful. Here Le Corbusier is our deity for a while.

Still, this monastery is certainly not exemplary as a case of superb execution. On the contrary, it is low-budget concrete and, fortunately, just perfect detailing is no longer synonymous with good architecture!

Perhaps Le Corbusier was fortunate to have lived then rather than today, with all its constraining regulations.

Prominence

Van Eyck's Orphanage in Amsterdam (1955-60) is an inspiring and monumental example of subtle design and employment of concrete. Shape, structure and space; floor, wall and roof; place, light and intimacy are all expressed in one material. It is poetry in concrete, in a highly disciplined manner.
For the Moluccan Church in Den Bosch (1984-85) the author explored the interference of square and round, of circle and cross. The columns and vaults of the classic cathedral were taken as a reference,



Vaulting of the Moluccan church in Den Bosch, the Netherlands, by Peter Thole, 1984-85.

A church just outside Vienna, where the sculpturor Wotruba appears to have stacked bricks, blocks and sheets like a sculpture.

translated into the double column and the domed-cross elements for the roof of this church.
A combination of prefabricated, *in situ* and even prestressed concrete made possible to have this concept turned into material. The load bearing structure of the church is, at the same time, the completed building: structure is architecture. A similar approach was adopted by the sculptor Wotruba for a church near Vienna that appears as a stack of bricks, blocks and sheets, almost like a sculpture.
Everyday buildings can be constructed in concrete as well, such as the series of buildings by Snozzi in the centre of Monte Carasso. Situated at strategic points, concrete boxes are prominently present in this town.

The architect Duiker was more modest, when locating his Open-air School on an yard enclosed by residential blocks in Amsterdam in 1927.

Weathering

The features of Le Corbusier's Villa Savoye (1929) near Paris seem less authentic today. Continuous renovations make the house ever whiter and the pollution on the pristine facades appears blacker and blacker. Snozzi and Zaha Hadid came up with better solutions for their buildings by colouring the concrete and by using perfect moulds. Bofill used coloured cements and aggregates in the concrete for the residential blocks in Marne La Vallée. The buildings

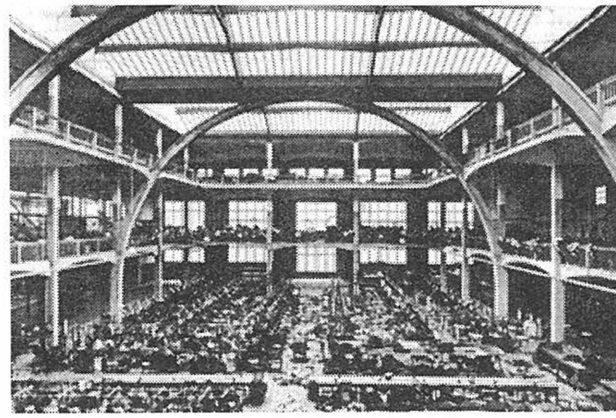
Logement Tassin-La-Dernier-Lune, by Jourdan et Perrandin, Lyon 1991-93.

are smooth and perfectly detailed but radiate a monumental despair -but it looks good on the pictures!
The houses by Lurçat and Mallet-Stevens in Paris, which are all in need of urgent renovation, show that concrete ages. If the weathering details are not well done, pollution and dirt easily lodge on the surface. The weathered appearance sometimes presents concrete almost as natural stone, though concrete can become drab and patchy soon. If the reinforcement is too close to the surface and the concrete itself has been poorly made it deteriorates and goes downhill fast. Cracking concrete might damage other components of a building as well, such as glass

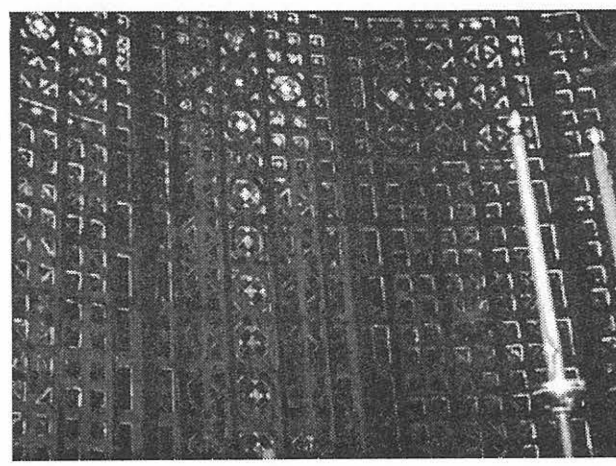
blocks which can break under the pressure of expanding reinforcement bars. This is unlikely to happen to Wiel Arets' Arts Academy of 1992-93 in Maastricht, which is very carefully detailed and will probably last for ages. On the other hand buildings by Guido Canella -who is like a godfather to Italian architecture like Aldo van Eyck to Dutch architecture- go to seed even before completion. The deterioration of his buildings are a result of excessive use of concrete-and-glass blocks and details that are too complicated. It is clear that the quality of the surface, the skin of the concrete, affects the quality and durability of the material as a whole.
Coarse gravel, coloured cement or aggregates such as natural stone granulates, or a textured shotcrete finishing can upgrade this simple material, as a result of which aging appears to take place naturally. Similarly, the display of centre pin holes or screw caps can give a concrete surface relief. The play of daylight and shadows will distract the eye from the exposed surface of concrete. The Japanese have been our examples in this, stressing the aesthetic and dramatic character of exposed concrete.

Interior

In principle, concrete is better protected against degradation indoors than outdoors, unless the material is subjected to external influences. In this respect Perret's Notre Dame at Raincy (1923) is both a good and a bad example. While the tower appears

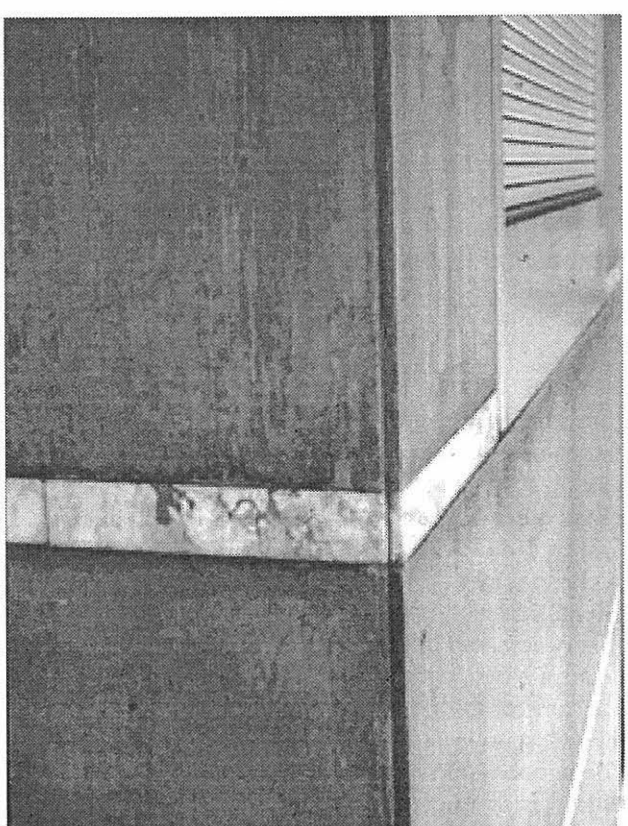


Atelier d'Esders by Auguste Perret (demolished).

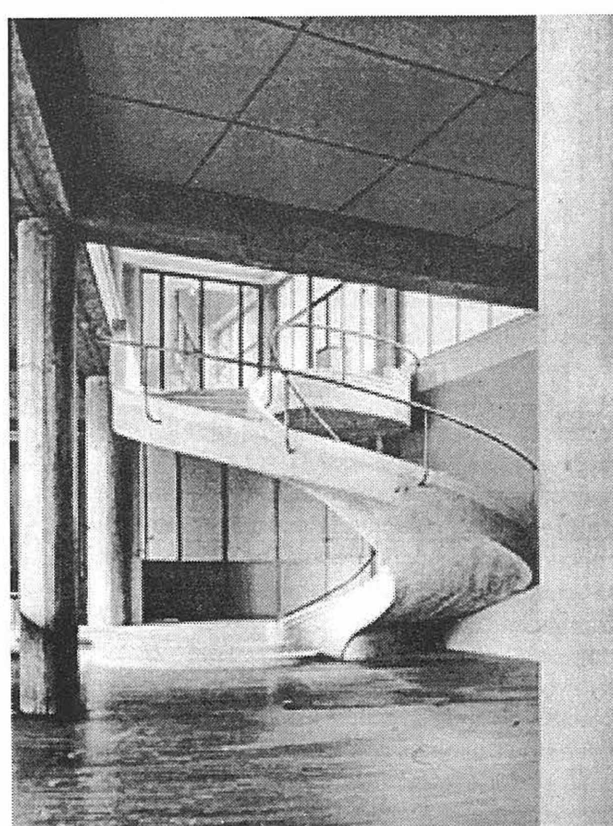


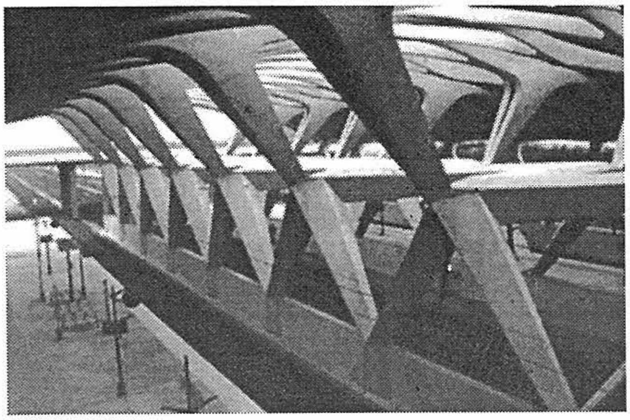
Interior of Auguste Perret's church at Raincy, 1923.

Villa Portone at Bellinzona by Galfetti.



Palais d'Iena by Auguste Perret, 1937.



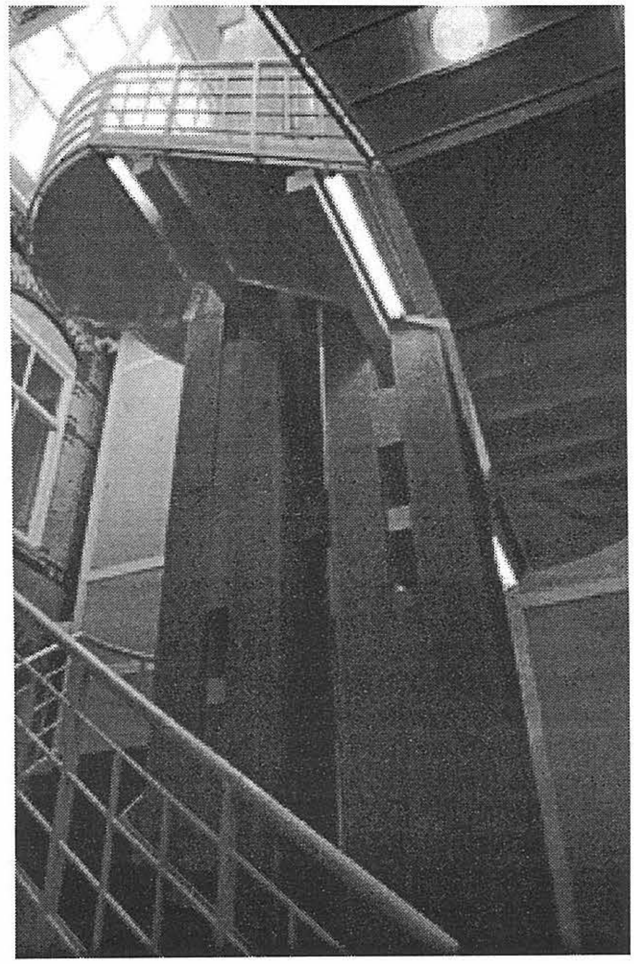


Calatrava's TGV station in Lyon which was cast *in situ*.

as unattractive and dull in the picture of Raincy's urban environment, by way of contrast the interior is enchanting with the blue twinkling of the glass-in-concrete. This feature, with simple grid blocks incorporating coloured glass, makes the inside of the church an experience and an inspiring example. Fortunately it has been restored in an inventive manner in recent years with the authenticity of Perret's architecture largely retained. The church at Raincy has also been the inspiration for the Moluccan Church, where the light enters between the double columns and the domes in the roof, colouring the wall when catching the sun.
Perret's cathedral in Le Havre (1950-55) can be described as powerful and almost brutal. The design of the church follows on from Raincy's principles, but the flair and refinement are gone. What remains is impressive and likely to give you a stiff neck.
There's more to see in Le Corbusier's masterpiece at Ronchamp. The *Fontaine de Lumière* can be experienced everywhere. The architect exploited every possible means to enhance this result, such as the virtually floating roof, and the use of smooth, exposed concrete, next to surfaces finished with shotcrete or painted, similar to his design for the monastery in La Tourette. Surface dressings such as stripe chiseling or bush hammering typically improves the expression of concrete more than painting, because the intrinsic architectural qualities of the material are emphasized: it stays 'real'.
The structural skeletons by Calatrava -today's number one architect of civil works, with Nervi as his superb example- are so sound, so perfect and homogeneous in terms of colour and finishing that they appear to be prefabricated. Yet the TGV station in Lyon was cast *in situ*. It looks so good that it has almost become too beautiful. Perhaps we have a weakness for irregularity and don't like perfection.

Rehabilitation

Exposed concrete can also very suitably be used in existing, historic structures, as a noble high-quality material. An Amsterdam branch of a bank, which is accommodated in a historic building that dates from 1881, features an impressive steel staircase,



A bank in Amsterdam where two bush hammered pylons support a steel staircase. Architect Peter Thole, 1985.

supported by two bush hammered pylons by means of consoles. An attractive staircase that opens up to the daylight and symbolizes the open structure of the organization.
In the case of repair to existing concrete structures one can ask oneself whether the repaired concrete should be of a higher quality and 'better looking' than the original, and whether one is allowed to change the appearance and 'improve' it according to current standards. This is the key question addressing the cultural value of authenticity, and probably more a matter of knowing than seeing.

Peter Thole is a principle of the Architect's Association Van Heumen & Thole in Zaltbommel, the Netherlands.

A miracle material
The abstract expression of concrete

We see, hear, smell, feel and taste the qualities of the materials which surround us. But emotions and ideas are also part of our reality, whether virtual or tangible. Every specific material is made up of matter, and matter is also the means by which we express ourselves when we create new objects and a new environment. We describe its properties and allow ourselves to be affected by its qualities. From this defined matter, specific materials with particular characteristics are derived.
Concrete is the material of change, of metamorphosis. Like a chameleon it appears in different guises and in different connections. The assessments of this substance have changed over the years. In the early modern period, it has been considered a miracle material which would solve all the problems of the building industry. Later it was seen as representing the inhuman scale of large building projects, sharply criticized by the postmodernists.
In many ways concrete is as well a universal material. It can take any form and shape, and it is made up of raw materials which are so commonly found that they can be extracted and produced virtually anywhere.
Concrete represents particular values that are hard to define but, at the same time, seem to be identified with modernity in architecture by many.

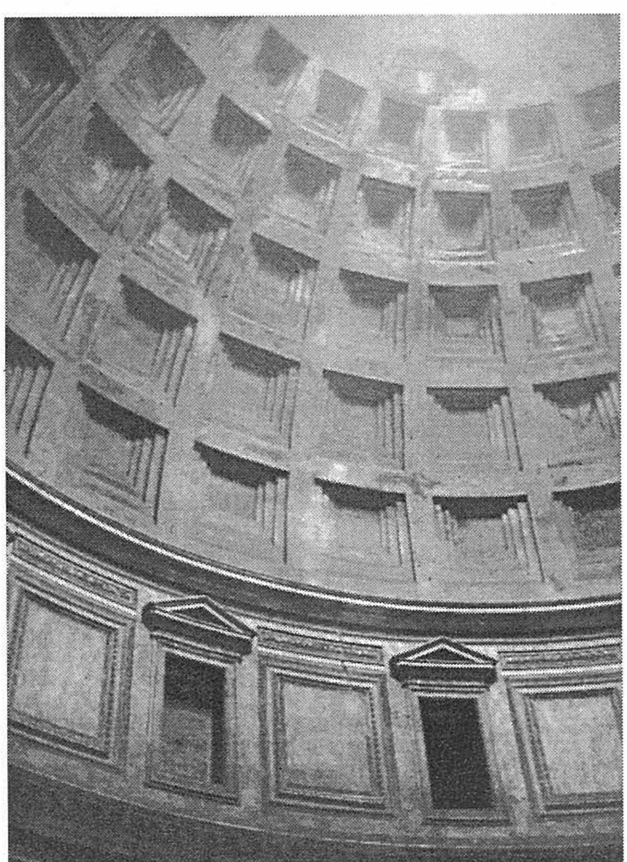
by Ola Wedebrunn

Since ancient times clay, plaster, and lime have been used in making stone walls. The first cast walls were erected in Greece as early as the 3rd Century B.C., but it were the Romans who developed the concrete of antiquity. Roman concrete was a mix of lime and volcanic pozzolana sand. It got its name from the village of Pozzuoli, which was situated on the slopes of Mount Vesuvius. The pozzolana had been spewed out from the glowing mass of fire inside the volcano. 'The fire and the heat of the flames, which emerge from inside the mountain through the cracks, make the soil light, and the tufa that is found there is porous and free from moisture. When lime, pozzolana, and tufa, all created in the same way by the fire, are mixed, they merge with the help of water, and the moisture causes them to harden rapidly into a substance which can neither be dissolved by waves or water.' This is how the Roman architect Vitruvius in the age of Emperor Augustus described the unique properties of pozzolana. In combination with lime and water it cures, turning into Roman concrete, as strong and durable as the best concrete produced today. Concrete was used more and more in the construction work of the Roman Empire, in aqueducts, docks and ports, baths and so on. When Nero had Rome rebuilt after the Great Fire in 64 A.D., the innovative concrete technology made for a new architecture. By casting huge domes and vaults in concrete, builders in Nero's time lay the foundation for a new concept of space, celebrating the mutual relationship between the shape of the space and the material qualities of concrete.
Fire burnt the soil to produce the raw material; combined with water the material took shape of structures which occupied space and, hence, air. Implicitly, pozzolana was connected with the four elements indeed.
However, Roman concrete never had a direct visual expression. The Romans either lined their concrete structures with rough stones or cast the concrete in a cavity between brick or stone walls. But even if concrete was hidden behind stucco, rough stones and terracotta, the use of concrete was a prerequisite for large span vaults and domes and a free use of space.

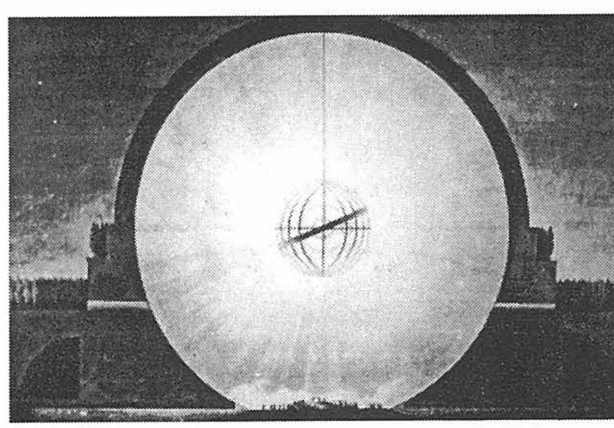
Modern concrete
By means of pencil and paper there is hardly any limitation in creating form and shape as long as only two dimensions are considered. Yet, in the past, many projects never got beyond the drawing board because no material could share the boundlessness of a design on paper. In the late 18th Century, French architects for instance designed ideal projects on a utopian scale. Large concrete structures like the

Pantheon gave evidence of the technology and the materials which the Romans had once mastered, and they were an inspiration to many architects. Still, the giant dome of Étienne–Louis Boullée's monument for Isaac Newton (1784) seemed to be too large to be realized in any material or any construction at that time. It was not until the 20th Century that technological advances created actual opportunities for building projects the size of the Newton memorial. However, the required material was already available in Boullée's time. The English engineer John Smeaton had been a pioneer in analyzing the properties of pozzolana. He made use of these findings in constructing a lighthouse at Eddystone off the south coast of England, using water resistant Roman cement consisting of pozzolana and lime to join the stone blocks. But Smeaton's concrete was dependent on the presence of natural volcanic soil, and it was only by burning lime and mixtures of clay at a temperature of about 1500 degrees Celcius that the Englishman John Aspdin was able to take out a patent for the production of synthetic concrete under the label Portland Cement in 1824. What used to be brought forth by volcanoes could now be produced anywhere in the huge kilns of the Industrial Age.
This was also the case with iron, a second prerequisite for the development of concrete technology. In the 19th Century both materials were used in the construction of buildings. The first skyscrapers and the Eiffel tower were constructions made exclusively of steel, while concrete was commonly used for construction work such as harbours and fortifications, and as artificial stone for instance in facade ornamentation. But when iron was first used to reinforce concrete, a completely new material had been created. As iron has great resistance to traction and concrete can resist high compression, together the two materials contracted a successful alliance, in which the alkalinity of concrete also protected iron against corrosion.
The Frenchmen Lambot and Monier were among the pioneers of the new material in the mid 19th Century. They each constructed rowing boats and planter boxes, among other things, by moulding concrete around steel mesh. It was, however, the engineer François Hennebique who was to develop the essential knowledge of the constructive powers of reinforced concrete. By determining the position and the dimensions of the reinforcement steel bars he also lay the foundations for a mathematically controlled use of reinforced concrete.
Roman concrete borrowed from long term experiences in practice, while Smeaton's scientific analyses has paved the way for today's concrete. The first entirely artificial concrete was produced by Aspdin, and, finally, when the reinforcement of concrete was introduced by the French, a building material emerged with properties that were new and

The Pantheon in Rome is among the best preserved structures of ancient concrete. All photos courtesy of O. Wedebrunn.



Boullée's monument for Newton seemed too large to build in 1784, but could be constructed today.



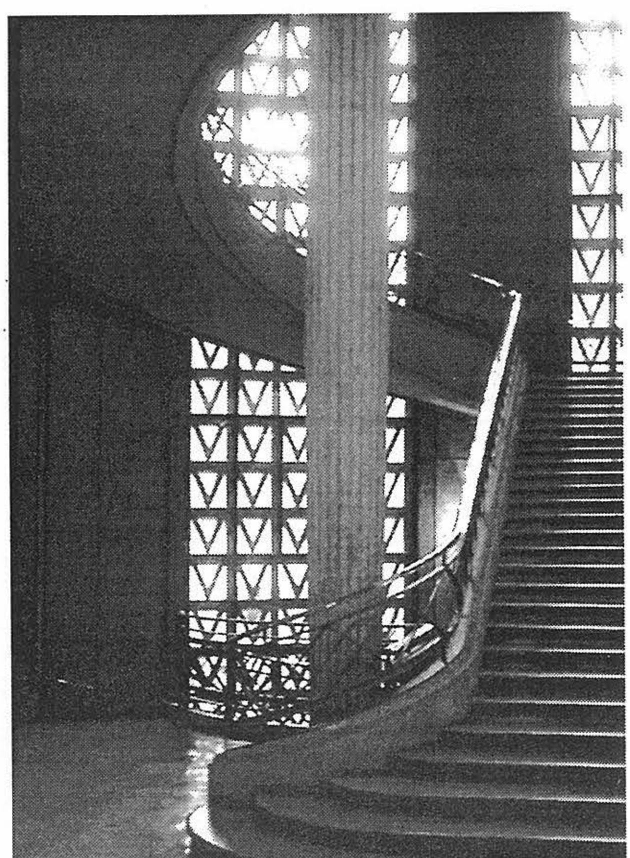
Bridge by Langwiess, Switzerland by engineer H. Schürch, 1912-14.

challenging. Today, concrete is produced through standardized industrial processes. It is either prefabricated in simple and more sophisticated shapes for structural components, or cast *in situ* for particular solutions in representative and monumental buildings with great sculptural qualities, such as the Sydney Opera House by the Danish architect Jørn Utzon (1957) or the bridges and halls by the Spanish engineer and architect Santiago Calatrava. Concrete is now applied in a variety of forms, from free and organic to the mathematically computed bold and slender shapes that characterize current civil constructions. The uses to which concrete can be put are as different as night and day – either to create heavy and essentially dark volumes or the thin and taut concrete sails of airy structures soaring towards the sky.

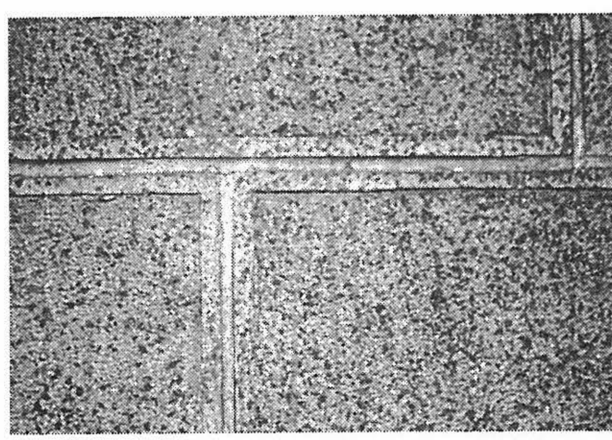
Surface and meaning

To stress an ideal geometry, the late 18th Century architects designed buildings with homogeneous facades in stucco or stone within a close colour range. The role of the material was to emphasize the entirety of the surface as much as possible.
To the Modern Movement the integrity and purity of surfaces represented also their ideals regarding the relation between appearance and contents. In the catalogue to the 1932 exhibition 'The International Style', Henry Russell Hitchcock and Philip Johnson write: 'The ubiquitous stucco, which still serves as the hall–mark of the contemporary style, has the aesthetic advantage of forming a continuous even covering. But if the stucco is rough, the sharpness of the design, which facilitates apprehension of the building's volume, is blunted. Rough stucco, because of its texture and because it recalls the stucco–covered buildings of the past, is likely to suggest mass.'[1]
However, in modern architecture stucco and concrete were not exclusively used with an even surface, as is illustrated for instance by the rich variety of textures in the works of the French architect Auguste Perret. In the early 20th Century Perret contributed enormously to the acceptance of concrete as an architectural material, in a structural sense as well as in terms of aesthetics. He added a new value to concrete as a construction material by introducing the concrete frame with his 1903 Rue Franklin apartments in Paris, creating the preconditions of the *free plan*. At the same time, he transformed the image of concrete from a rough material with clear board marks left by shuttering, to a sophisticated construction element that could be produced as precast blocks and beautifully cut and textured. Perret used concrete in the same way as the finest natural stone, dressed by hammer and chisel to produce a pleasant and expressive surface. As an apprentice with Perret Le Corbusier learned about concrete from his master, and when he started his own enterprise under the name

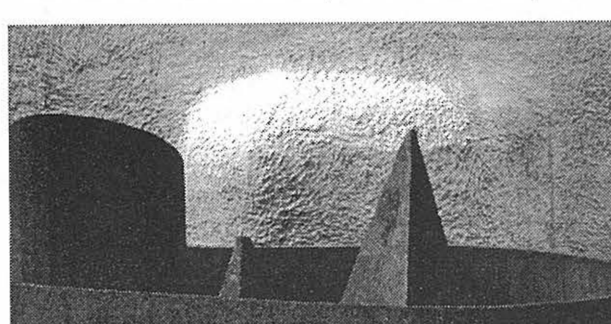
The Musée des Travaux Publics of 1937. Perret's works in dressed concrete mark the maturation of this modern material.



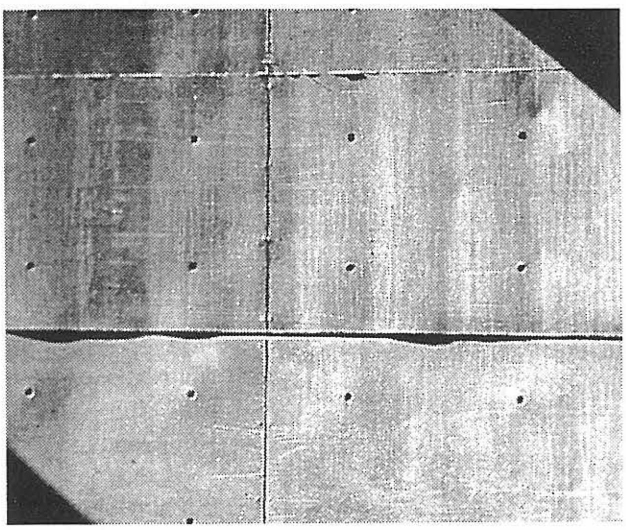
Cast and cut blocks of concrete, from the former Musée des Travaux Publics in Paris.



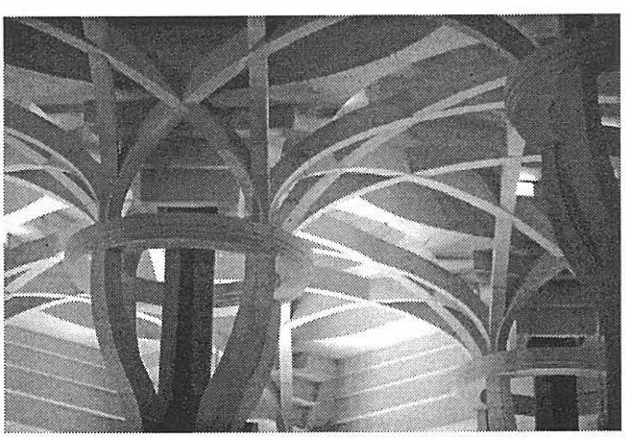
Water reservoir cast in the *béton brût* technique at the chapel of Notre Dame du Haut in Ronchamp (Le Corbusier, 1950-55).



'Ch.–E. Jeanneret architecte Béton Armé', this was no coincidence.
Still, the even surface remains emblematic for early modern architecture, and it was only from the mid 1930s onwards that textural contrast, for instance between concrete and natural stone, became an important parameter in architectural expression. In the 1950s the sculptural articulation of concrete became increasingly apparent, as well as the expressiveness of the material itself. Rough unfinished concrete that displayed a casual pattern of board marks later became a hallmark of an architectural style in its own right called 'New Brutalism',



Spacers of the formwork remain visible in the concrete walls of Tadao Ando's works.



Concrete constructions as dissolving ribbons in a mosque in Rome by Paolo Portoghesi, 1989.

characterized by an uncompromising and at best honest architecture.
Le Corbusier labelled the rough concrete surfaces *béton brût*, and in the 1950s he used the technique of the casual board patterns and rough coarse aggregates in several apartment blocks and public buildings.
The storm of criticism of the uncompromising character of late modernism, as well as the demand for energy efficiency, fueled the tendency towards decorative claddings evinced by postmodernism. The connection between construction and contents was mostly lost with a veneer of brick, wood or metal merely becoming a fashionable appearance of what is essentially a concrete construction. By referring to new values which allow gratuitous ornamentation and an undeveloped building technique, the disconnection between construction and expression might even be justified.
Could it be that a material link was lost in the criticism of the 'brutal' but honest articulation of late modernism?
Largely dating from the same period, the works of the Japanese architect Tadao Ando on the other hand show a plain connection between surface, expression and contents, particularly in the bare concrete walls of most of his buildings. The spacers connecting the formwork panels in between which the concrete is poured are a common feature in concrete technology, but remain visible in Ando's unfinished walls. The holes that held the spacing pins and the marks of the fixings and clamps are telling the story of how the wall was constructed and lend the surface a sense of scale and proportion at the same time.

Surface and time

Cement is a main ingredient of concrete. This bonding agent is essentially a powdered mixture of lime and silicates. With water, cement produces a slurry that can then be mixed with sand and various aggregates such as stone and gravel. If concrete is left bare the surface is typically cementicious, since the fine grain of cement causes the aggregates to be completely covered with a cement film. Changing the colour of the cement from standard grey to white, or by using additional pigments, will therefore have a strong influence on the appearance of exposed concrete. Another way of colouring is to use coloured aggregates, which is particularly effective if the cementicious skin is removed.
A very subtle example of colouring is the use of white cement and crushed white marble as an aggregate, which results in a beautiful white concrete. The Bagsværd Church outside Copenhagen, designed by the Danish architect Jørn Utzon in 1973–76, is an example where such a concrete has been used in a very smooth metal formwork and carefully compacted mechanically, producing a very white and shiny surface. A similar use is found in the new mosque in Rome, designed by the Italian architect Paolo Portoghesi in 1989. The white concrete in this building undulates in long, fantastic ribbons that filter the light and which are nearly as interlaced and as tasty as a plateful of *tagliatelle*.
The effect of colour and texture of the aggregates can be enhanced by removing the cement film from the concrete by washing the fresh surface before the concrete has completely cured, or by blasting it. A more extreme treatment is to remove the top layer of concrete by fixing a relief of steel cables or battens against the formwork, that is then broken out of the

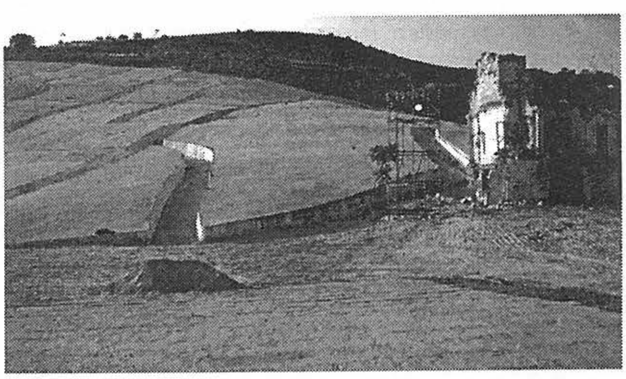
fresh surface in order to create a very rough texture. The walls of the elephant and rhino pavilion in London Zoo (Casson & Conder, 1962–65) are textured in this manner to create a surface against which the elephants love to rub their tough hides.
No material lasts for ever, and even concrete ages. Every material is affected by wind and weather and wear by humans. Sometimes the effect is a beautiful patina which enhances the expression. Weathering and pollution leave traces such as streaking effects near window sills, localized darkening or loss of colour, some of which can be foreseen and planned to some extent. Metal salts from green copper or corroded steel can stain colourful contrasts on monochrome concrete surfaces.
However, sometimes decay can proceed to such an extent that what remains is a useless ruin. Concrete surfaces which are eroded by the effects of frost or salts and where the reinforcement steel is being exposed and corroded as a result, will threaten the building with destruction and must of course be taken care of immediately. In whatever connection or condition a material is found, it has properties which can lead to new interpretations and attitudes.
Concrete is predominant in our culture, just as it was in Roman times. Hence it is particularly important that we appreciate this material and that we learn to understand and assess both the technology and the means of expression that go with it.

Reproduction

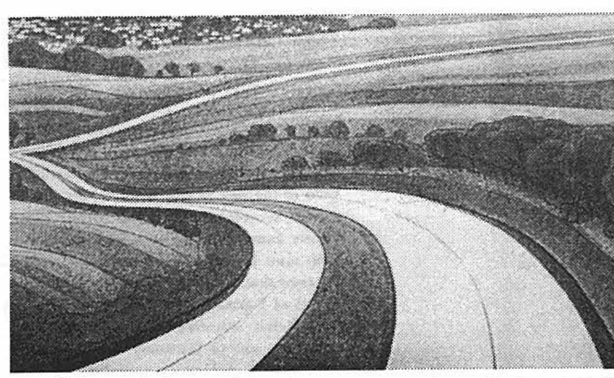
The formwork in which concrete is cast must be fashioned with some understanding of the transformation of the material through the process from an idea to a finished structure of cured concrete. The form can be compared to a machine waiting to be filled by the gravitational energy of a material and to be started. The history of modern concrete is approximately contemporary with that of photography. At the same time as Smeaton designed the lighthouse at Eddystone, it was known that silver salt, which is a main ingredient in traditional photography, darkens under the influence of light. Both materials share their suitability regarding reproduction. Concrete is cast against a form which is the negative picture of an idea, while the photograph is printed from the exposed and developed negative film.
Like metal, glass, and plastic, cast concrete is suitable for both repetition, reproduction and original works. With its simple and variable mineral substance, concrete is a material which can be used on a large scale, both technically and aesthetically.

Romanticism and tragedy

At the end of the 1960s an earthquake erased the Sicilian town of Gibellina. The artist Alberto Burri proposed to cover the blocks of the old village with concrete, in order to preserve the remains of streets and houses as a bas–relief, without too strong emotional connotations.
The imprint forms the scenery of an annual theatre festival, the drama lending a new and less risky life to the old village. The use of concrete to cover reactor 4 at Chernobyl after the catastrophe in 1986 was less romantic, but even more necessary. A similar idea came up after the disaster with the Estonia ferry in 1994, both to protect it against marauders and to create a dignified grave memorial. Earlier on, concrete was employed to protect the army of nazi–Germany creating another type of monumental landscape.
Along the Atlantic a chain of concrete bunkers formed the Festung Europa. Inspired by this example the French architect and philosopher Paul Virilio



Alberto Burri's reinterpretation of the Sicilian town of Gibellina after the 1960s earthquake.



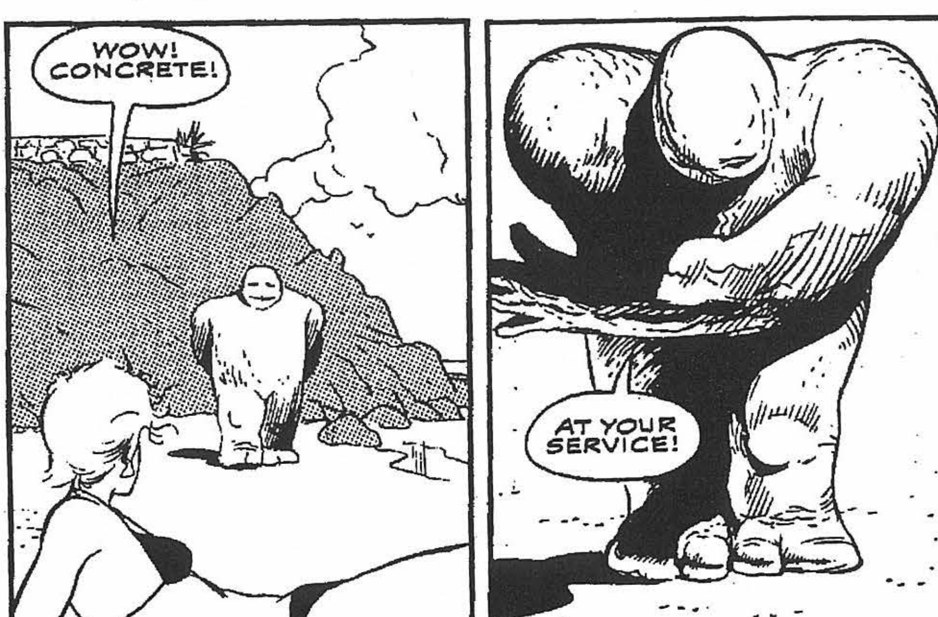
The first *Autobahn* predates the nazi-era and was built in 1932 under Mayor Adenhauer of Cologne to connect that city with Bonn.

Section of the ruined Berlin wall, after 1989.

wrote: 'In brick or stone constructions, in assemblages of discontinuous elements, the balance of the buildings is a function of the summit-to-base relationship. In the construction of single–form concrete, it is the coherence of the material itself that must assume this role: the centre of gravity replaces the foundation. In concrete casting, there are no more intervals, joints –everything is compact; the uninterrupted pouring avoids to the utmost the repairs that would weaken the general cohesion of the work.'[2] At the same time, the scenic qualities of concrete were brought out as it was used to create the miles and miles of new motor ways, as long ribbons through the landscape. Time is marked rhythmically, faster and faster, while cars accelerate across the joints in the cast concrete. As an ornament for a new age the concrete made the landscape accessible for both Volkswagen cars and Tiger tanks. In spite of its name even the iron curtain was largely made of concrete. When the wall was torn down little chunks of concrete, communist grey on one side and covered with colourful graffiti on the other, acquired a value as relics in the all enveloping market economy.

Epilogue

The English word 'concrete' comes from the Latin verb *concrescere* which means 'to grow together', 'to coalesce'. This goes very well with the bonding properties of concrete, but the word also gives rise to associations to the adjective 'concrete', meaning 'material', 'perceptible'. 'Concrete' is obviously the



opposite of 'abstract', 'theoretical'; however, concrete is to a large extent a material which has both concrete and abstract properties and means of expression.
Wet steam from lime and cement which have been mixed with water produces a warm smell of concrete. The wet concrete is poured into firm forms, and we can still make a foot print or a hand print and be enclosed in the sluggish slurry. But time works both for us and against us and soon the wet mass has cured. Further operations can only be performed by physical force and with the help of mechanical tools. The idea resided already in the empty form. Soon it is transformed into the cured substance, leaving a cold mass of concrete.

Ola Wedebrunn is the chairman of the Danish DOCOMOMO Working party. This text was originally published in the catalogue for the exhibition 'Concrete' in the Malmö Konsthall, Sweden, in 1996. Text based on a translation by Gunilla Florby, revised by the editor.

Notes:
1. Henry Russell Hitchcock and Philip Johnson, *The International Style: Architecture since 1922*, New York 1932.
2. Paul Virilio, *Bunker Archeology*, New York 1994.

Cast and cut blocks of concrete, from the former Musée des Travaux Publics, A. Perret, Paris, 1937.

A Modern Movement in engineering

Structural developments in architectural history

The development of concrete as a modern building material already began in the middle of the 18th Century, to respond to the needs for new building types, large span construction and mass production. A major impetus to the development of concrete technology was the acknowledgement of the technical and economical lifespan of buildings as factors of importance to the building industry. It was not until this century that the tectonic potential of reinforced concrete started to be recognized by architects and engineers. The poor comprehension of creative concrete design however still exists. It is vital to explore the connection between the development of modern architecture and the history of concrete construction, to arrive at a better understanding of the use and future development of concrete technology in modern architecture.

by Berthold Burkhardt

The invention of concrete is commonly dated in the middle of the last century -if the Roman concrete *opus caementitium* is left out of consideration. But the development of concrete as a modern building material already began a hundred years earlier with the onset of the Industrial Revolution. At that time, various test programs were carried out independently from each other in England, France, Germany, and other countries that were developing into industrial nations, which are indicative of the fact that the development of modern concrete technology is not a unique invention that can be attributed to one particular country.

The new building conditions of the late 18th, 19th, and early 20th Centuries called for new methods in building technology. There was a great need for many new building types, such as factory buildings, railway stations, bridges, and multi-storey buildings, some of which required large spans. Simultaneous, economy and the life expectancy of buildings became important factors in connection with the emergence of mass production, that provided another important impetus to building technology.

All such requirements could only be met through comprehensive material research, the conception of new theories, the introduction of regulations and standards, and, last but not least, by a competitive industry. The Englishman John Smeaton (1724-92) was the first to study and explain the binding process of hydraulic lime, a natural resource. In the first tests such a hydraulic binder was used as a joint mortar for brickwork to construct towers and bridges, as well as in civil engineering. Louis Joseph Vicat, a French engineer, specified the supports of a bridge near Soulliac, France, to be made out of 'cast concrete with hydraulic lime' in 1828. Around the same time, the English contractor Joseph Aspdin succeeded to produce a workable hydraulic binder, which he patented under the name Portland Cement. A new industrial branch was established. The first cement works in Germany, for example, were in business by 1855.

Competition

The scope of the building trade, that largely depended on traditional construction in solid masonry until then, was enlarged enormously by the introduction of concrete as a building material in practice.

Other new structural systems became available as well, such as the rapidly developing light steel structures and timber engineering. The main innovations in steel construction concerned the improvement of calculation methods and procedures for newly defined static systems, methods of jointing, and the optimization of material properties (from iron to steel). The transition from craftsmanship to timber engineering for wide span halls and bridges took place as well in the 19th Century.

An unprecedented competition emerged between construction in concrete, steel and timber, which were as such all regarded as appropriate materials for structural components. The evaluation of the different systems did not only refer to technical aspects, and conceptual debates about the relation between form and material led to severe conflicts. Most architects were averse to Eiffel's exhibition tower of 1886 in Paris for instance, because the structural iron framework was left uncovered. In architecture, exposed concrete on buildings was not accepted until the 1930s.

Eventually, through the simple and spectacular structures attainable in steel and concrete the appreciation of these materials took an upswing. Timber construction on the other hand fell back, mainly due to the assumed inferiority of wood regarding fire protection; the fire resistance of concrete and steel construction was still plainly overestimated at the beginning of the 20th Century. A little known though important side effect was that many skilled carpenters were drawn from timber to steel and concrete construction, mainly to produce scaffoldings and formwork. The dominance of concrete and steel over timber therefore accelerated, which had far reaching consequences for the building industry as a whole.

Historiography

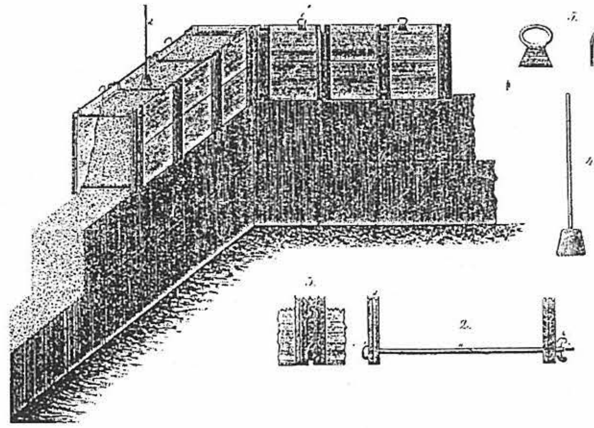
The remarkable interrelation between the development of construction systems in steel, timber and concrete in practice is essential to the history of architecture and building technology. However, the history of building technology and particularly of concrete and reinforced concrete construction is still insufficiently understood. The following reasons can amongst others be put forward to explain this backlog in historiography:

- Reinforced concrete is the most complex of building materials regarding structural design and execution.
- Concrete and reinforced concrete do not receive their final shape and load bearing capacity until it is actually used for construction.
- Technical and historical research must be comprehensive and include the fields of material research, design, calculation, economy, but just as well the organisational structure of businesses and the industry.
- The present engineers, who are indispensable as partners in such research programmes, are still hardly involved in exploring the history of their own discipline.

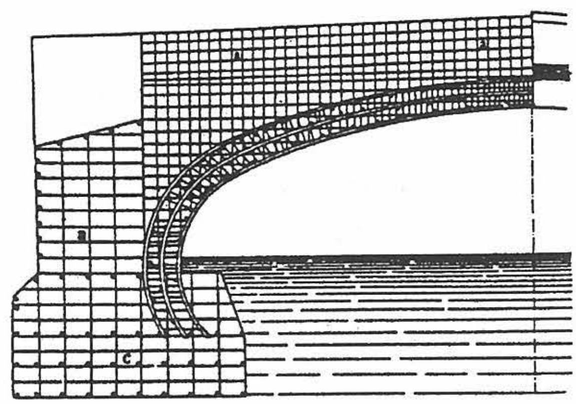
It is of utmost importance to initiate such research programmes to study the connection between the development of modern architecture and the history of building technology in more depth.

First applications

The early cementicious materials of the 19th Century were merely used to improve the quality of masonry construction by new types of mortars, until the French contractor F.M. Lebrun introduced the so called Pisé technique for producing building elements such as walls. His system, which is often described as 'cast concrete', is based on the use of stamped concrete. It involves a double-walled formwork with spacers, between which concrete was poured and then compacted by puddling, similar to traditional loam construction. The first constructions in stamped concrete remind traditional building forms in stone or brickwork, like arched bridges, piers, pillars, 'masonry' walls, and foundations.



The Pisé technique, an ancient loam construction method from Southern France, was introduced in civil engineering for stamp concrete construction in the early 19th Century. Illustration from Gustav Hägermann, *Vom Caementum zum Spannbeton*, Bd. 1, Wiesbaden 1964.

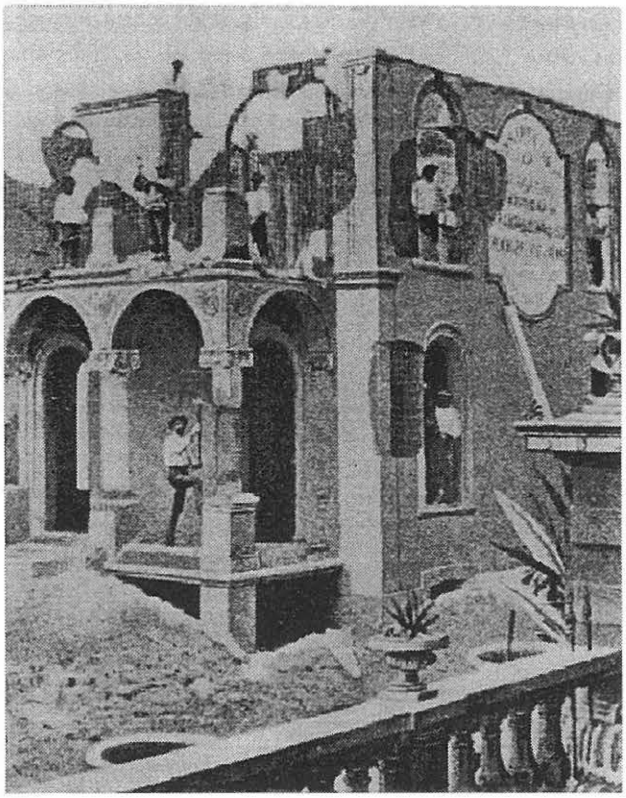


An arched bridge by Monier from 1873 represents the transition from classic bridge constructions in solid materials into bridges in reinforced concrete. Illustration from Monier's French patent of 1873.

The French-English engineer Marc Isambard Brunel was the first to experiment with reinforcements in 1835 in England. He designed so called masonry beams with flat iron strips in the mortar joints to reinforce the masonry work. The French engineer Louis Lambot produced a boat with the 'Fercimont' method that featured reinforced sides, which was exhibited at the 1854 World Fair in Paris. Such innovations in reinforcement techniques were essential to the application of concrete in components that received as well tension forces. The desire to use concrete also for floor slabs and girders triggered further developments in reinforced concrete technology.

Reinforcement

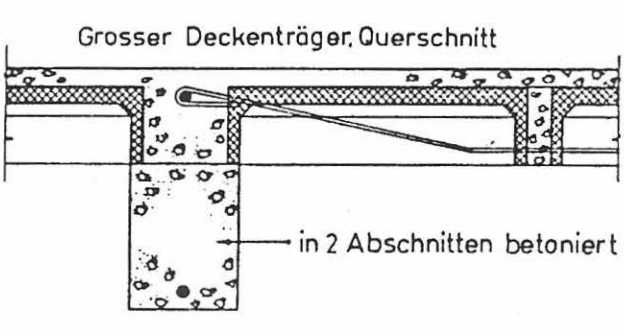
The technology to reinforce concrete eventually allowed for complete buildings to be constructed in the new building material. The Frenchman François Coignet was one of the first to design a 'monolithic house' entirely in reinforced cast concrete. His system for cross-braced reinforced concrete was patented as early as 1854. In the same year, William Wilkinson had a patent registered that is commonly regarded to



Monier's anti-seismic house in Nice, France, was built in monolithic concrete in 1887. Illustration from *Beton und Eisen*, Heft 1, 1903.

represent for the first time a general understanding of the principle of reinforced concrete construction as a system that responds to both compression and tensile forces. In his patent he described the construction of concrete floors to be reinforced with wire rope and light iron bars below the central axis of the elements, thereby acknowledging the typical distribution of compression and tensile stresses. In his patent of 1878 the American Taddeus Hyatt is even more precise about the location of iron bars and strips in concrete elements in order to respond most adequately to tension forces in beams or vaults.
The principles of reinforced concrete were established with these and other patents, but the construction method as such owes most of its technological development to engineers like Wayss, Koenen, Hennebique, and others, who continued to explore

Reinforced joists designed by William Wilkinson in 1865. Illustration from Gustav Hägermann, *Vom Caementum zum Spannbeton*, Bd. 1, Wiesbaden 1964.



the particularities of the bonding between cement and iron, and studied extensively the load bearing behaviour of the composite.

Appreciation

The planter boxes and containers made by Joseph Monier (1833-1906) are probably not as sophisticated as the innovations by Wilkinson or Hyatt, but his utilities of reinforced concrete became much better known to the public at large. Just like Lambot with his boat at the 1854 World Fair, Monier attained extensive publicity through his international patents, his designs, and his many practical applications. Through such demonstrations he contributed enormously to the public appreciation of the new material.

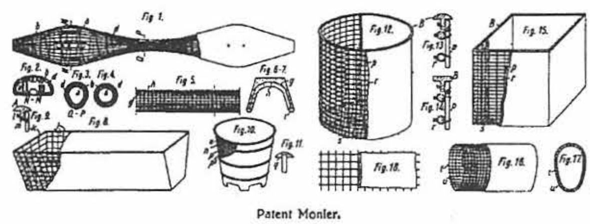
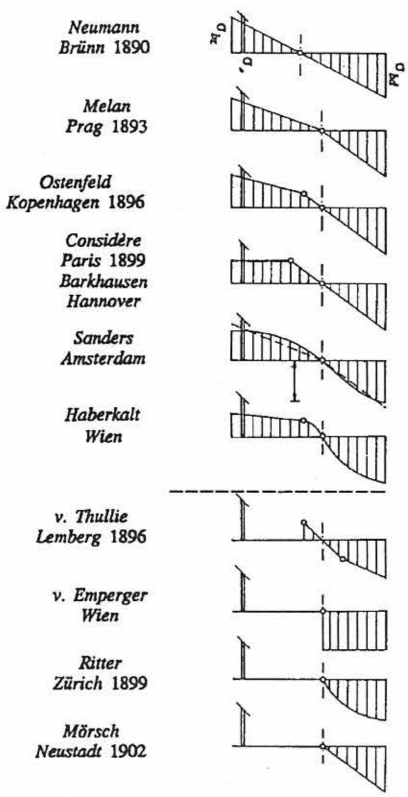


Illustration from Joseph Monier's German patent of August 4, 1881.

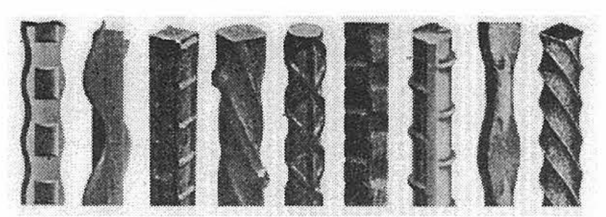
The construction of concrete boats might appear like a curiosity but some cargo ships with more than 6500 tons water displacement were actually built before the Second World War. The application of reinforced concrete in ship building and container construction refers to the design method like Lambot described it: 'I give this net a shape which suits best the item that I want to build. Afterwards I spread hydraulic cement over it.'

Design potential

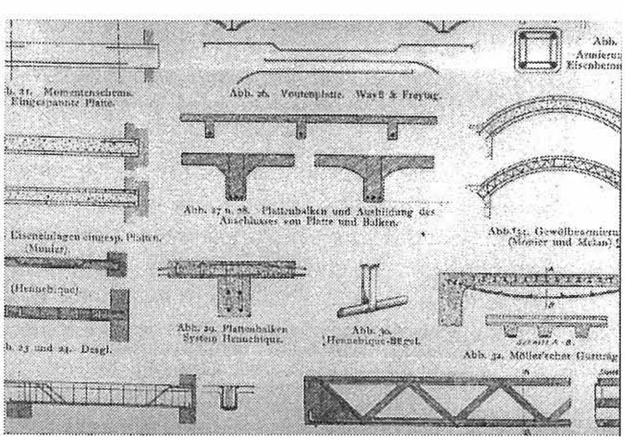
Until today, construction engineering has been focused on research and development to further improve the performance of reinforced concrete components and building parts, primarily beams and floor slabs. Research concentrates on the interaction of concrete and reinforcement, as well as on production and calculation methods. A number of systems for girders and slab constructions, many manufacturing processes, control methods, calculation models, and systematic solutions have been developed, tested, published, and many of them have been patented as well.
The development of concrete walls has always been of secondary importance until the introduction of prefabricated slab systems after 1950. The masonry wall continued to be applied as infill in solid concrete structural frames and even in precast skeletons, mainly for economical reasons and physical perfomance, particularly regarding thermal insulation.
No doubt the new structural systems and production



Various theories on the distribution of stresses in a beam section. Illustration from A. Pauser, *Eisenbeton, 1850-1950*, Wien 1994.



Various forms of reinforcement bars to increase skid resistance are usually named after their inventor, like 'Johnson bars'. Illustration from A. Pauser, *Eisenbeton, 1850-1950*, Wien 1994



Various girder systems, amongst others Visintini and Möller. Illustration from *Deutsche Bauzetung*, 1905.

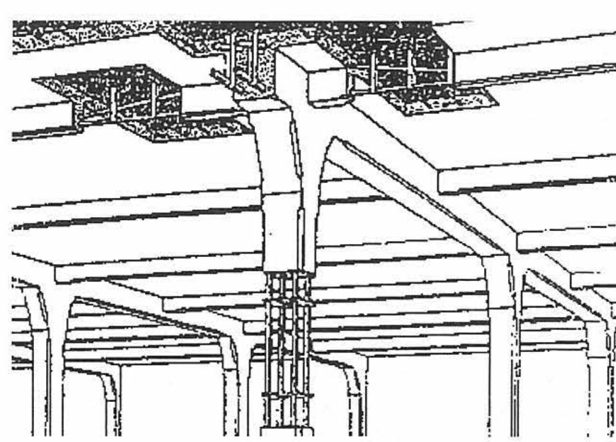
methods affected the shape of buildings in detail but it was not until the first decade of this century that the design possibilities of reinforced concrete and light steel constructions started to be appreciated for their architectural qualities. Architects and engineers like Pier Luigi Nervi, Le Corbusier and Robert Maillart tried to make up for the loss in the 1930s and 40s, as did the famous constructors of thin concrete shells like Candela, Silberkuhl, and Isler after the Second World War.

The poor understanding of creative design with reinforced concrete exists up to now. The full comprehension of the material's design potential is surpassed by arguments of production economy - an important fact indeed, but often put forward as an excuse for poor design in terms of material specificity.

Grand age

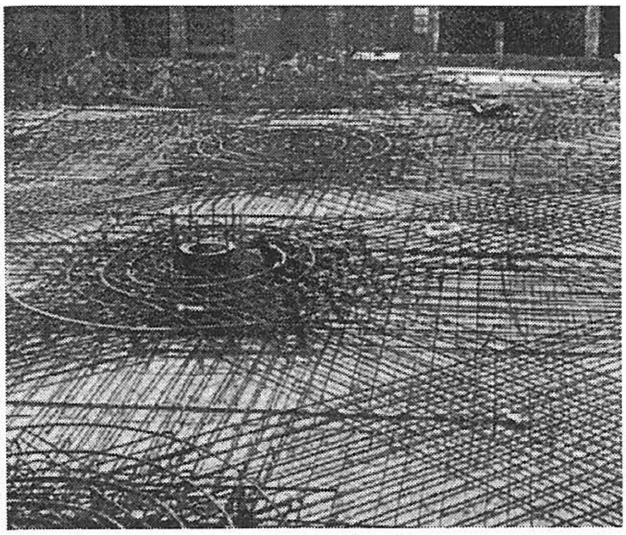
Also in the past, the technical, theoretical and practical advantages and optimization of concrete have always been most important. Hyatt and Lambot recorded the advantages of concrete about 150 years ago as fire resistant, water tight, durable even under excess loads, and cheap as compared to construction and maintenance costs with conventional materials and building methods.

The grand age of reinforced concrete started at the beginning of this century. The theories on construction and static behaviour, as well as calculation models, were sufficiently advanced for reinforced concrete technology to evolve into an independent field. By then, it became possible to erect multi-storey structures with floor slabs that were particularly reinforced to redistribute loads to such an extent that construction became essentially more simple as compared to conventional beam-and-support structural frames. Though, at that time, even flat floor slabs with mushroom columns had not yet been arithmetically recorded. The full scale tests of such constructions, like those by Robert Maillart in Switzerland around 1910, were a tremendous success that exerted a great influence on the design of concrete structures. Because of these tests the

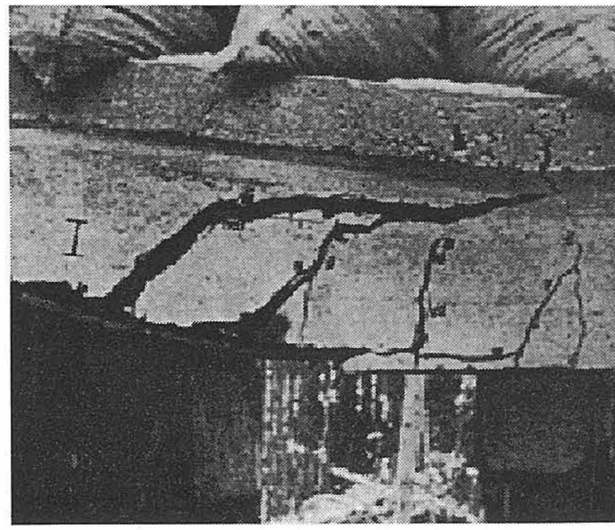


The Hennebique system is based on a traditional understanding of column-and-beam structures. Illustration from a period brochure.

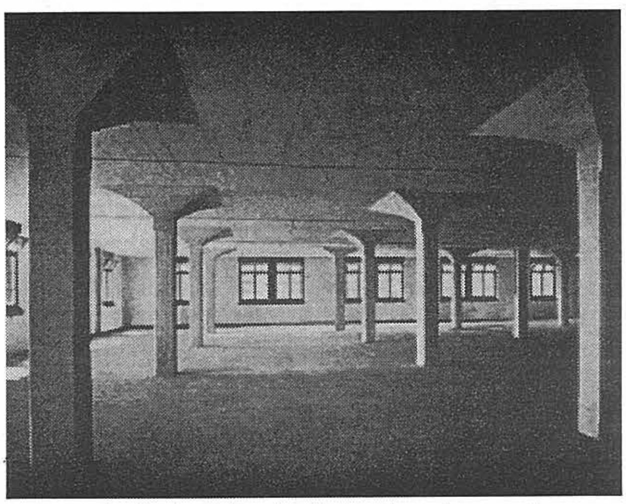
classic detail of a column with a rectangular head to support a beam -an anachronistic reminiscence of the



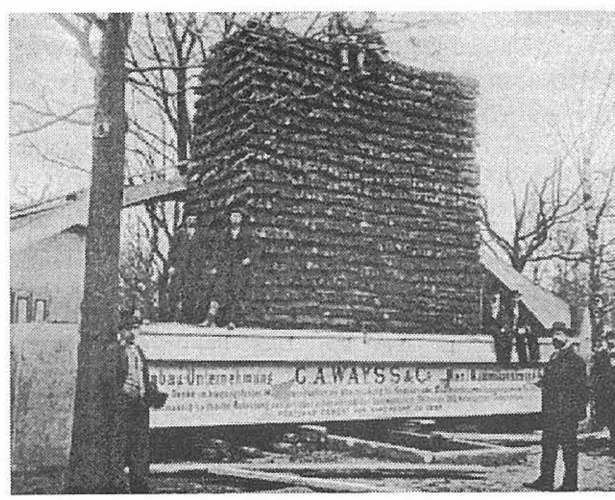
Reinforcement pattern of a flat slab floor before concrete is poured. Illustration from *Beton und Eisen*, Heft 2/3, 1918.



Test with a concrete beam featuring only longitudinal reinforcement, demonstrating the crack pattern. Illustration from E. Mörsch, *Der Eisenbetonbau, seine Theorie und Anwendung, 1908.*



An example of a beamless slab floor with mushroom columns. Photo: Madame Blumer-Maillart from David Billington, *Robert Maillart.*



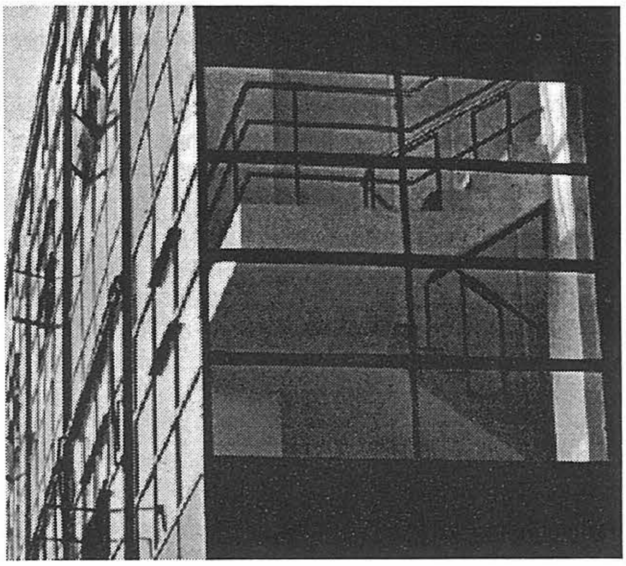
T-beams after the Wayss system tested at an exhibition in Vienna in 1898. Illustration from *Zeitschrift des Österreichischen Ingenieurs- und Architekten Vereins*, Heft 5, 1928.

antique capital- became obsolete. Concrete structures could be designed with beamless floor slabs supported only by columns, sometimes with multilateral mushroom heads.

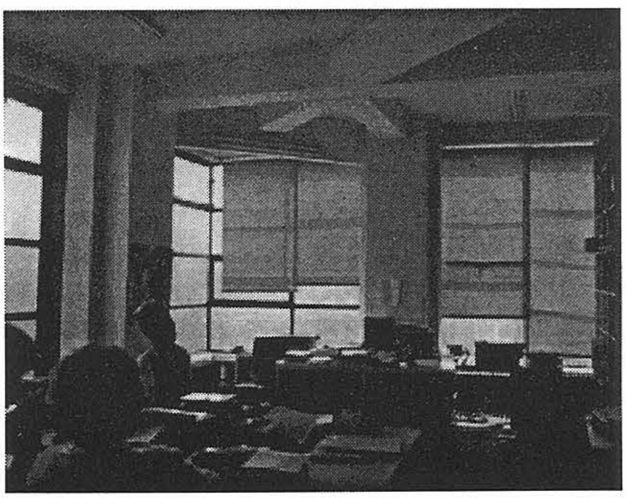
Modern Movement

At this point it is necessary to mention the contribution of engineers like Maillart, Hennebique, Moersch and many others to the architecture and building technology of the modern age. Their part in the development of new building principles has been so decisive, that it is appropriate to speak about a Modern Movement in civil and structural engineering as well. Not only do their works demonstrate an innovative and forward looking approach, also their professional starting points, the theories they developed, the material researches that were performed, the functional organization of building sites as well as the efficiency of their businesses, all emanate the spirit of modernity.

The architects of the 'classical' Modern Movement picked up these new achievements in concrete technology rapidly, because they were recognized as new means to realize their architectural, functional and technological concepts. In this respect the above mentioned girder constructions and slab floors again come to mind, but also the introduction of cantilevered floors for projecting balconies, landings, roof overhangs and the characteristic open corners of many modern buildings. Such elements were vital to elaborate the idea of the open plan and to shape the intermediary between interior and exterior, both of which are key issues in modern architecture.
An exceptional new element in the development of reinforced concrete is the introduction of structural glass. Many modern buildings feature round or rectangular glass blocks, mostly framed in concrete, to break up the mass of the concrete planes and volumes. In many solid parts of early modern buildings it is essentially possible to point out such

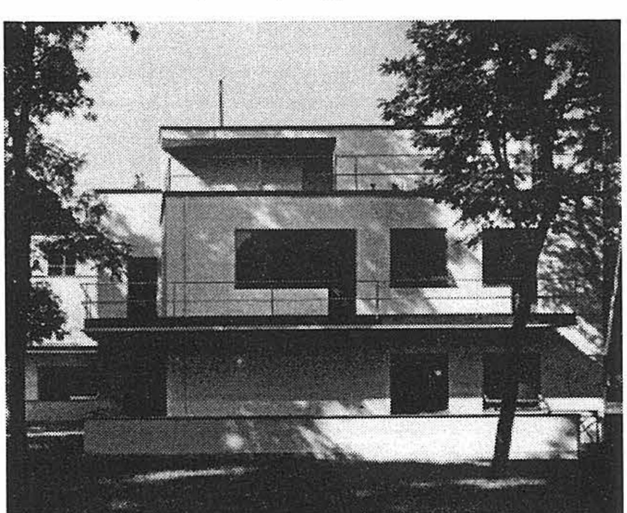


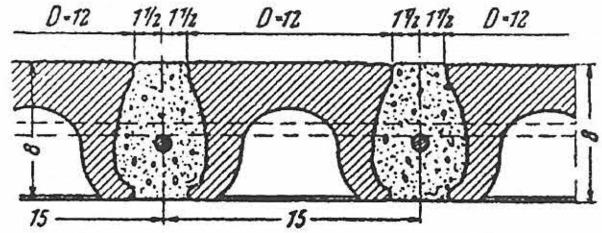
At the stairs the new technology of cantilevered floor slabs illustrate the transitional stage of the Fagus factory in terms of concrete technology. Photo: B. Burkhardt.



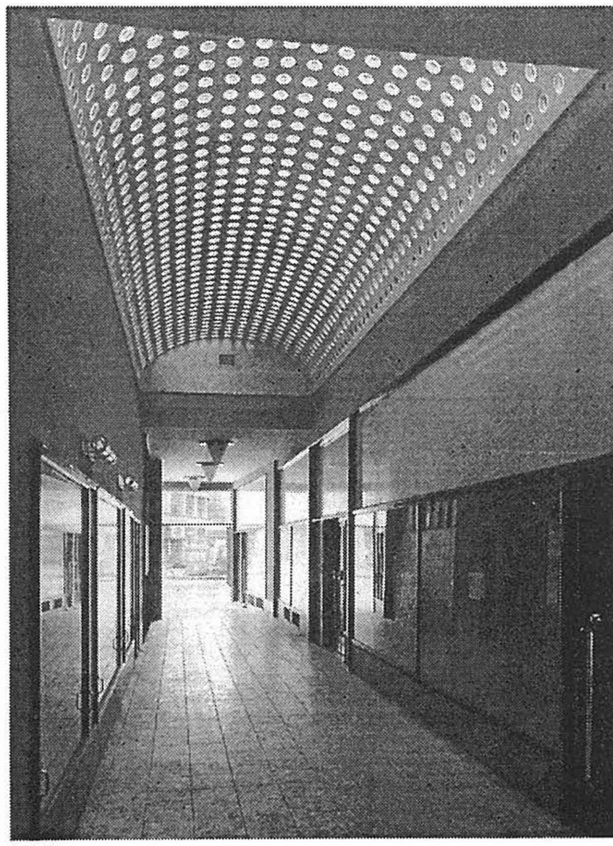
Cantilevered beams support a floor in the Fagus factory (Walter Gropius, 1911-15). Photo: B. Burkhardt.

The 1927 Master Houses in Dessau (Gropius *et.al.*, 1927) feature cantilevered balconies and canopies of reinforced concrete. Photo: Lucy Moholy-Nagy.



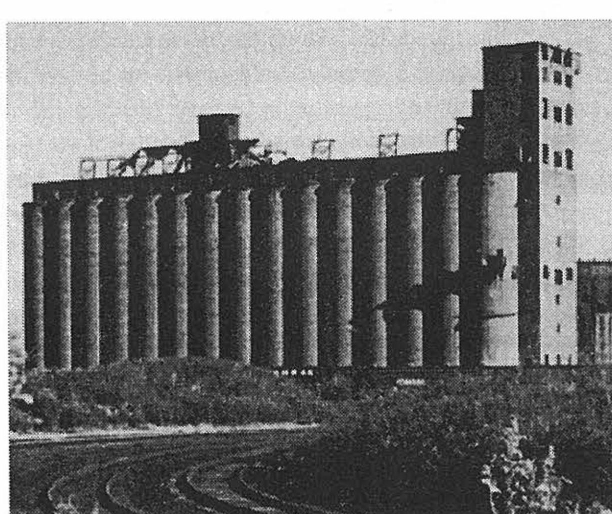


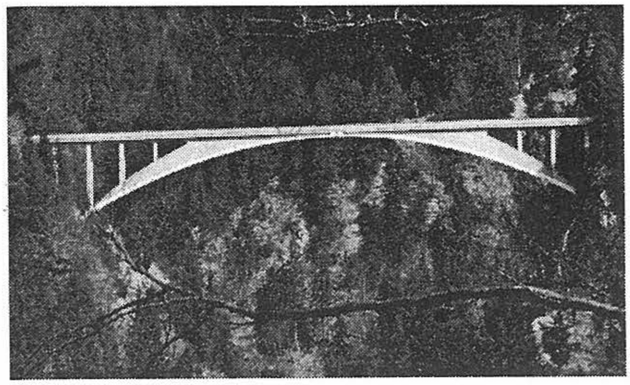
Round glass block as produced in Poland, 1931. Illustration from *Zement*, 1930.



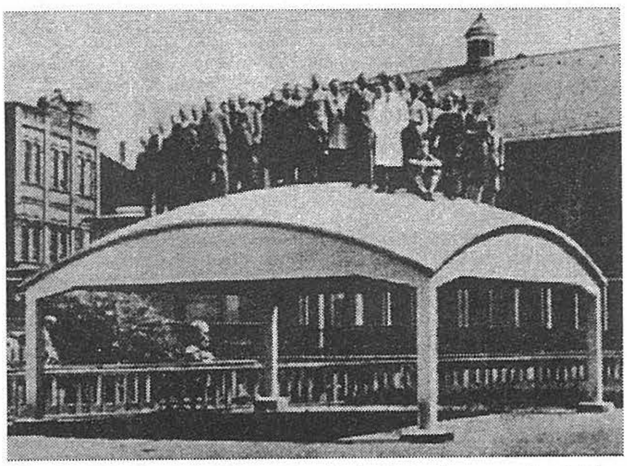
Emil Bellus' barrel vault of 1934-39 in Bratislava illustrates the lightness of glass block elements in concrete construction. Illustration from *Architekt Emil Bellus, Regional Modernism,* Bratislava 1992.

Silos in Buffalo, New York, 1931. Illustration from Banham, *A Concrete Atlantis.*

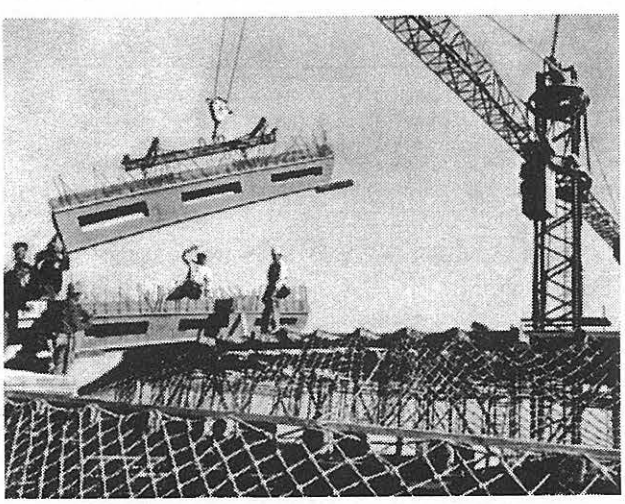




Salginobel bridge in Switzerland by Robert Maillart, 1930. Photo: Madame Blumer-Maillart from David Billington, *Robert Maillart.*



A test construction by the firm Dyckerhof+Widmann with a 7.3 m square dome shell in 1931. The structure still exists. Photo: Dywidag.



The development of precast units and light-weight concrete is mainly the achievement of the Italian engineer Pier Luigi Nervi. Illustration from Pierre Luigi Nervi, *Neue Strukturen*, 1963.

lightness in other, even more abstract terms.
The plasticity of concrete and its potential to be shaped and molded was though rarely exploited by the architects of the Modern Movement. Typically, concrete in prewar modern architecture was rendered invisible or at least painted. It remains still unclear why reinforced concrete was commonly not exposed as an architectural feature of the industrial society, as was indeed the case in many industrial buildings.

Great shapes

It was only after the turn of the century that the development and the use of concrete technology in civil engineering led to buildings that took full advantage of the material properties and the versatility of reinforced concrete. Large spans and heights were constructed for example in silos, bridges and towers, while concrete shells and saddle-shaped hyperbolic paraboloid roofs were used for medium and large halls. A great achievement also was the introduction of prefabricated units for decks, beams, supports, facade components, and shells.
In this paper the history of concrete and reinforced concrete has briefly been introduced mainly from an engineering perspective, but also design aspects have been taken into account. The quoted features of reinforced concrete, and the great expectations the industry had of this new composite material regarding fire proof construction, its strength and economic use, have to be looked at in connection with its constructional and physical characteristics, in order to arrive at a better understanding of the use and future development of concrete technology in modern architecture.

Berthold Burkhardt is an architect and structural engineer, a professor in structural design at the Braunschweig University of Technology, and the coordinator of the German DOCOMOMO Working party.

Literature:

- Alfred Pauser, *Eisenbeton, 1850-1950*, Wien 1994
- Deutscher Ausschuß für Stahlbeton, *Festschrift 75 Jahre Deutscher Ausschuß für Stahlbeton 1907-1982*, Heft 333, Berlin 1982
- Antoine Picon, *L'Art de l'Ingénieur*, Paris 1997

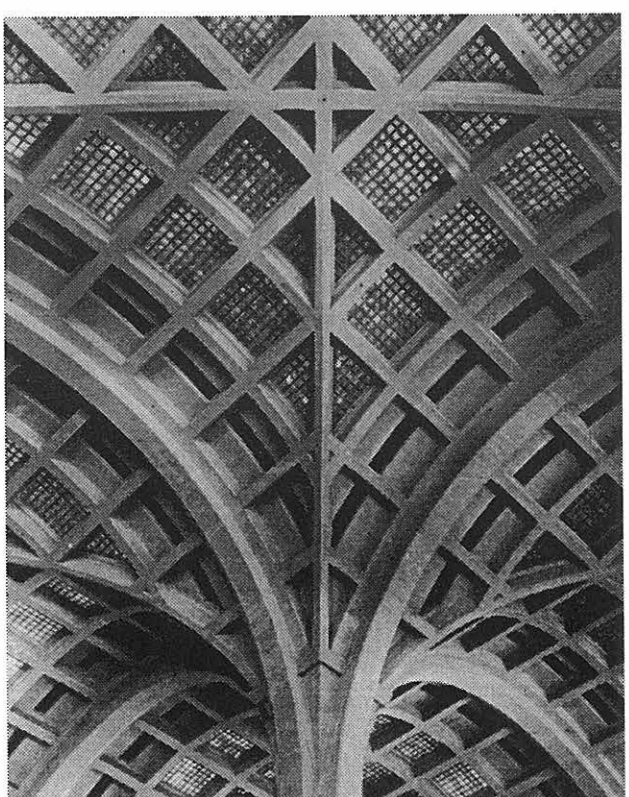
José Luis Delpini (1897-1964)
Centennial of an unknown master engineer

The Argentine engineer José Luis Delpini (1897–1964) has nearly but unjustly been forgotten as one of the great structural engineers of the Modern Movement.
His innovating spirit and highly individual professional approach resulted in such original construction types as 'preformed' concrete, that were put to practice with great confidence in a man–made future.
Despite being well recognized by noted contemporary pioneers like Nervi, Candela and Torroja, Delpini never received the general acknowledgement that they enjoyed. To celebrate this year's centennial of the Argentine Master of Concrete some of the most fascinating of his works are presented in these proceedings by his former student Juan Maria Cardoni. Among them is Buenos Aires' famous La Boca Juniors' stadium of 1932–34, that was consolidated under his direction in the late 1980s.

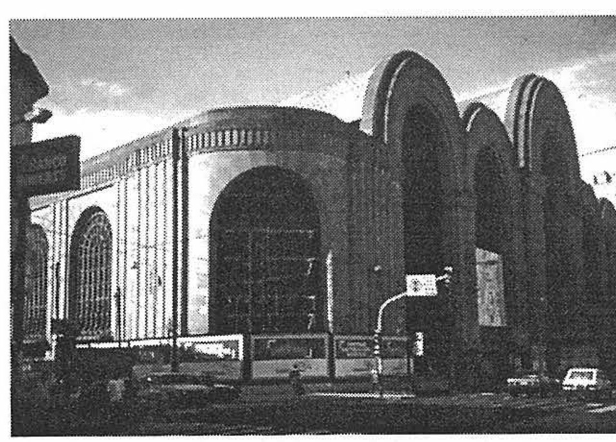
by Juan Maria Cardoni and Wessel de Jonge

Born in 1897, Delpini was educated as a structural engineer at Buenos Aires University, where he graduated *cum laude* in 1921. At the time, standards in concrete constructions in Argentina were relatively high, through the professional knowledge and experience of German engineers and contractors who immigrated to the young nation.
Fully in line with the spirit of the great engineers in Europe who anticipated a man-made society, Delpini had an inclination towards the innovative. In his search for optimal constructions he introduced a number of structural typologies that were unprecedented in Latin America. Working as an apprentice for Delpini at the age of 14, his later employee Juan Maria Cardoni recalls the *Maestro* as a designing engineer, who argued that 'calculation can never turn a poor design into a good structure'. He drew the forms of thin concrete shells, paraboloid foundation slabs and 'preformed' structures from his profound knowledge of the nature of materials, before calculations would prove his ideas to be right.

The extensive use of glass blocks in the concrete vaults of the Abasto market hall. Period photo: courtesy Cardoni.



The Abasto Proveedor market hall is under redevelopment today. Photo: W. de Jonge.

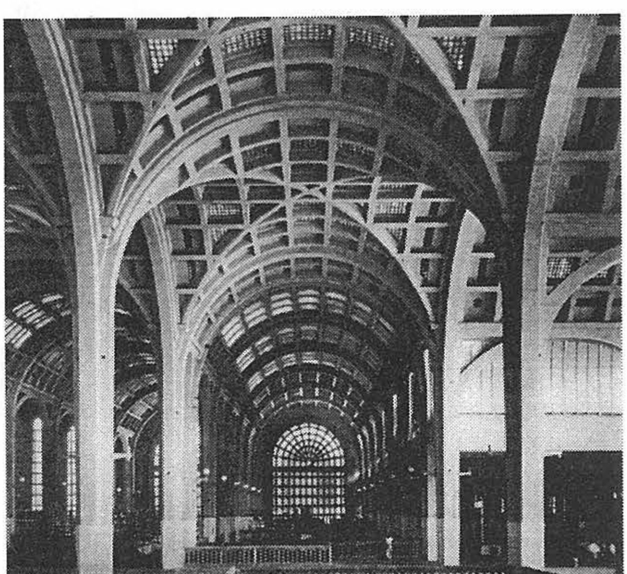


foundation slabs and 'preformed' structures from his profound knowledge of the nature of materials, before calculations would prove his ideas to be right.

On the edge

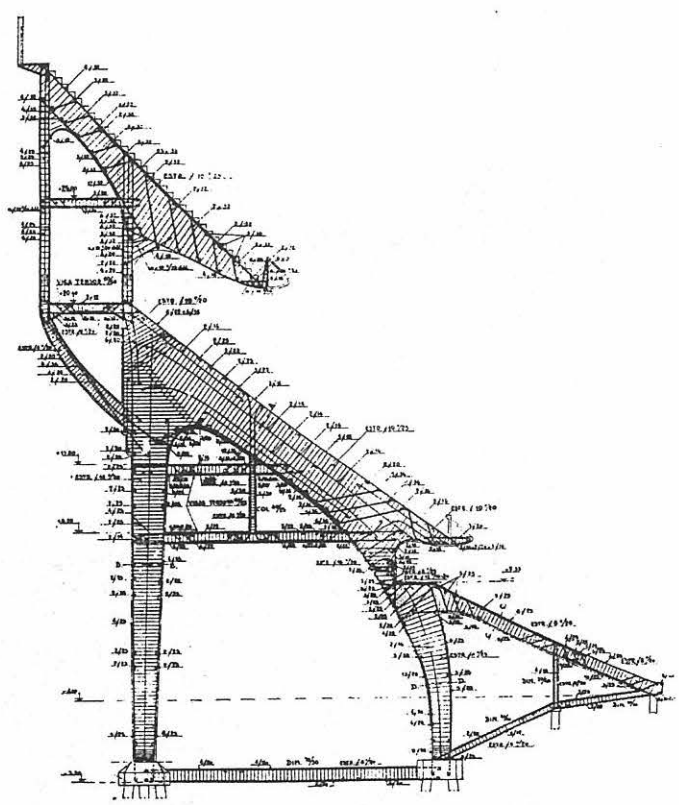
Already in his late twenties Delpini had the opportunity to design some of Buenos Aires' largest and characteristic buildings of the time. In the context of the era the Abasto Proveedor market hall, designed by Delpini, Sulcic & Bes engineers in 1924 and finished in 1937, is considered one of the first and prominent manifestations against academism and decorative architecture in Latin America. The building presents an early application of glass blocks in concrete of a scale unknown to this part of the world, thanks to which the 14,000 m² of floor area could be covered with roofs of translucent cassettes. The main vault spans 26 m and measures 36 m in height. The design predates the famous Fair Hall in Brno, Czechia (Kalous and Valenta 1926–28), that has some similarities as regards the parabolic form and the quality of daylight. Today the market hall is under redevelopment in an effort to revitalize the run down Abasto district in the Argentine capital.
The stadium for La Boca Juniors was designed by the same office in 1932–34, and was inaugurated in 1937. The engineers are noted for the splendid way in which they managed to design a stadium for 100,000 spectators whereas the site seemed to allow for an arena for 60,000 only. The lot in the densely populated La Boca quarter was limited to a slightly

The magnificent day lit interiors of the market hall. Period photo: courtesy Cardoni.



irregular 187 x 114 m rectangle. In order to master the problem Delpini projected an ideal, 187 x 170 m plan for an oval two–ring stadium on the site and cut off the part that could not be fitted in, producing a scheme with stands along three sides of the field. By introducing a third ring that projects over the boundaries of the property, high above the narrow streets, the capacity of the stands was increased by 60 %. In static terms, the additional stands are designed as a balancing construction supported by the row of perimetral columns that are part of the portals that carry the second ring. Delpini's solution is visualized by a graphic that explains as well the way the forces are guided through the portals to the foundations, the tension and compression diagrams in the structural members and the balance that inspired the marvellous design of the portals.
For a site next to La Boca stadium an olympic swimming stadium was projected in the 1950s. It was to be covered with an ingenious fold–away roof consisting of enormous arches with a span of 100 m. Though the covered stadium was never built the spring towers were constructed after Delpini's design. The main tower is a concrete construction of an astounding simplicity and beauty. It is a fascinating example of a series of contemporary works in which he exploited the distinction between compression and tension strengths in order to economize on materials. The tower features external reinforcement that has been post–tensioned. The main bars serve as handrails for the athletes at the same time. The 50 mm thick single concrete slab sufficiently withstands compression with just 1/8 of the material used for common spring towers constructed in integrated reinforced concrete.
The structure is such a clear and far reaching illustration of an engineering philosophy that it can

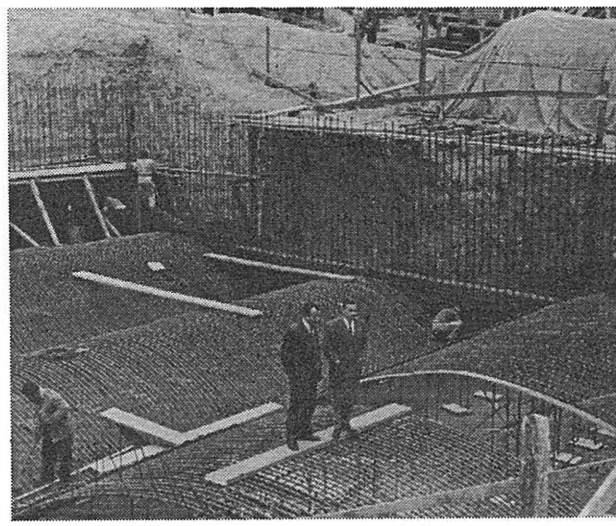
Section through the stands of La Boca stadium. Period drawing Delpini: courtesy Cardoni.



almost be read like a textbook. In 1953 the La Boca spring tower added a new dimension to Delpini's balancing act that had started with the arena design in the mid 1930s.

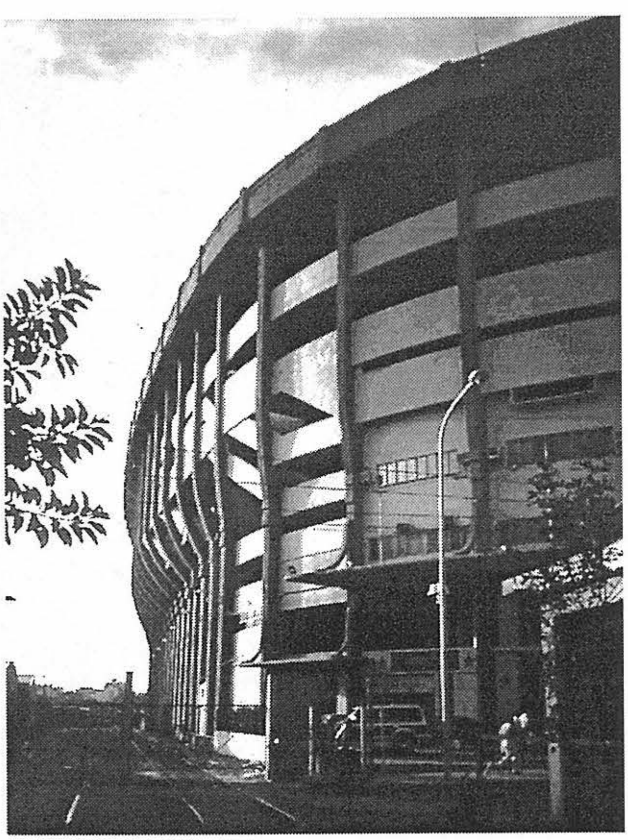
Paraboloids

Like many of his contemporaries, Delpini was involved in designing structures with a minimum of materials used. In doing so he increasingly challenged his skills to push the constructions he designed to their structural limits.
The Condor bus terminal in Buenos Aires (1941–42) is covered by *Dywidag* reinforced concrete shells with a 35 m span, with sky lights in between. The reinforcement is arranged to materialize the parabolic lines of the isostatic diagram of tension forces, so that they are loaded to their safe maximum. The reduction of rebar allowed for a concrete slab of just 80 mm. Another elegant illustration of Delpini's ideals is the Italar weaving mill (Morón, 1947). The structure consists of slender parabolic arches with a 40 m span that support horizontal trusses of 60 m length that protrude at both ends. In the midsection the trusses are suspended from the high parabolic frames, while at both ends they rest on the arches. The trusses on their turn support a perpendicular substructure that consists of sheds that are made up of three 25–30 mm thin, prefabricated concrete shells. The windows under the trusses allow plenty of daylight. Despite the large width of the required floor area of 60 m Delpini succeeded in designing an extremely lucid frame that predominates the architectural character of the building.
A similar motive to reduce materials led to a particular type of foundations for high rises such as the Chopitea and Donizetti towers and the 1957–60 Las Heras apartment building, with a height of 100 m above foundations, 33 storeys and 3 basement levels. A common solution on the banks of La Plata river is a foundation slab of several meters thickness. With the engineers H. Fernández Long and A. Bignoli, Delpini



The sinusoid foundation slabs of the Las Heras and Donizetti towers 1957-60 save almost 30% of concrete mass as compared to standard foundations. Period photo: courtesy Cardoni.

The third ring of La Boca stadium projects over the boundaries of the narrow site. Photo: W. de Jonge.



La Boca spring tower with external reinforcement that serves as a handrail. Period photo: courtesy Cardoni.

developed an undulating foundation slab, with the support walls positioned at the lowest sections. Due to the sinusoid form of the slab, only tension forces are solicited and double reinforcement could be largely avoided. Moreover, the loads are transferred to the subsoil in an extremely even manner. This way, the thickness of the sinusoid slab could be limited to only 0.65 m with just 45 kg of reinforcement steel per square meter. With the 128 m Donizetti Tower a further reduction to 0.40 m could be achieved.

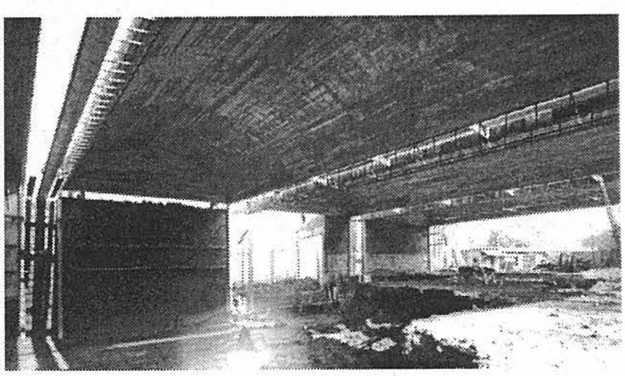
External reinforcement

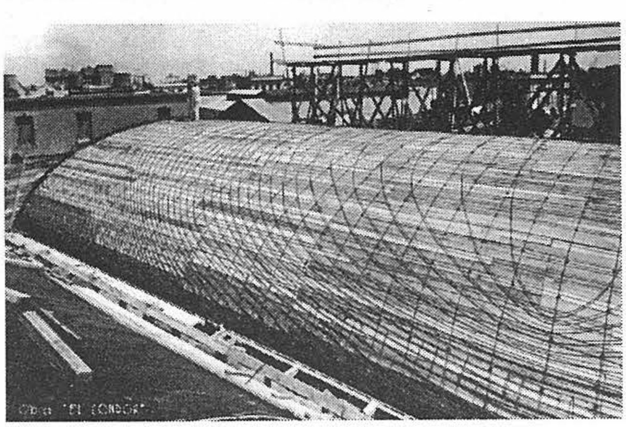
Like some of his European contemporaries, Delpini took the issue of material economy to a spiritual level with his exploration to materialize the distinction between compression and tension strengths, as was so evidently demonstrated in the spring-tower at La Boca. But also his designs for more common usages, such as the Juarros spinning mill of 1942 and the Colgate Palmolive factories of 1960 suggest to exploit this distinction, taking account of the specific properties of various materials. The Juarros spinning mill in Florida would be an ordinary factory if not for the peculiar trusses. These large structural elements span 27 m and can be understood as lattice girders with indeed concrete members to resist compression forces. Parts that exclusively solicit tension forces, however, just feature exposed steel bars as tension rods. In addition the roof is made of slightly curved sheds that consist of very thin *Dywidag* concrete shells. The overall impression of this structure with visible reinforcement is that of lightness and ingenuity. The Colgate Palmolive factories in Llavallol are covered by just 25 mm thin, paraboloid sheds that span 30 m, with double steel profiles 70/70/7 that serve as tension rods. The shells are inclined to allow daylight in through vertical lights that, at the same time, are designed to serve as a stiffening construction for the sheds. Exposed steel rebar is welded to the inside steel of the concrete shells to serve as stiffening members against flexion.
Apart from these daring constructions with exposed reinforcement Delpini experimented with steel fibre reinforcement for concrete shells already in the 1950s, resulting in concrete roofs of just 20 mm thick.

Preformed concrete

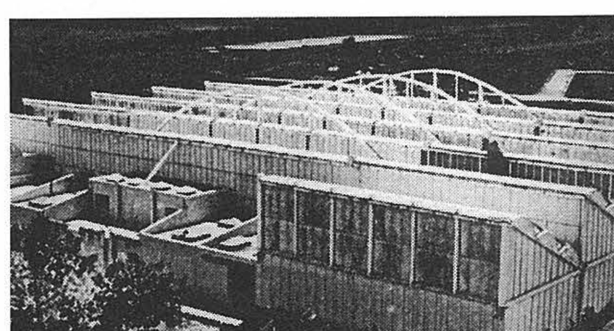
In a further effort to rationalize wide span construction Delpini developed a technique for the production of large concrete components, that is referred to as 'preformed' concrete. Typically, preformed elements are produced at ground level and then lifted to the required height to avoid extensive wooden formwork and scaffoldings inside the structure, which is a great advantage during execution of large halls in particular. The overall form is best described as a 'folded cupola', consisting of concrete 'vaults' with a relatively large rise and strengthened by ribs in which the reinforcement is concentrated. The skin of the vaults can sometimes be

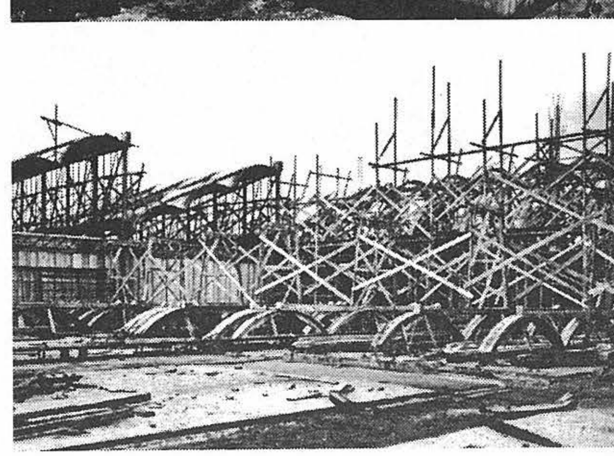
El Condor bus terminal in Buenos Aires (top). Reinforcement patterns in the roof shells follow isostatic paraboloid lines. Period photos: courtesy Cardoni.





The Italar weaving mill in Morón (1947) with its slender parabolic arches. The construction photograph shows, left, the substructures with each three concrete shells, which actually cover the hall. Period photos: courtesy Cardoni.





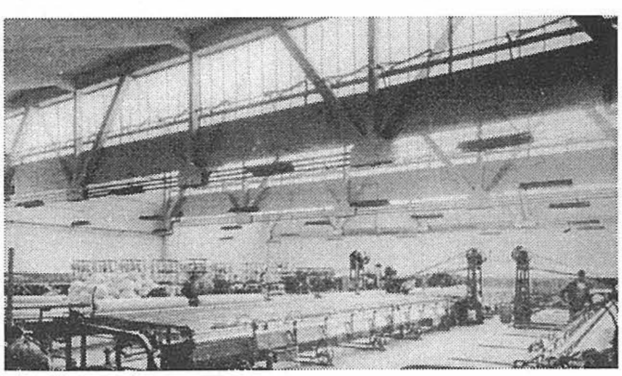
as thin as 20 mm. This technique was used for a number of structures, the last of which was the 1961 extension for the Gomycuer factories in Castelar that involve 6.60 m wide, preformed elements with a span of 33 m. The Italar boiler house of 1959 for a large weaving plant in Morón is an earlier successful example. The use of a forced air stream through a series of large ventilators from above, to control the heat radiation from the boilers and to master the interior climate, was the main cause of the architectural disposition of the building. The vertical elements that make up the facade are curved in such a way that the narrow strip of windows in between them never allow direct sunlight to enter into the interior.
All the window frames, either horizontal or vertical, are made of prefabricated concrete.
The roof over the boiler room has a span of 25 m with a free height of 22 m and offered an excellent opportunity to apply preformed elements. The roof consists of three 'folded cupolas' with a rectangular basis, that were produced on site before being lifted to a height of 22 m. The large folded shells are strengthened by ribs that spring from the corners of each rectangle and incline towards each other in the middle of the span. It is a pity that this magnificent construction can only be enjoyed from the top of the neighbouring tower that serves the water supply of the Italar plant. Still, the elegant concrete elements in the facade produce a spectacular architecture as well, especially at night when the light oozes through the narrow windows to touch the curved columns.

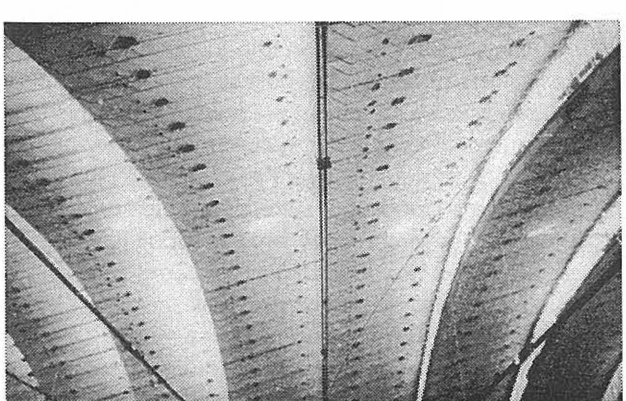
La Boca Stadium

Although the self–evident lightness and ingenuity of Delpini's works suggests their ability to withstand the ages to serve a future destiny, La Boca stadium appeared in need of mayor renovation by the mid–1980s. The works carried out were twofold. For the first time since its inauguration, the concrete structure needed some repairs. On the other hand some functional shortcomings needed to be solved. The lack of sufficient drainage systems posed problems already for years. Despite regular maintenance, the structure had suffered from various types of concrete damage. Most important problems related to the concrete structure were:

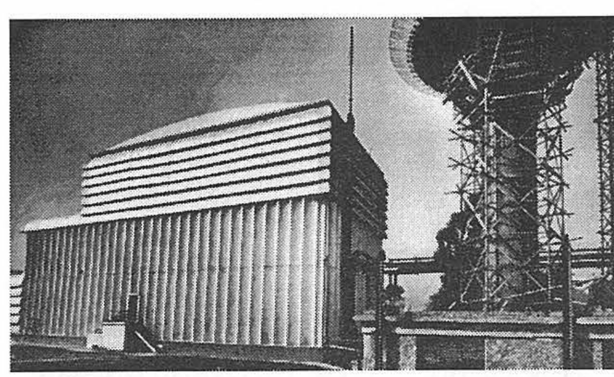
- Advanced concrete damage through carbonation as a result of insufficient concrete covering; at the foot and along the outer edges of the perimetral columns of the main portals deterioration was particularly alarming.
- Microcracks of structural members of the stands caused by the irregular heavy loads produced at rhythmic intervals by enthusiast soccer *aficionados*, that allowed for water penetration and, consequently, rebar corrosion and spalling of concrete.
- the poor condition or even virtual lack of a drainage system at the joints between the

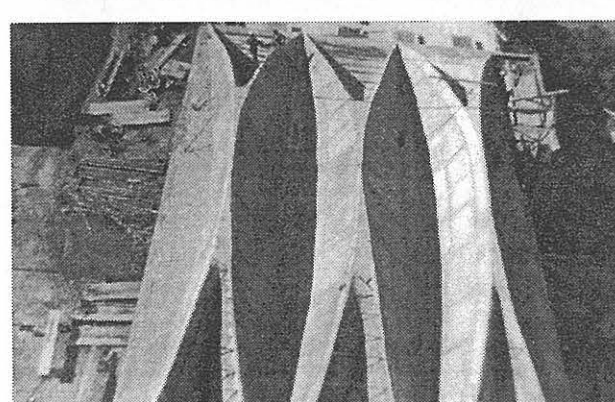
The trusses of the Juarros factory feature exposed reinforcement (top). The inclined shells of the Colgate factory, with external reinforcement against flexion. Period photos: courtesy Cardoni.

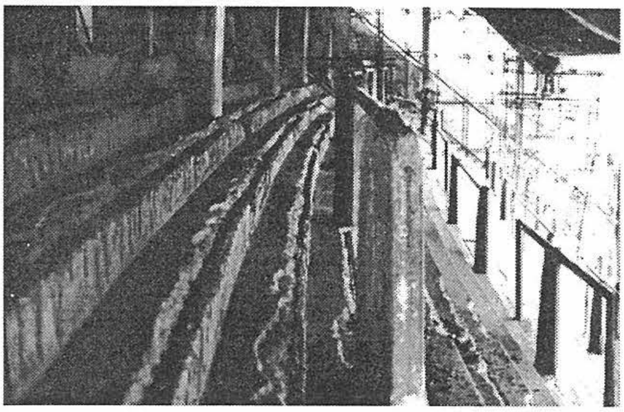


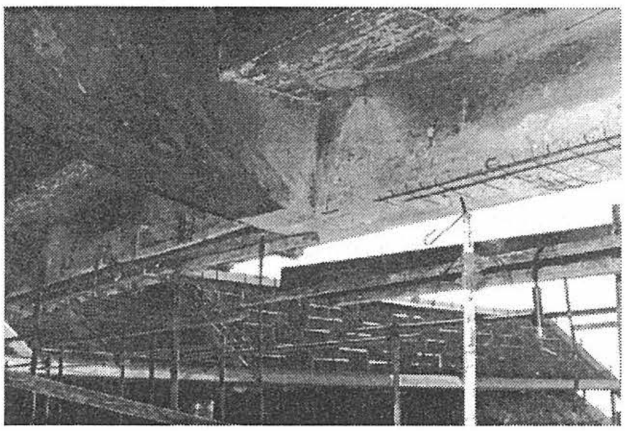


The Italar power house features preformed, curved concrete elements (top). The three preformed 'folded cupolas' over the boiler room. Period photos: courtesy Cardoni.

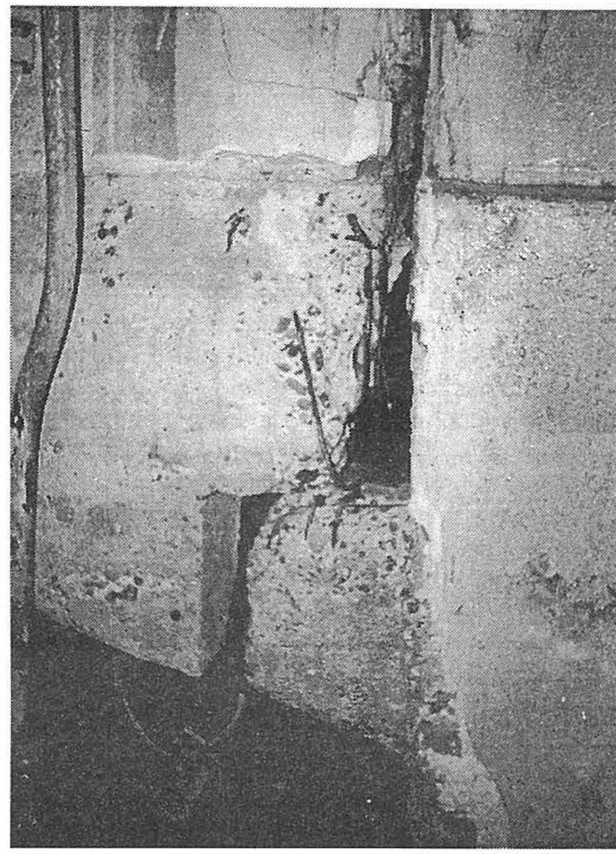






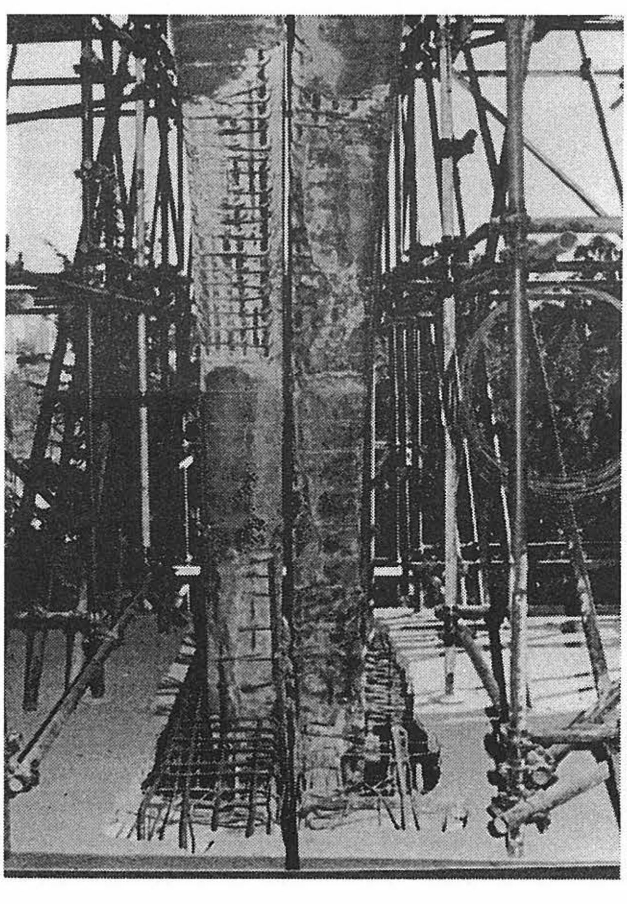


The damaged edges of the stands at La Boca stadium (top). The bottom of the curved spandrel beam along the lower end of the third ring. Photos: J.M. Cardoni.

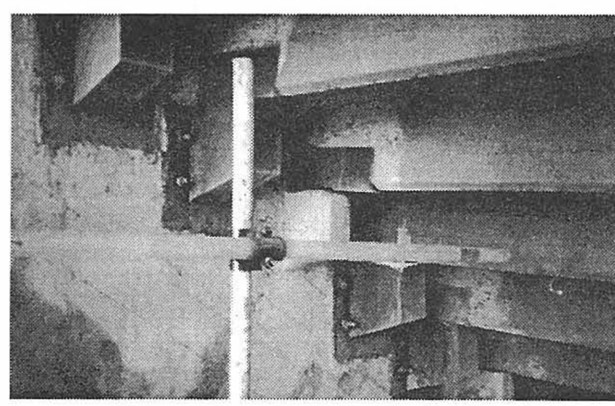


Decay of corbels under the main concrete members of the grand stand posed a serious threat to safety, reducing the actual support surface to less then one third. Photo: J.M. Cardoni.

Repair works at the columns of the double portals involved various epoxy techniques. Photo: J.M. Cardoni.



Repair of the corbels with high-performance epoxy mortars and steel jackets, anchored to the portals. Photo: J.M. Cardoni.



structural members and the portals, as well as between double portals at expansion joints, which worsened water infiltration into the structure; particularly at the double portals and at the curved spandrel beams at the lower end of the rings major damage was recorded.

- additional damage frequently occurred along the edges of the stands that suffered from significant spalling of concrete – not through rebar corrosion, but due to the concrete being kicked off by spectators to use as projectiles.

Some members of the concrete structure were deteriorated to such an extent, and spalling was so far advanced, that the strict safety requirements could no longer be met. The structural distress as found in the concrete frame suggested a strategy in two stages, repairing first the most urgent failures and those elements that prevented the functional rehabilitation of the stadium. This first stage of the repair works were directed by engineer Cardoni, employing concrete repair methods that cover the full range of epoxy techniques. On the longer term, some older damages as well as failures that only appeared during the execution of the first works were taken care of. This second part of the project was done by a colleague, who has been responsible for aftercare and maintenance as well. After this extensive remedial programme the stadium entered a second stage of its life and it is anticipated that the arena will again be able to accommodate Diego Maradona and his team in the coming decades with pride.

Juan Maria Cardoni is a structural engineer in Buenos Aires, a member of DOCOMOMO Argentina, ICOMOS, the Argentine Ass. of Prestressed Concrete (Directive Member), and the Argentine Committee for Monuments and Sites. He was trained by Delpini and worked with him until his death in 1964, after which Cardoni was the only engineer to continue Delpini's studio. Since then Cardoni is the only Argentine who has published and lectured extensively on the Master's life and works, amongst others as a Senior Professor in Civil Engineering at Buenos Aires University. This article is written by Wessel de Jonge on the basis of an extensive interview with J.M. Cardoni in April 1997. Special thanks to Dr. Jan Molema for his help in translations from the Spanish.

Literature:

- *L'Architecture d'Aujourd'hui*, 1964, pp. 32-33.
- J.M. Cardoni, 'Metodología y Pautas de rescate de estructuras de máximo riesgo de hormigón armado del período 1930 a 1940 en la República Argentina', *Habitat*, December 1996, pp. 8-15.
- 'Obras del Ing. Jose L. Delpini', *Revista de Ingeniería*, November/December 1961.
- J.L. Delpini, 'Estadio del Club Atlético Boca Juniors', *Revista Informes de la Construcción*, June 1955.
- *Engenharia*, nr. 132, August 1953.
- V. Leonovitch, 'Frames and Arches', *Engineering Society Monographs*, 1959.
- *Nachrichten des Österreichischen Betonverains XIII*, 1953, Folge 3, Heft 4.
- Bruno Zevi, article in *L'Architettura*, December 1956, pp. 607-611.

Concrete Atlantis

The 'faces' of concrete in the United States

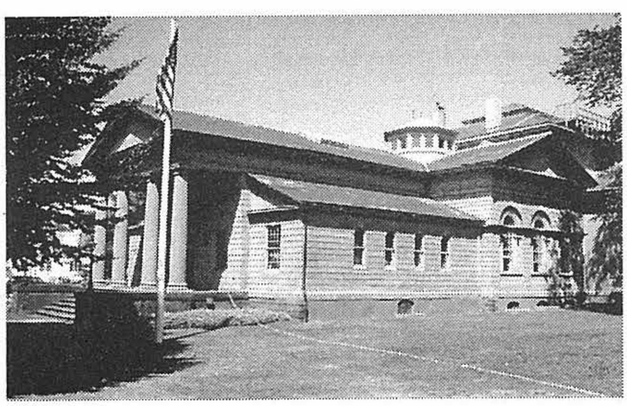
Concrete, while an ancient building material, has come into its own at the end of a long aesthetic, philosophical and technical journey.
However, with the acceptance of concrete as a material for architectural expression also have come new challenges for the preservation community and its professionals. The philosophical, aesthetic and conservation questions surrounding historic concrete are different from the issues involved in the preservation of some other building materials, precisely because of concrete's past and evolution.

by Theodore H. M. Prudon

While the history of concrete in the United States is largely chronologically, there are several distinct 'faces' or parts to the development which, however, frequently interconnect or occur simultaneously. In summary form these directions are:

- Concrete as a substitute material.
- Structural, engineering and fireproofing applications.
- Concrete as a material of architectural expression.

While the latter may be the best known to students of modern architecture, particularly because of the works of the 1960s and 1970s, earlier examples do exist. The first and second categories also represent a substantial volume of significant work, primarily in the 19th and 20th Centuries.[1]

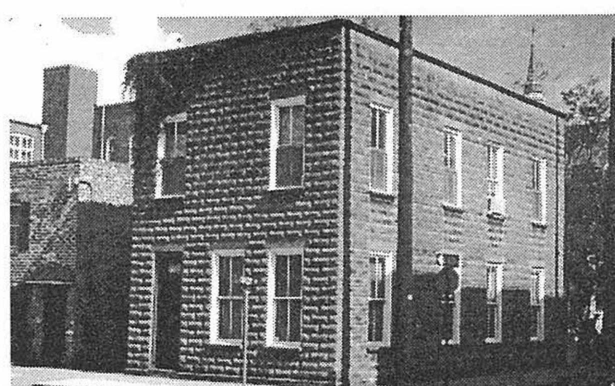


Newport, Rhode Island, Redwood Library. This wood frame structure was designed by Peter Harrison at the end of the 18th Century and was made to resemble stone masonry in its architectural design. To further the illusion of stone the exterior was finished with paint to which sand was added to simulate the right texture. Photo: T. Prudon.

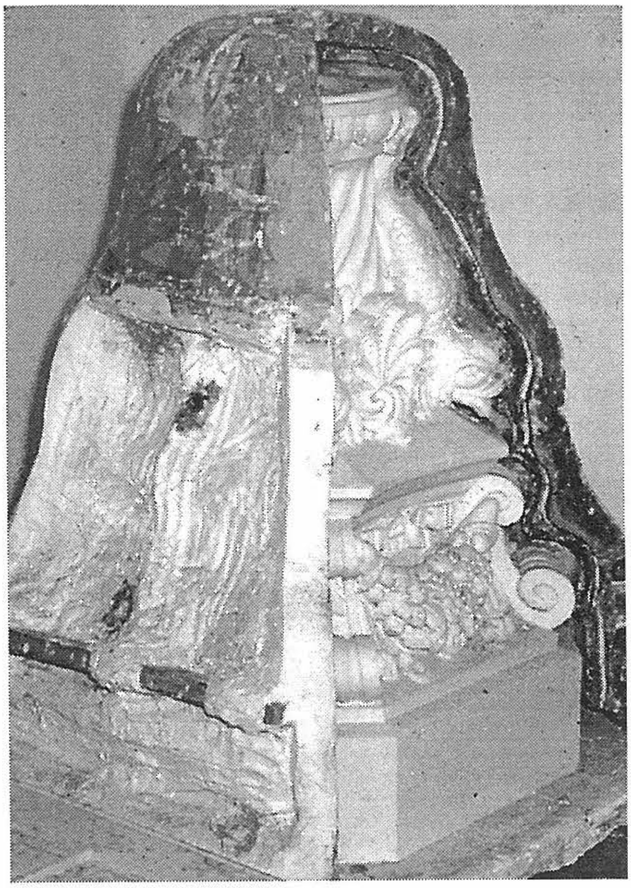
The desire to imitate or simulate the appearance of more noble materials is an age-old practice and is certainly not limited to the building trade. For instance, the desire to suggest (natural) stone can be seen as early as the 18th Century in the Redwood Library in Newport, Rhode Island (Peter Harrison, architect) or Mount Vernon, George Washington's residence in Virginia. In both instances, the architectural detailing of these wood frame buildings suggests stone and sand was added to the exterior paint finish to further the illusion of stone textures.

Substitute material

The 19th Century in the United States saw the emergence of a middle class that was interested in acquiring the symbols of wealth including substantial dwellings, preferably in stone. Where suitable stone was not available, concrete seemed to offer unique opportunities to simulate that appearance. Artificial stone, manufactured stone, cast stone, architectural stone are some of the names found, all touting the ability of concrete to provide a durability and a look that was just like the real thing.[2] While the earliest examples attempted to recreate a simple ashlar block, some of the later versions are elaborate simulations of marble or even terra cotta. In order to achieve these



Charleston, South Carolina, residence. The use of mass produced rusticated concrete block for residential construction was widespread throughout the United States. When studied closely a limited number of variations in the rustication of the different blocks can be observed. Photo: T. Prudon.

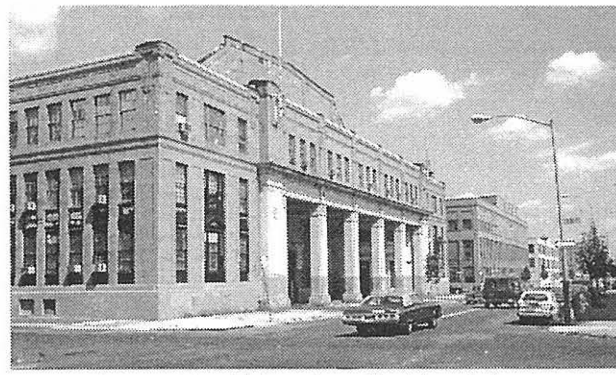


To produce elaborate units with a great deal of undercut complex forms that could be released in sections moulds were made out of plaster, wood and natural fibers. Manufacturing cast stone of elaborate configurations and details - with some stylistic changes - remained common till the beginning of World War II. The form and unit are from a private residence in Florida. Photo: J.Fagin.

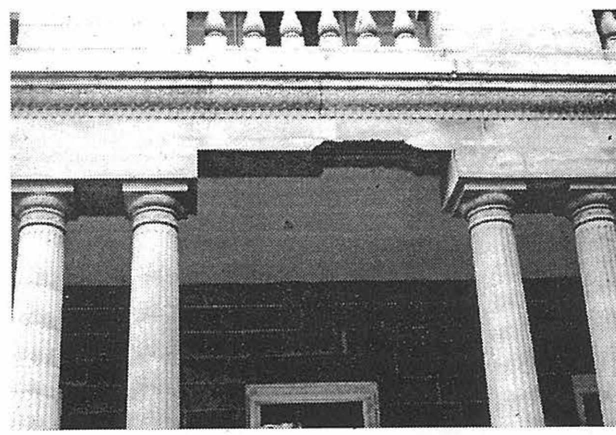
results elaborate plaster molds and casting techniques were employed. Where the initial use of concrete block was for low-rise construction -terra cotta was more readily applied to high rise buildings- by the 1930s that changes. Cast stone, as it was usually called then, begins to replace terra cotta largely because of changes in architectural style and the potential cost savings. Terra cotta requires fabrication of elaborate models in order to accommodate the shrinkage of the fired clay but cast stone could be more economically made. Ironically, some of those reasons have reemerged in the present time and cast stone has been reintroduced as a substitute material that is less expensive and more readily available.[3]

Engineering form

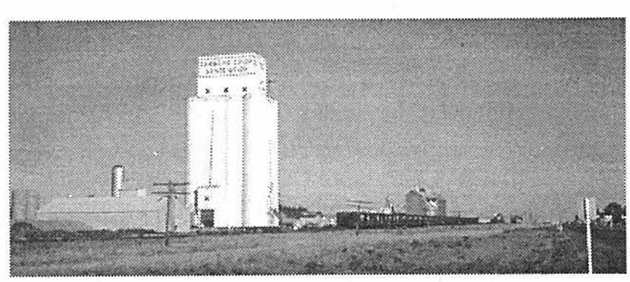
The second 'face' or development is the use of concrete as a structural and engineering material. At the end of the 19th Century the increased building activity, the heightened concern for fireproof construction and the ever-growing scale of buildings, gave impetus to an increase in the use of concrete in two ways. Where concrete was utilized in a building considered to be of some architectural significance ('serious architecture') the concrete structure would be



Astoria, Queens, New York, industrial building. Industries required buildings that were large, regular in shape, safe and fireproof. The functional nature allowed the concrete to be shown and expressed as an external material while still employing a traditional, albeit reduced, architectural vocabulary. Built in the first quarter of the 20th Century the building is presently the Museum of the Moving Image. Photo: T. Prudon.

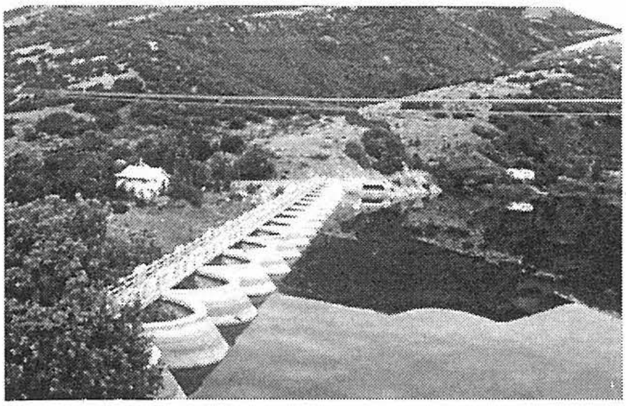


Beaufort, South Carolina, residence. With the evolution of reinforced concrete technology and engineering and the acceptance of the material the use of concrete was not just limited to industrial buildings. Even in residential architecture buildings still resemble an earlier style mostly associated with natural stone. Quality control of the original concrete and the lack of rebar coverage are the problems most frequently encountered. Photo: T. Prudon.

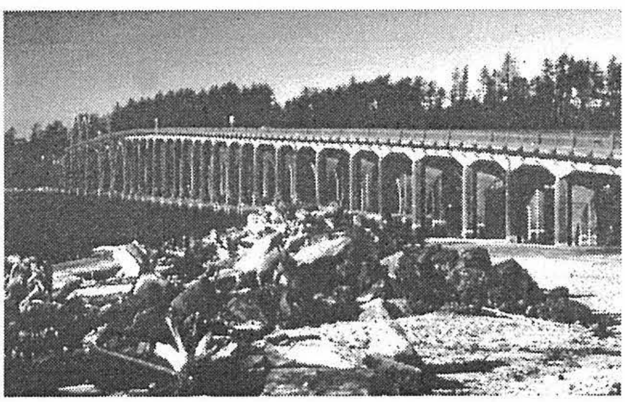


McLaughlin, South Dakota, grain silo. With the grain elevator, the grain silo was typically made of reinforced concrete because of concerns for durability and fire. Many silos once dominated the Great Plains in the United States. Photo: E. DeLony, HAER.

embellished with stone, terra cotta or sometimes cast stone (sic) decorative features. Where concrete was used in more utilitarian structures the material was unabashedly shown. The factory buildings of the



Mountain Dell Multiple Arch Dam, near Salt Lake City, Utah. Designed by engineer John Eastwood in the first quarter of this century, this unusual dam structure is located in the foothills of the Wasatch Mountains in an area that is presently considered at seismic risk. As a result the dam structure does not satisfy contemporary code requirements and is technologically obsolete unless upgraded. Photo: E. DeLony, HAER.



Alsea Bay Bridge, Waldport, Lincoln County, Oregon. Designed by the engineer C. B. McCullough in 1936, this bridge is one of many built in concrete at the time and remains in use. To enable continued use and to accommodate modern high way safety conditions often significant changes are required. Photo: E. DeLony, HAER.

early part of the 20th Century and the work of the architect/engineer Albert Kahn, in particular, are cases in point. The plain and minimally adorned concrete structures were shown without pretense and often with remarkable results.
The design of highway or railroad bridges, dams and silos was in many ways even more remarkable. The silos of the American plains were well known to European architects and were greatly admired. The silo in McLaughlin, South Dakota, is an example of those early engineering structures. Some of the lesser known engineering structures are equally remarkable, for instance, the Mountain Dell Multiple Arch Dam (near Salt Lake City, Utah, and designed by the engineer John Eastwood in the first quarter of this Century) or the Alsea Bay Bridge in Walport, Lincoln County, Oregon. John Eastwood designed the dam in Utah in the first quarter of this Century, while the bridge in Oregon, the design of engineer C. B. McCullough, dates from 1936. The power of the engineering form is very much the result of the expressive use of the monolithic quality of concrete, a quality not captured in architectural form until much later.[4]

Merritt Parkway

Before concrete came into its own as a design material, remarkable structures combining the monolithic aspects with the decorative opportunities were built. Bridge and engineering design in the 1920s and 1930s often is a combination of poured in place concrete freely expressed and distinctive ornament embellishing the structure. A unique collection is the some 60 or so rigid frame concrete bridges on the Merritt Parkway built between 1930 and 1936.[5]

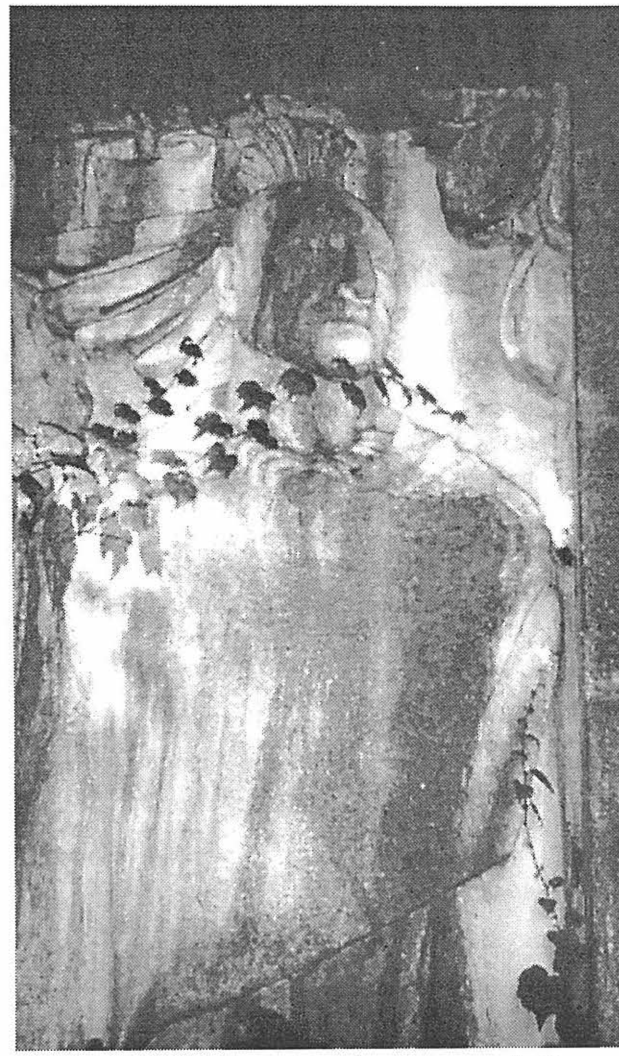
While concrete was selected because natural stone - the preferred material- was considered too expensive, concrete was used in the most innovative way and not in simulating natural stone.

Merritt Parkway, North Avenue Bridge, Westport. The parkway was completed in the 1930s when traffic volume and speeds were considerably lower than today. All bridges are rigid frame and constructed in reinforced concrete. All bridges are embellished with extensive ornamental detail in either poured in place or cast stone. Details vary from bridge to bridge but all are inspired by the state of Connecticut, its people, history, flora and fauna. Photo: ConnDot, c. 1935.

Here, as in other public work projects of that era, the bridges were the result of a successful collaboration between an architect, George Dunkelberger, and the engineers of the state transportation department. While the basic structural frame was poured in place concrete, the wingwalls, abutments, railings, parapets and entrances were often embellished with decorative features. These decorative treatments were achieved in two ways, through insets or molds in the formwork or through the installation of off-site fabricated cast stone ornaments. The design of the ornaments created through reverse molds or profiles created in the formwork are generally simple without significant undercut. The cast stone ornaments can be very elaborate and have detailed configurations. The cast stone sections were either installed after the structure was completed or were placed integrally with the formwork before the structural frame was poured. In

Merritt Parkway, North Avenue Bridge, Westport, sgraffitto ornament. Different techniques were used to embellish the bridges. Sgraffitto like the original Italian technique involved removing the outer layer of concrete to expose the darker colored inside to form decorative patterns. The concrete had to be poured in several different layers in a mold to achieve this effect. Photo: N. Wilks.

Merritt Parkway, ornamental panel. Some of the ornamental detail was achieved by placing reverse plaster molds inside the form work. Because the large formwork had to be removed in large sections and without too much difficulty this type of ornament was kept simple and without any undercut. Photo: N. Wilks.

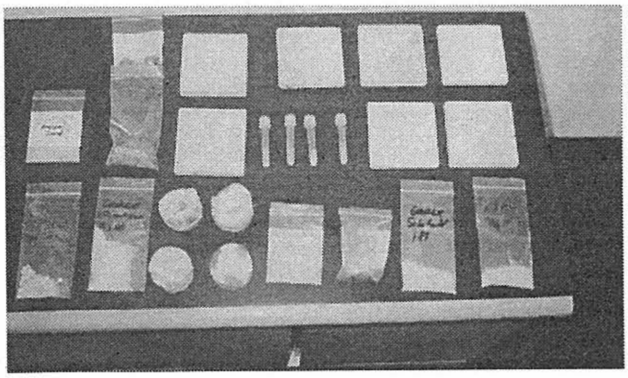


Merritt Parkway, Canstock Hill Road Bridge, Norwalk. The image of the native American which forms integral part of the wingwalls of the bridge has been eroded and covered with algae and moss as a result of excessive vegetation. The concrete itself remains in a remarkably good condition. Photo: N. Wilks.

the design of the bridges considerable attention was also given to the shape of the bridges and the architectural effect as well as the types of aggregates and surface finishes used. In many ways the architectural effects and the technology explored and applied here are the precursors to later concrete architecture.

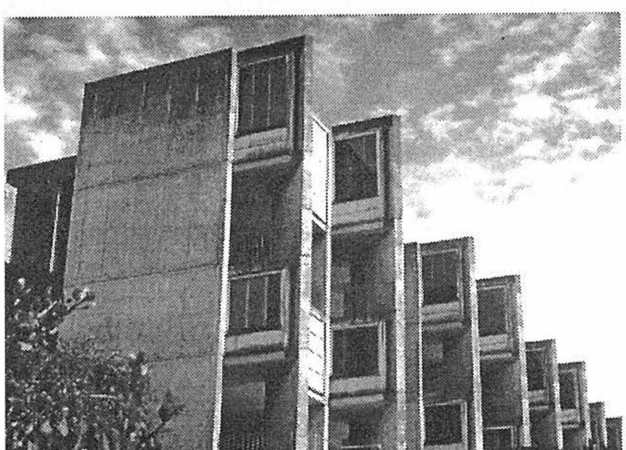
Different aesthetic

The final and third 'face' of concrete as a building material is represented by the architecture of the Post World War II period when the material and its unique versatility was used to the fullest extend. The architecture of Louis Kahn or Marcel Breuer bespeaks these opportunities in many ways not unlike the work other architects in Europe or elsewhere. With the full exploration of the monolithic qualities of concrete also comes a different aesthetic. The roughness of form, the uneven but frequently elaborate surface techniques and the stained and weathered



Merritt Parkway, sample analysis and replication samples. To develop appropriate repair materials for the replication and repair, cores of the original historic concrete were analyzed and their constituent elements identified. Of particular concern was the proper identification of the aggregates by size, type and distribution throughout the mix as well as the ratios present. After identification, replication mixes were prepared and new samples fabricated. After comparing the new samples to the original concrete further adjustments were made to achieve the best possible match. Photo: N. Wilks.

appearance add to the architectural expression. It is this aesthetic that in its visual strength presents the preservation challenge.
The restoration and conservation of historic concrete is in many way not unlike other building materials but



La Jolla, CA, The Salk Institute for Biological Studies. Designed by Louis Kahn between 1959 and 1965, the institute's buildings show the expressive qualities of reinforced concrete at its best. The uneven weathering and surface deterioration have further added to this expressive quality. Because of the monolithic appearance of this type of architecture, repairs will be more difficult to execute without a patch work appearance. In those instances, extending the repair work into the 'natural' lines of the design is one of the ways to minimize contrast between old and new. Photo: C. Hall.

also has several unique aspects. The evolution of concrete as a building material is very much tied into the development of proper restoration techniques and their philosophical acceptance.
The issues can be divided into several distinct categories: technical and structural obsolescence, material deterioration, and philosophical considerations.

Obsolescence

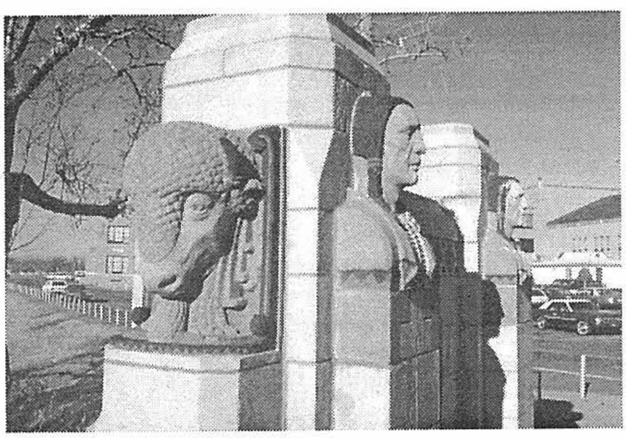
When older buildings and engineering structures are evaluated in accordance with contemporary codes, many are, not surprisingly, found to be no longer satisfactory, inadequate and even unsafe. For instance, the Mountain Dell Multiple Arch Dam near Salt Lake City, located in the foothills of the Wasatch Mountains, an area with considerable seismic risk because of active fault lines in the general vicinity, was not designed to resist major earthquakes and is therefore of some concern. In evaluating any historic structure it is important to understand that the engineering requirements have changed.
Understanding of seismic hazards, for instance, continues to evolve. Frequently, aspects that were historically not considered in the design have led to an upgrade to reflect this better understanding.
While seismic concerns also exist for concrete bridges in regions at risk, more frequently the issues are those of highway and traffic safety as well as allowable loading. The Merritt Parkway bridges are good cases in point. The design criteria for the parkway envisioned far less traffic volume than experienced today and much lower speeds. Upgrading the parkway would unquestionably alter its character and all the features and structures. Highway safety is a primary concern. The historic railings and balustrades, for instance, existing along the sides of the bridges do not have the required crash or impact resistance, which, in a society that is highly sensitive to legal liability, is often considered an unacceptable condition. The result is, at best, the addition of crash resistant barriers, or, at worst, the elimination of the historic balustrade and the installation of a contemporary and safe but visually unsuitable barrier.
Similarly the width of the road and therefore the width of the bridges are constantly being reviewed. Where the road is found to be inadequate and the bridge is to be widened the original concrete structure is generally considerably altered or reconstructed -in a similar appearance- altogether.
Historic concrete structures will continue to come under considerable pressure because of their (perceived) technological obsolescence. A careful evaluation of what is truly necessary and a great deal of ingenuity and design sensitivity will be required to assure their survival. For instance, the highway safety issues can be resolved with some imaginative solutions without sacrificing safety. For the engineering works such as dams, these solutions are more likely to be complicated and possibly more costly and could, in some instances, affect the visual appearance of the structure. However, these issues can be resolved.
For building structures of concrete, these problems do also exist but are generally more easily dealt with. The loading and other structural members are easily

reinforced or can be dealt with otherwise without necessarily requiring demolition. The major exception are early industrial structures were highly toxic facilities may have been located and that are environmentally no longer acceptable.

Material deterioration

Concrete deterioration is reasonably well understood. Considerable literature and experience is available that addresses the structural, not necessarily aesthetic, repair of concrete. So are the problems surrounding some aggregates. For older concrete inadequate rebar coverage, advanced carbonation and loss of pH are probably the most common problems. However, a number of deterioration phenomena of older concrete are unusual and have been unresolved to date.

Several technical issues relate particularly to cast stone or precast concrete. In early concrete unusual decorative finishes were often achieved through the use of a so-called 'face' mix. A colored or decorative layer of concrete was placed in the form first and subsequently common concrete was placed as a backup. While these 'face' layers can vary in thickness, usually they are quite thin. Delaminating or separating of these layers may occur caused either by differential movement or when placing the backup concrete was delayed. Because these colored finishes use different mineral pigments the color may also



Wichita, Kansas, bridge. Elaborate concrete castings were only used to simulate natural stone -as the name cast stone would suggest- but even historically was utilized to suggest terra cotta. The Indian head and the buffalo are located on a bridge entrance next to a high school decorated with the same details but executed in terra cotta, which was probably considered too vulnerable for the bridge railings. Photo: T. Prudon.

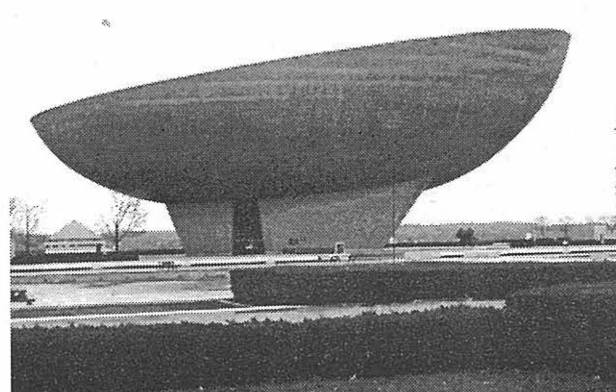
fade over time making proper matching more difficult.

Aside from the more common deterioration problems the later precast as well as the poured in place concrete present problems with its, often unique, surface treatments and discoloration and staining patterns. Postwar concrete has frequently very elaborate finishes which can range from a board finish to traditional bush hammering. While the argument can be made that the surface erosion is part of the natural weathering process, it certainly becomes difficult to accomplish the repair of the concrete satisfactorily. Repairs are limited to the areas directly affected resulting in a blotchy and patch work appearance. If that is not acceptable, the option exists to extend the repair out until it coincides with the natural lines of the original design. In that manner the direct contrast between new and old work is avoided. The other alternative is to treat the entire surface with a masonry stain to 'soften' the glaring difference between the new and the old. It is important to note that frequently the difference is not much the result of actual color differences as it caused by the difference in texture and finish.

The matter gets further complicated if the exposed aggregate of the finished surface is failing. The cement matrix in which the aggregate was once embedded has weathered away and, in that instance, substantial pieces of gravel or other stone pieces have come loose. Aside from a change in the appearance of the building this is also a potential safety hazard. Many aspects of this type of surface loss or deterioration and its appropriate repair remain to be explored and investigated.

Philosophical considerations

Aside from the technical issues a number of philosophical questions can be raised, particularly for



Albany, New York, State Performing Arts Center. This theater is an integral part of the so-called Empire State Mall, a new government center designed by the architects Harrison and Abramowitz in the 1960s. While this building is also one of the many examples of the period in which the monolithic character of concrete has been expressed, the visual impact of the repairs will be much more difficult to mask when necessary. In these examples the issue of masking the repair through the application of a masonry stain may be one of the options. Photo: T. Prudon.

the conservation of more contemporary concrete. Here, the very monolithic nature of concrete -its ability to be cast at one time in large sections and the ability to take any form- may require a philosophical approach that is different from the one for unit stone masonry. The weathering of natural stone is romantically accepted as a 'beautifying' process adding value to the appearance of the structure. Differences in weathering and staining are seen as giving character to the building.[6] For poured in place concrete such conditions are likely to be described as blotchy or as patchwork. This also applies to the repair work. Masonry walls consist out of individual units that can be repaired and replaced and because of its unitized character slight variations in color or texture are acceptable and sometimes even desired. For concrete these natural divisions do not exist generating the perception that the work is patchwork and unsightly. Here the argument can be advanced that the very nature of the concrete and its ultimate adaptability is the reason that such distinct divisions can not be made. Therefore visual expectations that are based on stone masonry should not be applied to concrete. However, it is highly unlikely that such a point of view will get much support but it does raise the issue of the need for a different (visual) evaluation for concrete.

Unique characteristics

The conservation of concrete continues to present technical, philosophical and also aesthetic considerations, particularly with regard to the degree of matching old and new concrete surface finishes, texture and color that can be accomplished. Where variations in matching in stone masonry are visually acceptable and even desired, for concrete, which is of a more uniform and monolithic appearance, this will lead to the perception of unacceptable work. Approaches may vary and can be one or a combination of the following:

- Minimize the amount of structural repair necessary through use of different non-destructive repair techniques where possible.
- Carefully match the new work in design, color and texture by meticulously analyzing the original concrete and identifying its constituents and mix ratios.
- Accept the somewhat uneven appearance as a specific characteristic of concrete and define the repair parameters within that context.
- Delineate the new work area (where possible) to be coinciding with the natural lines of the design of the building to minimize the contrast between old and new.
- Apply a surface coating or stain over the entire area to hide, mask or minimize the same contrast between old and new. This has to be a solution of the last resort because it must not become an excuse for improper repair. It adds additional long-term maintenance to the project and also negates the very nature of weathered concrete by trying to make the surface uniform.

The conservation and repair of historic concrete will become more and more an issue to be dealt with as time progresses. The architectural design importance of concrete is finally, after many generations, well established. Similarly a consistent and well thought out repair and restoration philosophy and practice needs to be established, one that is based on the unique characteristics of the material itself.

Theodore Prudon is an architect in New York City, a professor at Columbia University and a member of DOCOMOMO US.

Notes:

1. The significance of concrete as an early material of expression in the United States seems to have been appreciated particularly by European architects and writers. Le Corbusier, *Vers une Architecture*, 1923, is one of the examples. See Reyner Banham, *Concrete Atlantis*, Cambridge, 1986.
2. For a detailed description of the development of the 'stone' uses of the concrete block, see Theodore Prudon, 'Simulating Stone, 1860-1940: Artificial Marble, Artificial Stone and Cast Stone', *Bulletin Association for Preservation Technology*, Vol. XXI, No. 3-4, 1989, pp. 79-91.
3. Cast stone (or precast as the more contemporary term) has been used recently by the author on such projects as the Woolworth Building to simulate terra cotta -including the colored varieties- as well as the New York Public Library Main Building to replicate Vermont marble.
4. For a review of some of the examples of concrete bridges found in the United States, see Eric DeLony, *Landmark American Bridges*, New York 1992.
5. For a detailed description of the concrete work on the Merritt Parkway bridges, see *Merritt Parkway Bridge Restoration Guide*, prepared by the author and staff members of Stone & Webster Engineering and Swanke Hayden Connell Architects for the Connecticut Department of Transportation in 1997.
6. For a discussion of the romantic aspects of weathering and modern architecture, see Mohsen Mostafavi and David Leatherbarrow, *On Weathering, The Life of Buildings in Time*, Cambridge 1993.

Authenticity is more than skin deep

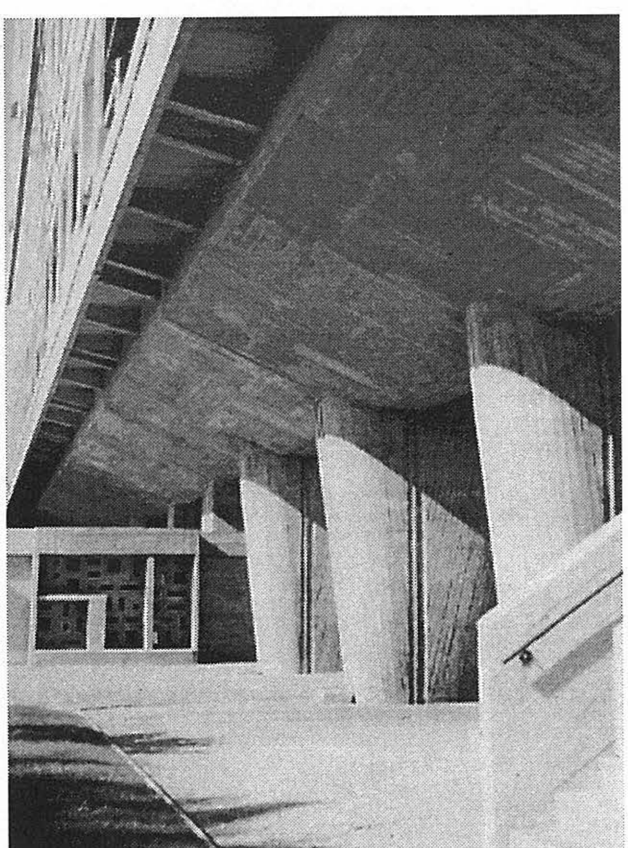
Conserving Britain's postwar concrete architecture

The increasing recognition of postwar heritage is directing attention to the specific technical and philosophical problems posed by the conservation of concrete buildings. Cultural barriers that have inhibited progress include lack of experience and undeveloped repair technologies to meet conservation needs. As appreciation grows for postwar concrete buildings these obstacles will gradually be dismantled.
Analyses of technical problems do not always identify the causes of the decay, which can lead to inadequate repairs. Moreover, they often fail to recognize the qualities of the building which need to be conserved. This paper outlines the difficulties of conserving material and design authenticity and illustrates the importance of challenging technical barriers.

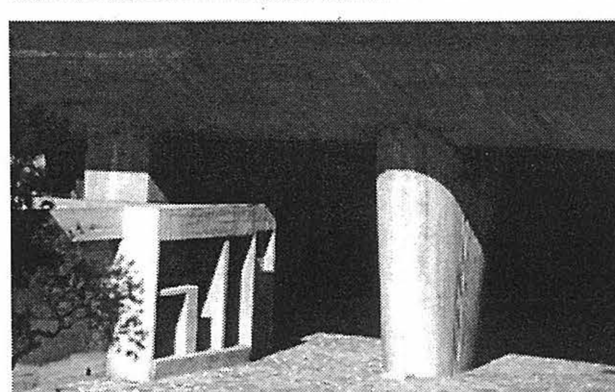
by Susan Macdonald

Of all the new materials and building systems that have come into widespread use over the past century, reinforced concrete is one of the most dominant. It also presents some of the most urgent, the most prevalent, and the largest-scale conservation problems in Britain today. These problems relate to architectural expression, construction techniques, and material composition. The use of exposed concrete[1], which combines material honesty with economical construction techniques to define a new aesthetic, is

Le Corbusier, Unité d'Habitation, Marseilles (1947-52) provided the model for exposed concrete in the architecture of many mid-century modernists. All photos: S. Macdonald, except where stated otherwise.



The natural, rough finish of the material emphasizes the monumentality and solid structural qualities of the Unité d'Habitation. This material honesty became an important characteristic of much of Britain's postwar architecture.



causing difficult technical problems. Applied finishes to concrete, such as mosaic and tile, are equally problematic. Surface finishes, be they plain or decorative, integral with the structural material or applied, are fundamental to the appearance and character of the building.

Currently these buildings cannot be repaired without radical visual, and often material alteration. What can be done to salvage these buildings, and how much change is acceptable to ensure their continued use, yet retain their significance? Is the conservation aphorism 'less is more' any less relevant for modern buildings generally and for concrete buildings in particular? These are questions facing English Heritage as an increasing number of postwar concrete buildings are added to the List of Historic Buildings of England.[2]

This paper outlines the historical and technical development of postwar concrete in Britain in order to highlight the difficulties of conserving material and aesthetic authenticity and illustrates the importance of lateral thinking, perseverance, and the willingness to challenge technical barriers. In addition, acknowledging existing conservation principles and methodologies is as important in the conservation of a modern concrete building as any other.

The difficulties of achieving the aim of UNESCO's Venice Charter of handing down our cultural heritage to future generations in 'the full richness of their authenticity'[3] has been discussed at length over the last ten years and has resulted in a reassessment of authenticity.[4] Recognition of the value of 20th Century cultural heritage has coincided with, and in part generated, the debate on the concept of authenticity, its meaning, and how current philosophy and methodologies accommodate and interpret it. The characteristics of modern architecture that make achieving authenticity problematic are by now familiar.[5] Table 1 attempts to summarize these issues.[6]

Towards a concrete architecture

What makes concrete buildings from the second half of this century so much more difficult to deal with than those pioneering structures of concrete's first century?

There are in fact many concrete buildings from the early 20th Century, and even a few from the 19th, which left the structural material exposed, although they were usually engineering structures or utilitarian buildings such as bridges, factories, docks, and warehouses. Economy and the unimportance of the appearance of such buildings was the rationale for leaving the concrete unadorned. Despite a burgeoning interest in the possibilities the material had to offer, concrete did not enjoy high regard in the early years of this century.

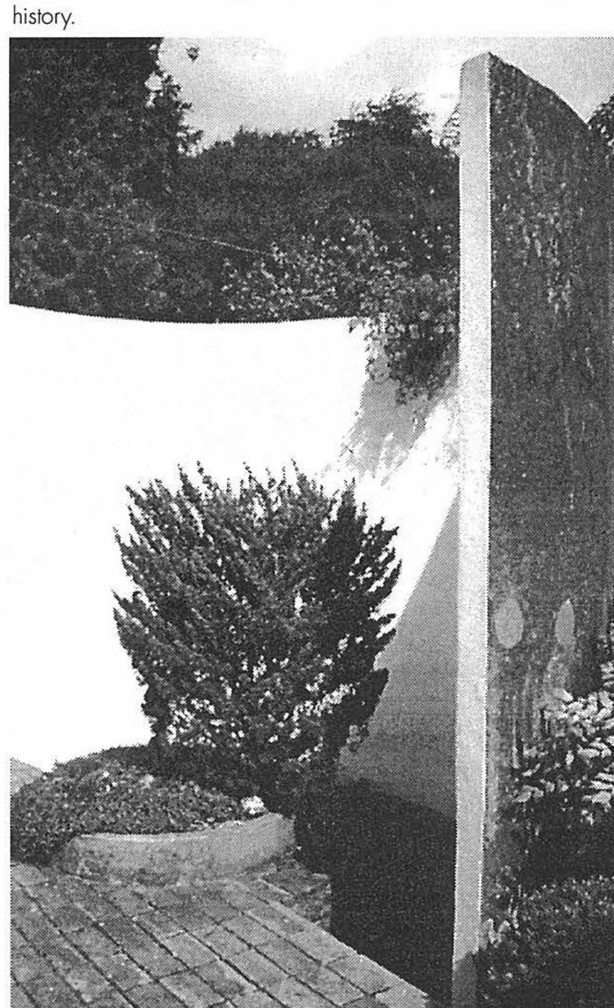
Until the 1950s most concrete buildings tended to be clad in more conventional materials, such as brick, stone, or terra cotta, thus taking advantage of concrete's structural and economic advantages but hiding what was thought of as its unacceptable appearance. There are of course exceptions: Auguste Perret's Notre Dame du Raincy on the outskirts of Paris (1923), Max Berg's Jahrhunderthalle in Breslau (1911), and Frank Lloyd Wright's Unity Temple in Chicago (1906) are all architectural icons, that are celebrated for their architectural and structural bravado.

They exploited reinforced concrete in ways that were not realized on a larger scale until well into the second half of the century.

Pristine image

In Britain there are fundamental physical differences between the pre-World War I, interwar, and post-World War II buildings, both in the use of concrete and the resulting technical problems. Despite the low cost of reinforced concrete construction, the use of a minimally skilled workforce, and opportunities for the replacement of many of the laborious site tasks through mechanization, many of Britain's early concrete buildings tended to be more carefully

The suntrap at Lubetkin's house (1936), exemplifies the modernist's use of reinforced concrete, with the walling reduced to the thinnest possible *in situ* concrete, rendered, then painted. The present owner decided to retain the back of the wall in its pre-repaired state, taking the patina as part of the building's history.



crafted, and the limited regulations that governed the material's use were more technically rigorous than in the second half of the century. Conservative recommendations as regards minimum cover to reinforcement, cement content, structural limits and the monopolies of the patentees of the various reinforcement systems that carefully controlled site work, meant that many of Britain's pre-World War II exposed concrete structures have survived relatively well.

During the interwar period in Britain the influence of the European modernists began to be felt more strongly, and the structural and architectural potential of reinforced concrete began to be exploited by more avant-garde architects.[7] Lobbying of regulatory bodies resulted in the relaxation of some of the more conservative building regulations, and the monolithic concrete and rendered structures associated with the Modern Movement began to appear where the local planning authorities would permit it.[8] The emergence of the structural engineer as part of the professional design team at this time helped lessen the control of the patented-concrete construction companies, resulting in greater freedom of expression.

However, although concrete claimed to be the new wonder material of the age, providing new structural opportunities and allowing the clean expressive language of the modernists to come to fruition, the concrete was virtually always rendered and painted. The final pristine image of the building, with its thin walls and smooth jointless surfaces, in effect denied the true aesthetic of the building's structural material.[9]

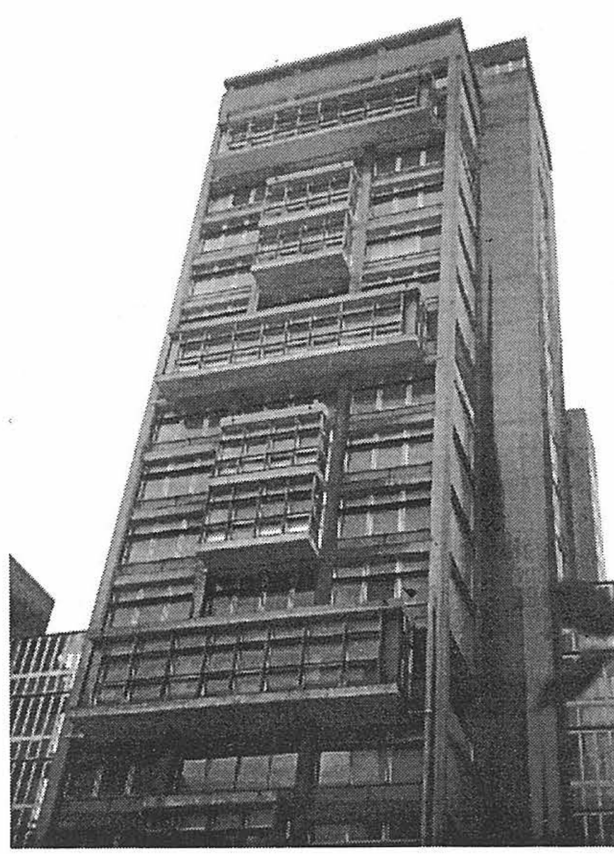
Honest expression

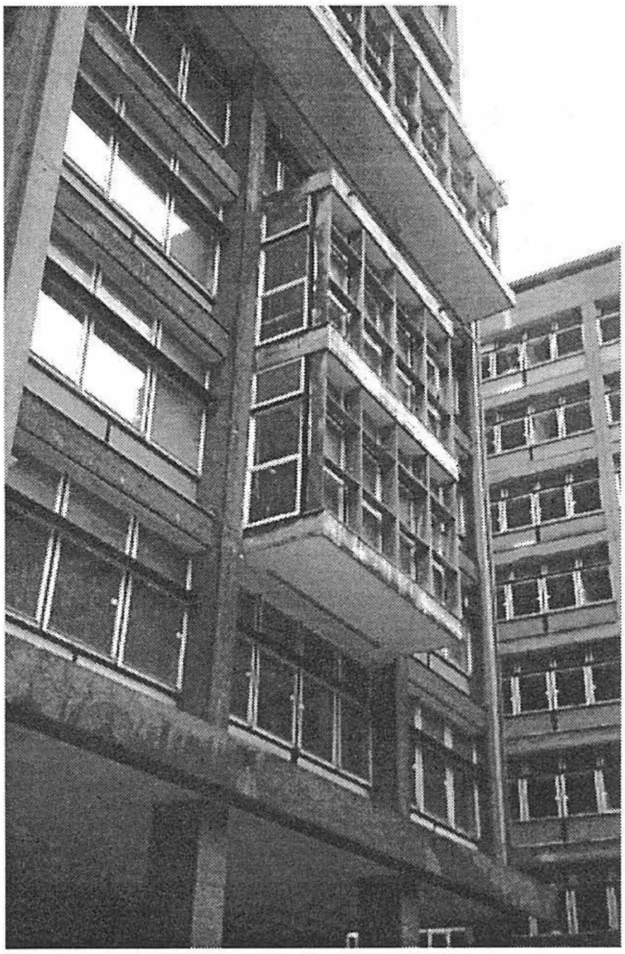
In England postwar modernism did not really begin to exert itself until the early 1950s. Adopting industrial production on a huge scale, the new architecture was able to provide larger housing projects, new towns, schools, hospitals, and public amenities. Many of the postwar exemplars of modernism in Britain followed Le Corbusier's lead at the Unité d'Habitation, where exposed concrete became a fundamental part of the language of modernism. Le Corbusier's *beton brut* emphasized the material qualities of concrete, its rawness and roughness, which impart an organic quality in a manner completely different to the careful crafting of the Modern Movement's rendered concrete buildings. The so-called New Brutalists focused on the honest expression of materials, and concrete became the undisputed material of this period, although the early material failures of the rendered concrete buildings of the Modern Movement had been recognized by the mid 1930s as being problematic, particularly in the damp English climate. Exposed concrete was accepted as the logical material to achieve modernism's aims. Economy was the principal catalyst but postwar shortages of timber and steel, the dearth of skilled labor, an unlimited supply of local raw materials, and technical developments in the concrete industry spurred its widespread use. However, these developments are today the cause of many of the problems associated with postwar concrete. Cement contents were reduced, the use of chlorides and other additives to hasten curing became widespread, the depth of cover to reinforcement specified by the official recommendations was well below what we know today to be good practice, and often poor workmanship and lack of site supervision contributed to future problems.

New techniques

By the mid-1950s the use of precast and *in situ* concrete in combination was increasingly popular. However the interwar monolithic, *in situ* method of construction had now largely been abandoned in favour of the frame-and-infill method, an important catalyst in the use of exposed concrete. Despite the interest in precast work, *in situ* concrete continued to be used extensively, either to provide entire buildings or in combination with other materials such as brick, steel, glass, and stone cladding.[10] Where concrete was exposed, board marking was the most popular and economic finish, eliminating the need for shuttering lining and finishing and emphasizing concrete's material qualities and its construction processes.

Ernö Goldfinger, Alexander Fleming House (1959-66). The complex combines a bush hammered *in situ* concrete frame with the Miesian curtain wall, granite-clad ground-floor columns, and exposed precast units. The retention of the original material aesthetic is now posing difficult conservation problems.





Alexander Fleming House suffers from the poor quality of the concrete and inferior workmanship typical of its date. The concrete required extensive patch repairs and has been coated with an opaque elastomeric coating to mask the patches and micro-cracking.

By the early 1960s the use of exposed concrete was widespread, and other means of improving the appearance of concrete buildings inexpensively were beginning to be used. Integral decorative treatment of the concrete surfaces, sandblasting, casting in patterns and profiling, acid etching, bush hammering, and applied surface treatments, such as tile and mosaic, are typical of this time. Such methods had to be cheap to implement and offer minimal maintenance. By the late 1950s construction methods had moved so far from the traditional craft-based processes of the past that even when materials such as mosaic or tile were used, centuries-tested methods of application were completely abandoned in favour of new techniques.[11]

Conservation issues

Current programs focussing on the recognition and protection of postwar heritage, both in Britain and abroad, have directed attention to the specific technical and philosophical problems posed by the conservation of concrete buildings. As appreciation grows for them cultural barriers that have inhibited progress, including lack of experience and undeveloped repair technologies to meet conservation needs, will gradually be dismantled.

Technical limits

It is the emphasis on the honest expression of concrete which is the crux of the problem in terms of material authenticity for many postwar modern buildings. The concrete surface expresses not only the conceptual and structural intention but also the detail. Here material authenticity and aesthetic authenticity are inseparable.

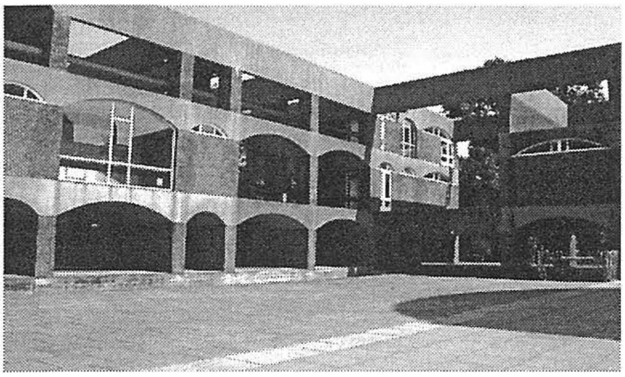
At present the repair options for decaying postwar concrete buildings (traditional patch repairs, over-spraying/rendering, the application of protective coatings, realkalization and cathodic protection) do not readily accommodate the general aims of conservation.[12] In theory all of these options have the potential for minimal intervention and retention of authenticity. However, none specifically attempts to preserve the original aesthetic, the assumption being that the structural problems are paramount and that the image of the building is unimportant or needs 'improving'.

The patentees of these systems are now beginning to be challenged, and although heritage buildings offer a very limited market, there is a slow willingness to at least acknowledge the issues. Table 2 summarizes the range of problems typical of postwar concrete, and identifies where options are inadequate.

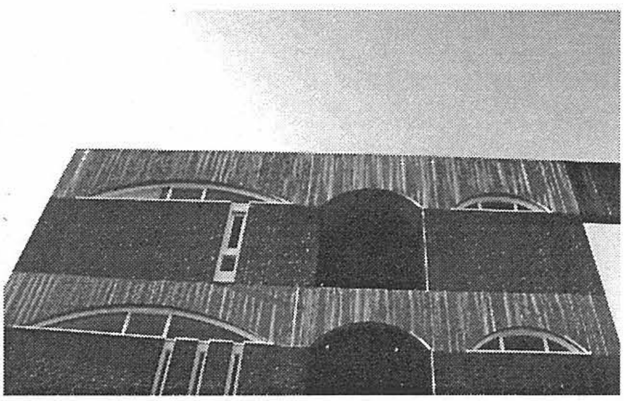
As is immediately obvious, traditional repairs (patch repairs to areas of latent and patent damage) and the use of coatings are the most intrusive methods of repair for exposed concrete buildings, and the most common. In addition, once concrete has suffered patent damage (most commonly as a result of spalling due to expansion of the corroding reinforcement), patch repair will be necessary. Realkalization, desalination, and cathodic protection are also invasive to the surfaces of concrete unless specifically designed to be carried out with minimum intervention, which may not always be possible. New corrosion-inhibitor products (which are applied as a colourless liquid to the concrete surface, penetrate the concrete, reactivating the passivating protective layer around the reinforcement and thus prevent corrosion) do appear to be one option that has no effect on the material or aesthetic authenticity of the concrete.[13] They have not yet been used on a listed building in England. Each of these options has advantages and disadvantages, and the appropriate method will depend on the specific problem, an analysis of the buildings significance, and all the usual influences affecting the site, and the budget.

Coatings

Buildings at the University of Sussex, designed by Basil Spence (from 1960) demonstrate some attempt to retain aesthetic authenticity for exposed concrete. Falmer House, which is listed Grade I and therefore subject to the most stringent conservation controls,[14] is



The board-marked concrete and red brickwork is fundamental to the aesthetic of Falmer House (1960-62). Opaque coatings have been applied to adjacent buildings, with the expressive structural concrete elements now reading as cream-painted trimmings that have no relation to the architect's intentions.



Recent concrete repairs at Falmer House have been relatively successful in matching the original concrete in the limited number of patch repairs. Improvements in the texture and placement (e.g. observing board marking lines) could improve the repairs further.

typical of Spense's use of *in situ* and precast board-marked concrete in combination with red brick to provide a rich expressive language, clearly influenced by Le Corbusier's Maison Jaoul. The buildings have been repaired using traditional repair methods followed by the application of an opaque anti-carbonation coating, which has fundamentally changed their appearance. The arguments for the use of opaque coatings or coatings of any type are that they are part of the guaranteed repair system offered by the manufacturers and that they mask the standard patch repairs, which do not match the existing concrete.[15] The recent repairs provided the opportunity to attempt a more sympathetic approach to the building's original appearance.[16]

Analysis of the areas of patent and latent damage to the concrete showed that the areas requiring patching were in fact fairly minimal and that a coating was not immediately necessary. Working with Sika, a manufacturer of concrete repair products, a palette of colour matched polymer-modified mortars was developed. Although the repairs are visible on careful inspection, they do meet conservation aims far more satisfactorily than the usual standard approach. With additional care in the placement and texturing of the patches, it would be possible to make the repairs even more discreet.

Mortar repairs to stonework can provide a useful model here; however, there is still a cultural barrier to be overcome. Most concrete repair companies are not accustomed to a conservation-led approach, and building owners may be equally bemused by the importance of the building and the level of care required by regulators. Lack of appreciation for existing exposed concrete has in fact meant that manufacturers marketing coatings have argued for improving a building's appearance through use of their product. Since the early 1980s in Britain, concrete repair has been based on proprietary bagged mixes. Matching aggregates and finishes requires more care. Ensuring good and consistent workmanship is often difficult, and with the reliance on proprietary guaranteed repair systems, contractors are reluctant to adopt a conservation-oriented approach.[17] There will always be some obvious signs of a patch repair, after heavy rain for instance (an important factor in England).

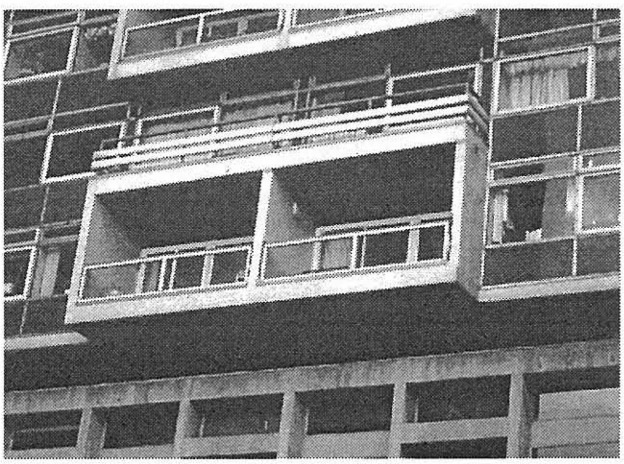
However, is it so terrible to have some signs of weathering and age on a building? Perhaps we are not yet used to our more recent buildings having a patina.[18]

The manufacturers and repair companies still require the application of a coating to complete their guaranteed system. For many building owners, a product or repair system's guaranteed performance is often the main reason for its selection. To ensure material authenticity suitable patch repair methods and unobtrusive coatings must be developed.

Methodology

There are as yet no universally accepted methodologies for the investigation and repair of concrete and other modern materials. Often the repairs are based on a cursory investigation, done as a free quote, and with little information as to the nature or the extent of the work. Concrete repair is a specialist activity. Specialist contractors are usually aligned to, or holders of, licenses for repair methods, such as desalination, realkalization, and cathodic protection. Their traditional repair method (patch repairs) virtually always uses a proprietary bagged product, bought off the shelf, with standard use requirements that are part of a guaranteed system. Conservationists rarely use standard products and argue that every building must be assessed to determine its specific problems, and to define a specific response. All too often, analysis of the problem does not identify the cause of the decay, and the action addresses the symptom and not the cause. This can often lead to inadequate repairs, that fail to recognize the qualities of the building that need to be conserved. Determining the most appropriate treatment for deteriorating concrete should follow the same approach for any historic building and needs to

include the selection of an appropriate independent consultant, information gathering (historical), physical inspection and examination, diagnostic investigation, interpretation of results by an experienced person, and selection of a repair strategy based on the analysis of the building's specific problems.[19]
The mosaic-clad apartment building that forms part of the Centrepoint complex in central London is a case in point. Proposed repairs threatened to change the appearance of the building radically and irreversibly. A concrete repair company recommended the use of an elastomeric coating over the mosaic, with the areas where the mosaic had been lost (and was no longer available) built up with render, cast with an impression of the mosaic. The justification for this solution was that the mosaic had been lost as a result of problems with the underlying concrete.

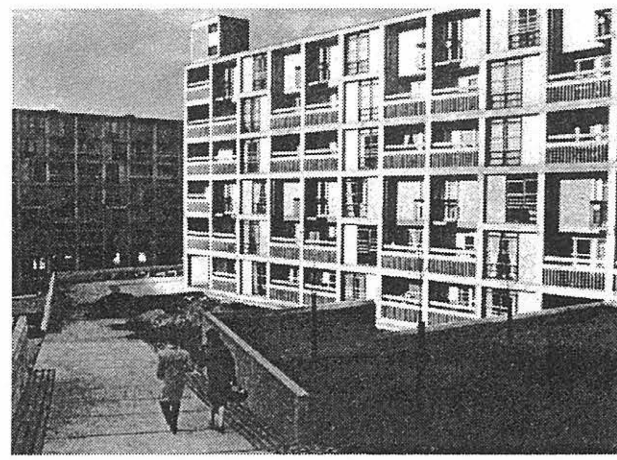


Centrepoint apartment building, Richard Seifert, 1961. The detachment of the mosaics is confined to the balcony areas, where the application method and unsuitable weathering details are unsatisfactory. Addressing the cause of the problem rather than the symptom will ensure a more acceptable result.

Following extensive discussions with English Heritage the importance of proper analysis was recognized, and suitable investigation work was initiated. This proved that the concrete structure was in fact in excellent condition, and the problems associated with the mosaic were a result of its original method of application. Much of the mosaic was still firmly adhered, and detachment was found to be confined principally to the balconies where the application problems were exacerbated by poor weathering details. It was anticipated that the proposed coating would 'waterproof' the structure, thus preventing further damage to the underlying concrete and detachment of the mosaic. The repair did not address the problems, and, in spite of the use of an etching primer, the sample coating panel proved the coating peeled off easily.
Minor structures on the roof (lift hoist and plant rooms), which are not visible from ground level, have suffered extensive loss of mosaic and potentially could supply the missing areas of mosaic for the balcony areas. Understanding the hierarchies of significance in the building was also thus important in the decision making process. Unfortunately a blanket approach to concrete repair is the norm rather than the exception. There are many other examples where coatings to concrete buildings have been recommended as a panacea without proper analysis of the specific problem, and in such instances they may be unnecessary, do not solve the technical problem, may be a waste of money, and require ongoing maintenance to retain the appearance of the building.[20]

Role of design

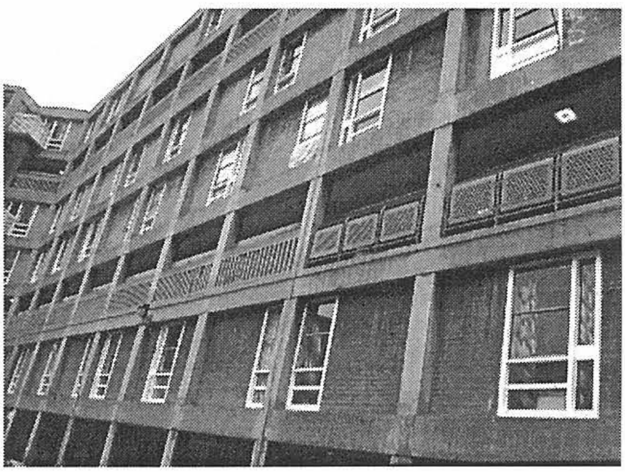
At the huge housing estate of Park Hill in Sheffield, which is under consideration for heritage protection, there are problems with the *in situ* reinforced-concrete balconies, now suffering varying levels of deterioration. Due to the potentially vast scale of the problem (there are nearly one thousand apartments), prefabricated metal replacement balconies, which could be inserted from the wide internal walkways, were designed. These could be mass produced and



One of the courts of Park Hill housing, by J. Lewis Womersley in Sheffield (1960). Photo: Roger Mayne for *Architectural Design* of September 1961.

The deck walkways at Park Hill with the original concrete balconies, which can be considered as a series of precast components. Photo: Roger Mayne for *Architectural Design* of September 1961.

would remove the necessity for scaffolding. However, they would also radically alter the buildings' appearance.
Inspection revealed that the condition of the balconies varied greatly. Some were in a very poor state, but many were in reasonably good condition, with limited elements of their constituent parts requiring attention. The balconies could be seen as a series of precast items (balustrades, support beams and uprights), which could be repaired or replaced individually. This could reduce costs. Understanding the design of the balconies and their construction, and adopting a designed solution rather than merely responding to the technical problems, has ensured a more satisfactory alternative to the metal balconies that were initially proposed.



Comparing the original concrete balconies and the proposed metal replacements at Park Hill housing. The precast balconies could be repaired or replaced as necessary. The works could be accessed from the walkways, which would alleviate the necessity for full-scale scaffolding.

Securing the future

The level of intervention depends on the extent of decay and how the decay is likely to continue, the future role of the building, and the knowledge and resources available to carry out the work. General conservation practice subscribes to the idea that the less intervention the better. At present it appears that there may be unsolvable difficulties resulting from inherent material problems as a result of these buildings' experimental or economic rationale, which may mean the fabric has a limited lifespan without intervention. Unfortunately, many postwar buildings are being irreversibly damaged in the belief that preservation means reconstruction.
This is a new area of conservation, and as yet there is little written information dealing with the technical problems.[21] Lack of experience and undeveloped repair technology are the main causes of the current predicament. Increased understanding of the many technical issues and the development of economically viable repair techniques will clarify some of the controversial philosophical issues. Research is required to surmount technical barriers and to achieve minimum intervention and retention of authenticity. Industry has an important role to play. Concrete construction has always been a contractor-led activity; the specialist contractors and manufacturers of concrete repair products need to be included in the search for appropriate, affordable repair techniques. Adopting a methodology based on well-established conservation principles is as important for postwar concrete buildings as any other. Creativity is important in determining approaches to apparently unsurmountable problems. Growing appreciation of postwar architecture and the broader consensus for its conservation will also ensure these issues are brought to the fore.
Arguments concerning authenticity will subside as less intrusive repair methods are developed and the acceptance that loss of material authenticity may, in some instances, be unavoidable due to physical problems associated with a building's design, its material make-up, or unforseen environmental influences. There is a huge legacy of postwar concrete coming up for repair. It is essential that conservation needs are included in the development of successful options for safeguarding our postwar heritage's future.

Susan Macdonald is an architect with the architectural conservation team at English Heritage. She is currently the secretary of DOCOMOMO UK.
This article is reprinted courtesy of the Association for Preservation Technology International and the author.

Notes:
1. The term exposed concrete has been used to describe concrete left as a visible surface including integral decorative finishes such as board marking, bush hammering, acid etching, profiling, and so on, to both *in situ* and precast concrete.
2. English Heritage is the organization responsible for the preservation of ancient monuments, historic buildings, conservation areas, historic gardens, and for archeology in England on behalf of the government. In addition to managing an estate of some 400 properties, English Heritage is responsible for the protection of the national heritage through the listing and legislative process, the provision of grants for repairs, and for a wide range of activities concerned with the care and conservation of 20th Century heritage. This includes technical advice, research, training, and the production of guidelines.
3. *The International Charter for the Conservation and Restoration of Monuments and Sites (The Venice Charter)*, Venice 1964.
4. Recent discussions on authenticity are summarized in the following documents:
Knut Elnar Larsen (ed.), *Nara Conference on Authenticity Proceedings*, Proceedings of Nara Conference on authenticity in relation to the World

Table 1. Reconciling authenticity with repair: philosophical difficulties for modern buildings.

PHILOSOPHICAL / PHYSICAL PROBLEM	CAUSE OF DIFFICULTY
Material failure	• Use of new materials with unproven performance records • Use of new materials without knowledge of best practice methods for use • Use of traditional materials in new ways, or in combination with new materials • Poor workmanship and quality control (new materials chosen for reasons of economy)
Detailing failure	• Lack of knowledge for best methods of detailing new materials to ensure long-term survival • Adaptation of traditional materials to new detailing to achieve aesthetic
Outmoded production	• Rapid development of materials and equally rapid supersession of materials • Use of environmentally unfriendly materials now banned • Lack of salvage industry yet established for modern buildings
Maintenance failure	• Naivete regarding maintenance requirements for new materials and building systems • Failure to implement maintenance recommendations
Patina of age	• Comparative accelerated aging of modern architecture • Short-term performance of modern materials • Unrecognized nostalgia for aging modern buildings • Material problems for deteriorating modern buildings
Design and functionalism	• Adaptation for new spatial and planning requirements (open plan and glazing expanses) • Upgrading for modern environmental performance requirements (energy conservation) • Health and safety requirements • Large scale of some modern buildings
Lifespan	• 'Throwaway architecture', intentionally designed for short lifespan • Poor technical performance of materials and systems • Economic viability • Recording as a valid form of conservation
Cultural circumstances/position on the time line	• Lack of recognition/appreciation for modern buildings • Poor understanding of 20th Century architecture (incomplete histories) • Lack of experience • Lack of knowledge of modern materials and their performance over time • Lack of knowledge of repair systems in the longer term • Undeveloped repair methods to meet conservation aims • Availability of resources (expertise, financial and salvage material) • Presence of the original architect (wish to restore and improve)

Table 2. Typical reinforced concrete decay problems for postwar buildings, current repair options, and conservation dilemmas

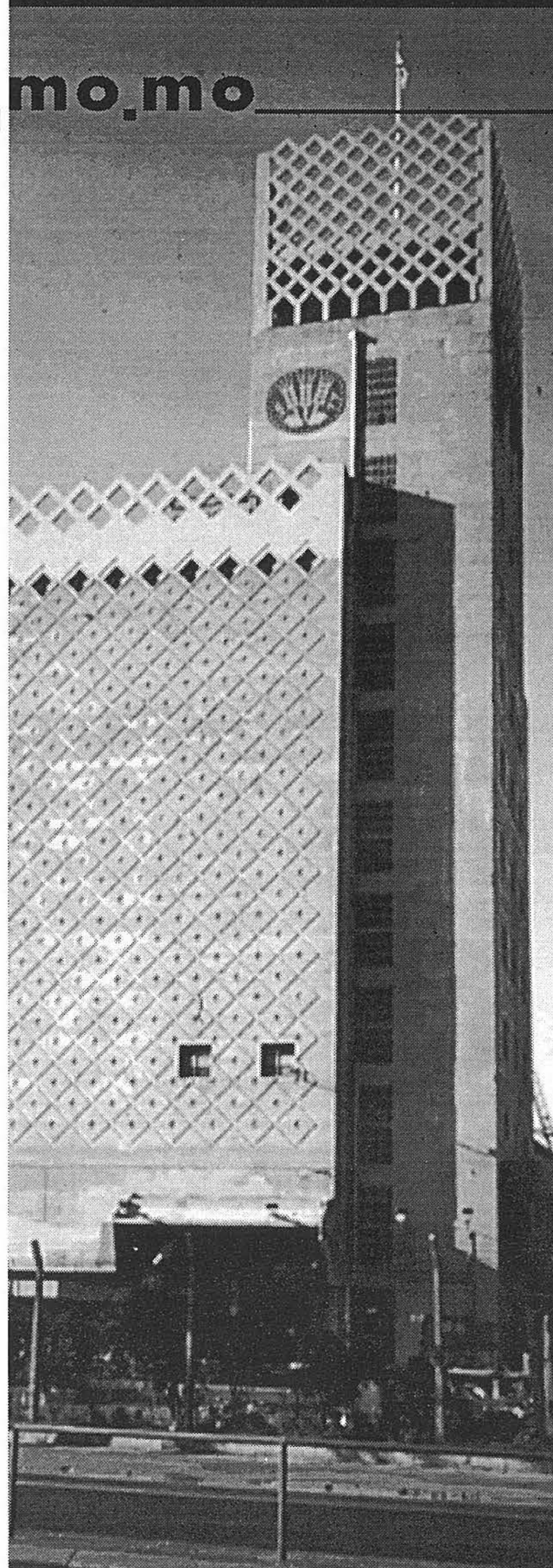
CAUSE OF DECAY	MANIFESTATION	REPAIR SOLUTION*	CONSERVATION DILEMMA
1.0 Inherent material problems			
1.1 Low cement content and Finely ground cement	Highly permeable concrete: poor durability leading to reinforcement corrosion	Traditional repair and coating Realkalization and coating Cathodic protection Corrosion inhibitor Sprayed cementitious over coating/render	Loss of original material, change in appearance (unless patches match original concrete), coating changes surface appearance Some physical damage from application of process, coating changes appearance Potentially none Potentially none New surface to building
1.2 High alumina cement	Gradual loss of strength leading to structural failure	No cure	
1.3 Poor-quality aggregates: - Impure aggregates (unwashed sea sands) - Poorly graded/shaped aggregates	Poor durability Chloride attack Poor workability, high water/cement ratios leading to poor durability and reinforcement corrosion	Desalination As 1.1	Some physical damage from process As 1.1
1.4 Alkali aggregate reaction	Concrete breakdown	No cure	
1.5 Presence of calcium chloride additives in mix	Chloride attack	Cathodic protection or Desalination	Potentially none Some physical damage from process
1.6 Creep	Structural failure Surface cracking	No cure Crack filling	Aesthetically intrusive unless fillings match original concrete
1.7 Decorative finishes: - Acid etching - Bush hammering /surface profiling	Reduced alkalinity of concrete, increasing susceptibility to reinforcement corrosion Reduced cover to reinforcement	Cathodic protection or Realkalization As 1.1	Potentially none Some physical damage from process As 1.1
1.8 Poor quality/lack of reinforcement, scrap and inconsistent type	Different levels of cover Structural failure	As 1.1 No cure	As 1.1
2.0 Environmental influences			
2.1 Acid gases	Poor durability leading to reinforcement corrosion	As 1.1	As 1.1
2.2 Air and moisture	Poor durability leading to reinforcement corrosion	As 1.1	As 1.1
2.3 Freeze thaw	Poor durability leading to breakdown of concrete	Coating Sprayed cementitious over coating/render	Coating changes appearance New surface to building
2.4 Sea water	Chloride attack	Cathodic protection and/or Coating	Potentially none Change in appearance
2.5 Road salts	Chloride attack	Cathodic protection and/or Coating	As 2.4
2.6 Sulphate attack	Concrete breakdown	Coating	Change in appearance
3.0 Poor design and workmanship			
3.1 Lack of cover to reinforcement/placement	Poor durability leading to reinforcement corrosion	As 1.1	As 1.1
3.2 Remote site batching - poor mix quality	Poor durability leading to reinforcement corrosion	As 1.1	As 1.1
3.3 Inadequate control of water content	Poor durability leading to reinforcement corrosion	As 1.1	As 1.1
3.4 Inadequate curing	Cracking, loss of strength, and poor durability	Crack filling and elastomeric coating	Change in appearance
3.5 Inadequate compaction/vibration	Cracking, loss of strength, and poor durability	As 3.4	As 3.4
3.6 Plastic shrinkage	Cracking, loss of strength, and poor durability	As 3.4	As 3.4
3.7 Accessibility for maintenance	Lack of maintenance	Dependent on how manifested	
3.8 Design faults	Water ponding, choice of fixings of attached materials, weathering details, etc.	Improvements to detailing	May involve alteration to building's appearance

Heritage Convention, Nara, 1-6 November 1994 (UNESCO, ICCROM, ICOMOS, 1995); J. Jokihleto and H. Stovel, 'The Debate on Authenticity', *ICCROM Newsletter*, nº. 21, July 1995, pp. 6-8; B. Feilden and J. Jokihleto, *Management Guidelines for World Cultural Heritage Sites*, Rome 1993, pp. 59-76.

5. See Thomas Jester and Susan Bronson, 'Mending the Modern: A Selected Bibliography', in *APT Bulletin. The Journal of Preservation Technology*, Vol. XXVIII, no 4, pp. 59, for more key references on the subject.
6. Table 1 is a summary of the issues as discussed in S. Macdonald, 'Reconciling Authenticity and Repair in the Conservation of Modern Architecture', *Modern Matters*, pp. 87-100.
7. The arrival of a number of architects from continental Europe (such as Berthold Lubetkin, Walter Gropius and Ernö Goldfinger), who had direct experience in the experimental use of reinforced concrete within the modernist oeuvre, helped stimulate this. Amyas Connell (later of Connell Ward and Lucas) established his own architectural/building firm and went on to build a number of seminal modern concrete houses in England.
8. In Britain the modernists developed a monolithic poured-panel-and-slab method of construction, which enabled building joints to be reduced to a minimum and reduced wall thicknesses to as little as 2 inches in some cases.
9. There are now reasonably well-established means of coping with the repair of interwar, typically rendered concrete buildings that do retain these smooth jointless finishes and thus the aesthetic authenticity of the building relatively well, although often at the expense of the original material.
10. The two-man weight limit on lifting equipment restricted the use of large-scale prefabricated components until the 1960s in Britain. In addition, the association of precast concrete with the temporary housing of the immediate postwar period had established it as a low-status material, a perception which took some time to shift.
11. A paper discussing English Heritage's research into mosaic-clad concrete and the options for its repair will be published in *English Heritage Research Transactions*, Volume III, in 1997. It will be available from: English Heritage, Architectural Conservation, 23 Savile Row, London, W1X 2AB, United Kingdom.
12. For a general explanation of concrete decay phenomena and repair options see: J. Allan, 'The Conservation of Modern Buildings' in E. Mills, *Building Maintenance and Preservation: A Guide to Design and Management*, Oxford 1994; for more detailed information see: P. Pullar-Strecker, *Corrosion Damaged Concrete: Assessment and Repair*, London 1987.
13. For an explanation on corrosion inhibitors see: J. Broomfield, *Corrosion of Steel in Concrete: Understanding Investigation and Repair*, London 1997, pp. 104-106.
14. Grade I listed buildings are subject to listed building consent for any works deemed to alter the character of the building including internal works.
15. Opaque coatings due to the presence of pigments offer better long-term protection against carbonation than clear versions.
16. The repairs to Falmer House were broken down into four phases of work, of which this is the first.
17. There are limitations associated with patch repairs, and there are instances where other repair methods for areas of latent damage will be more appropriate.
18. For an interesting discussion on the weathering of buildings see: D. Leatherbarrow and J. Mostafari, *On Weathering: The Life of Buildings in Time*, Cambridge 1993.
19. The methodology developed at English Heritage is outlined more fully in: S. Macdonald, 'Conserving Carbuncles, the Dilemmas of Conservation in Practice: an Overview of Current English Heritage Advice and Research for Twentieth-Century Buildings' in M. Stratton (ed.), *Structure and Style*, London 1997, pp. 207-224, and 'Technical Responses to Typical Conservation Problems for Postwar Architecture in England: Current Research and Case Studies from English Heritage' in *Conference Proceedings, Fourth International DOCOMOMO Conference*, Bratislava 1997.
20. This is not to say that coatings do not often play an important role in a repair strategy; however, the decision to use a coating and determine which coating is most appropriate should be made in response to a building's particular problems. There are other repair methods (such as cathodic protection), which may provide viable alternatives.
21. Most information to date is contained within conference proceedings and is often case-specific. See for instance the 1990, 1992, 1994 and 1996 DOCOMOMO International Conference Proceedings, and various articles in the DOCOMOMO Journals since 1990. For lists of key texts see T. Jester and S. Bronson (note 5) and J. Allan (note 12).

DIAGNOSE AND REMEDY

do_co_mo_mo



Concrete diagnose

Failure and repair of reinforced concrete

Architects and conservation officers are increasingly confronted with exposed concrete surfaces in recent architectural heritage, which are compromised by visible damage. In terms of architectural characteristics their primary concern is to restore the expressive qualities of the concrete, for which various methods are available today. In order to select the most appropriate repair strategy, it is essential to understand the main principles of the underlying mechanisms of deterioration. Anthony van den Hondel presents the common types of failure found in reinforced concrete, and compares the available options for repair.

by Anthony W.M. van den Hondel

The most important threats for the durability of concrete constructions are, in random order:

1. Chemical attack of the concrete.
2. Physical attack of the concrete.
3. Electro-chemical attack of the reinforcement steel, causing secondary deterioration of the concrete.
4. Construction errors.
5. Calamities.

Categories 1. and 2. are being taken together as direct causes of deterioration of the concrete itself. Category 3. represents the most widespread cause of concrete deterioration. This attack mechanism operates in an indirect way and eventually leads to rebar corrosion. The expanded corrosion products are the immediate cause of concrete deterioration through spalling.
Category 4. involves errors and flaws in design, construction and usage (failure or deterioration due to, for example, poor construction techniques or inadequate workmanship). Category 5. involves calamities like damage caused by fire, overload or collisions with transportation vessels. The last two categories are not relevant for this paper.

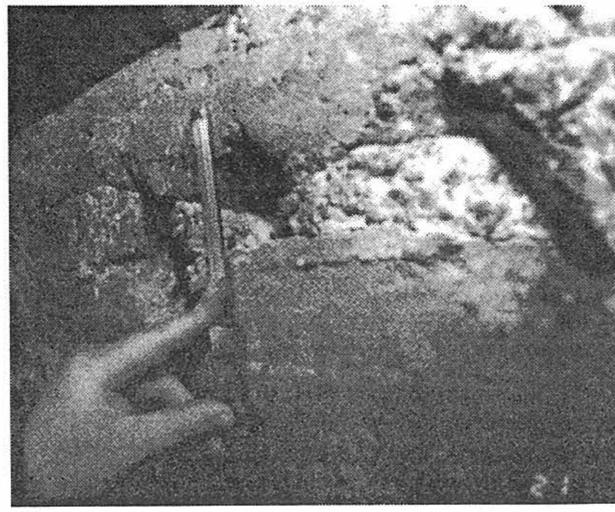
Direct attack of concrete
The locus of causality of the chemical or physical attack of concrete can be placed internally or externally with respect to the material. An external cause of attack can be either chemical or physical and is initiated out of the construction's environment. An internal cause of attack is always a chemical threat where the 'aggressive' species are present as of construction, that is 'from day one'. Chemical attack mechanisms include:
Alkali Aggregate Reaction - AAR concerns a reaction

Petrographical analysis is used to diagnose the occurance of Alkali Silica Reaction and ettringite formation. It can also determine the susceptibility for future occurrence of these reactions. Photo: NEBEST bv.

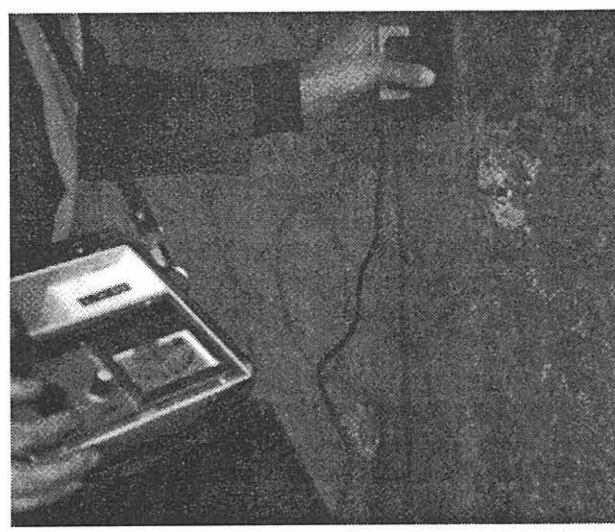
of chemical species (alkalis: sodium and potassium) with susceptible aggregates. The most important form is called ASR, short for Alkali Silica Reaction, where low-crystallinity silica modifications, like chert, react with the alkalis to form silica gel. The expansive reaction of the gel with water can cause concrete deterioration. This process mostly occurs as a result of internal causes, but penetration of alkalis from deicing salts can be considered an external cause, which is fairly rare in architectural constructions and therefore not further elaborated in this paper.
Ettringite formation - A reaction of chemical species (gypsum) with specific clinker (C3A) from the cement. The reaction product, ettringite, is a highly expanded substance causing concrete deterioration. Ettringate formation mostly involves internal causes, but penetration of sulphates can be considered an external cause. The water consumption with this reaction is typically very high and therefore this attack mechanism is only seen with very humid -e.g. continuously wet- constructions, which are uncommon for architectural structures and therefore not further discussed in this paper.
Acid attack - This involves a reaction of the concrete with acids from the environment resulting in a dissolution of the cement stone by the acid and total degradation of the concrete. This attack mechanism is always due to external causes and only seen in industrial environments and sewers, and therefore not further discussed in this paper.
Physical attack mechanisms are always external causes of concrete deterioration and include:
Wear and erosion - Wear and erosion are caused by mechanical loading of the concrete surface inducing, on a micro scale, tensile forces above the strength of the concrete. This mechanism always involves external causes. This attack mechanism is only seen in heavy-load situations or industrial piping and therefore not further discussed in this paper.
Frost damage - Freezing water will become ice involving an expansion of volume by 9%. This can cause concrete deterioration when occurring inside of the concrete but is, in its pure form, rather rare in the Netherlands. In combination with penetrated deicing salts there is a risk of lock up of water in between two layers of 'frozen' concrete. On subsequent phase transition of the locked-up water, spalling could occur. This mechanism always involves external causes. It can be avoided by usage of correct concrete mixtures during fabrication, including special consideration to the water-to-cement ratio which needs to be limited to a maximum of 0.45 or 0.55 in presence of air entraining agents.

Indirect attack of concrete

Differentiation between an internal or external locus of causality with respect to the concrete can be made for indirect attack mechanisms, as done with the direct mechanisms, only the distinction between the two is less useful in this case. The indirect attack of



Exposed reinforcement steel and rebar corrosion as a consequence of acidification of the rebar environment caused by carbondioxide penetration (carbonation). Photo: NEBEST bv.



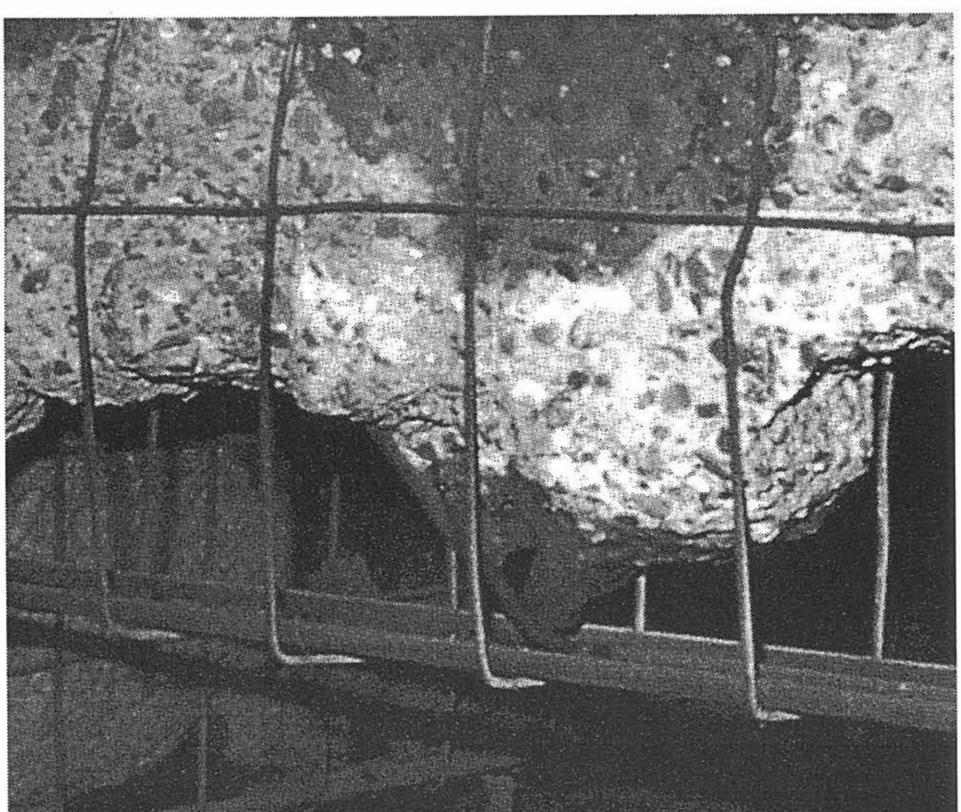
Investigation of advancement of carbonation fronts under the surface, and chloride content of the concrete.
Photo: NEBEST bv.

concrete is always due the external causes with exception of the presence of bound-in chlorides, mostly added as calciumchloride (CaCl2) as an accelerating additive for cement hydration. The tolerance for chlorides in new constructions in the Netherlands is presently limited to 0.4 weight % relative to mass of cement, which is considered to be a safe limit for concrete durability.
Reinforcement steel in concrete is well protected against corrosion. On the one hand the concrete cover itself is a barrier to chemical processes. On the other hand the high alkalinity of the concrete environment, with pH values of typically 13, is ideal for the steel. The reinforcement is covered with a thin layer of iron-oxides and hydroxides which prevent the iron substrate from further corrosion -the so called passive layer or film. The speed of corrosion of steel in normal concrete is therefore not relevant. Nevertheless, the protective environment can change into a relatively aggressive environment either by

penetration of chlorides -mostly from sea water, sea breeze or deicing salts- or by the penetration of carbondioxides from the atmosphere. The carbondioxide effectively neutralizes the high alkalinity of the concrete after which the pH drops to values below 10. After the 'neutralized' zone has reached the rebar the passive film becomes unstable and corrosion activity starts. The presence of chloride ions in the pore water solution near the rebar also causes instability of the passive film, even at high pH values.
When the rebar actively corrodes, the steel is transformed in iron-oxides and hydroxides (rust). The corrosion products are expanded as compared to the original steel volume, and therefore induce tensile stresses in the concrete. After a certain amount of corrosion products have formed, the concrete starts cracking and eventually spalling can occur. Due to the corrosion-initiated concrete deterioration the aesthetical demands for the construction are no longer met. Furthermore, the concrete cover is damaged and effectively removed and the reinforcement steel is damaged, resulting in an effectively reduced diameter of the rebar which eventually can cause the construction to mechanically fail even with a 'normal' load.

Concrete repair

With corrosion-initiated concrete deterioration, traditional concrete repair is essentially aimed at restoring the structural integrity and reassuring the protection of the reinforcement steel, thereby arresting further development of concrete deterioration. Defective concrete -either material near the rebar contaminated with chlorides above a certain threshold level or concrete covering that is carbonated up to or beyond the rebar- is removed by cleaning the reinforcement steel and concrete surface, recasting the concrete section and taking preventive measures against new concrete attack. This can be achieved by coating the surface, applying extra layers of concrete cover at certain surfaces, or usage of polymer concrete repair materials. Evidently the visual quality of the surface is not a primary objective in such a case. When the aesthetical aspects matter, as is the case with works of architecture, this traditional approach is no longer adequate.
Three relatively new techniques, which are based on the idea to eliminate the main cause of damage by reversing the electro-chemical process of corrosion, have been tested and used for the past two decades. These so called electro-chemical repair methods have proven to be able to solve this problem, and are:
Cathodic Protection (CP) - By applying an anode and an electrical current from the anode to the reinforcement steel the corrosion is arrested. CP is a very effective way to stop corrosion with a permanent system, but the anode and electrical wiring are not supposed to alter the visual quality of the construction. Therefore CP has a limited applicability to architectural works: only for those constructions which can be protected from a non-visible side CP can be used.
Chloride Extraction (CE) - Also called chloride removal or desalination, this method is effective when penetration of chlorides is the cause of rebar corrosion. Through application of a temporary anode system an electrical current is applied from anode to



Traditional repair methods typically involve complete removal of all defective concrete behind the rebar. It is mostly a very severe measure that compromises the integrity of the material. Photo: NEBEST bv.

the reinforcement steel. Due to the electrical current, negatively charged ions, like chloride, move to the external anode and are removed with the anode system after treatment. Typically the treatment will take 4 to 8 weeks. The system is technically very similar to CP but the used current densities are approximately a hundred times higher, and the system is only installed temporarily.
Realkalisation (RA) - When carbonation of concrete is the cause of rebar corrosion RA is effective. Through application of a temporary anode system an electrical current is applied from anode to the reinforcement steel. Due to the electrical current, positively charged ions, like sodium, move to the reinforcement steel where hydroxyl ions are formed, in effect forming NaOH which will typically increase the pH at the rebar to values of 14 or higher. Typically the treatment will take 1 to 2 weeks. The system is technically very similar to CP but, again, the used current densities are approximately a hundred times higher and the system is only temporary.

Conclusions

Chloride extraction and realkalisation are obviously interesting techniques for repair of works of architecture, but even more these techniques have proven to be efficient and cost effective in some cases were 'traditional' repair would have meant general surface chiselling and major concrete repair. Furthermore, these techniques provide optimal durability with minimal annoyance from vibrations, dust, noise and so on. For concrete repair of architectural works chloride extraction and realkalisation are important maintenance techniques which can arrest rebar corrosion without altering the visual appearance of the construction.

Anthony W.M. van den Hondel is a consultant with NEBEST bv, an engineering and consultancy firm in Groot Ammers, the Netherlands.

Preserving more... by doing less!

Principles of electro–chemical concrete repair

Over the years the use of electro–chemical concrete repair has gained an increasing market share, particularly for constructional works such as bridges, motorways and parking garages. Because of its electro–chemical nature this technology allows for deactivation of ongoing reinforcement corrosion with minimum noise and dust, and thus causes minimal disruption to the surroundings. Since only already cracked, spalled or delaminated concrete needs to be broken out and replaced, the extent of patch repair is limited and, hence, most original and mechanically sound concrete can be preserved. This relatively new and sophisticated technology seems to provide excellent opportunities for the conservation of authentic exposed concrete in recent architectural heritage.

by Guri E. Nustad

A majority of concrete damage originates in corrosion of the reinforcement, through the strong expansion of corroding steel that causes the concrete to spall and eventually disintegrate. In principle, there are three ways of addressing corrosion problems in reinforced concrete:

- Isolation: i.e. by separating the reinforcement metal from the surrounding electrolyte, which is effectively a corrosive environment.
- Immunization: i.e. by creating an environment where corrosion can not occur.
- Passivation: i.e. by creating an environment where a corrosion reaction produces a corrosion protective oxide film on the metal surface.

Carbonated and/or chloride contaminated concrete suffering from reinforcement corrosion has traditionally been repaired by replacing the contaminated concrete with alkaline and chloride free concrete mortar. Traditional concrete repair falls into the third category listed above.

Electro–chemical remedial techniques most commonly applied to reinforced concrete structures today are those of *cathodic protection* (CP), *realkalisation* (RA) and chloride extraction (CE).
The latter is also known as chloride removal, but is mostly referred to as *desalination*. Cathodic protection falls into the second category of addressing corrosion problems, while realkalisation and desalination both fall into the third category. The key differences between these techniques are summarized in the above scheme.

Method	Halting rebar corrosion by	Applied current density	Treatment time	Main control of achievement
CP	Sacrificial anodes	None	Continuous	Measurements of corrosion activity of the sacrificial anodes
	Impressed current	5-10 mA/m^2 steel	Continuous	Potential measurements between rebar and probes
RA	Increasing the alkalinity	1A/m^2 concrete	5-7 days	pH indicator and analysis of concrete samples
CE	Removal of chlorides	1A/m^2 concrete	4-8- weeks	Chloride analysis of concrete samples

Cathodic protection

Cathodic protection using sacrificial anodes has been known for more than 150 years, but it is only recent that sacrificial anodes have come into use for submerged reinforced concrete. As the name indicates, anodes are installed to corrode, i.e. to be sacrificed, so that corrosion of other materials is prevented.

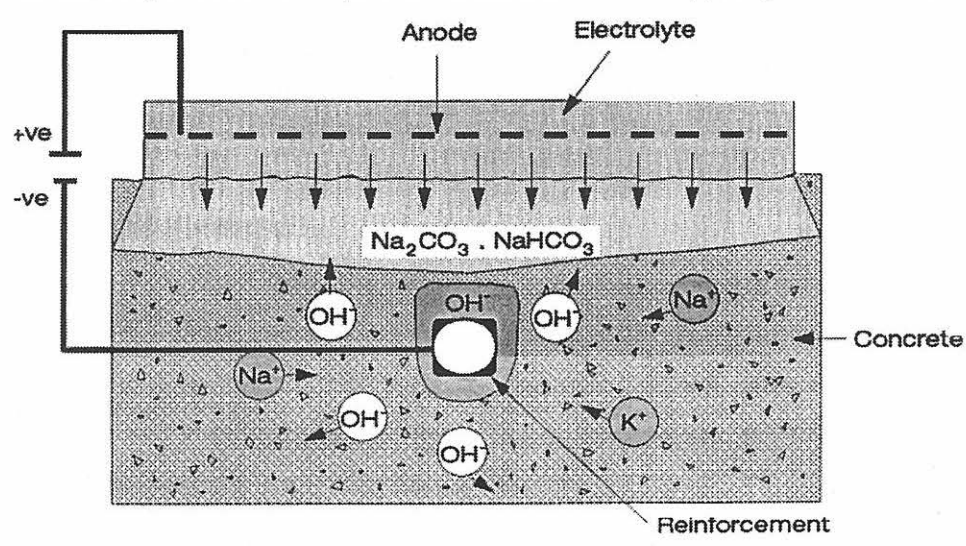
Another well known electro–chemical remedial technique for reinforced concrete structures is cathodic protection, using impressed current. This technology has been recommended for reinforced concrete structures already since 1977.[1]
A variant of impressed cathodic protection, using a lower current density, may as well be applied on new concrete structures as a preventive measure against corrosion. Cathodic protection is a permanent installation, which so far has been applied to some 500,000 m^2 of corroding concrete structures in Europe. Cathodic prevention has been applied to about 140,000 m^2 of new concrete structures.[2]
Realkalisation and desalination have been used commercially since 1987.
During the first year, 400 m^2 of concrete were realkalised and 60 m^2 desalinated. In 1996 alone, about 40,000 m^2 were realkalised and about 15,000 m^2 desalinated. By the end of 1996, a total of more than 200,000 m^2 had been treated with these methods.

Realkalisation

Carbonation occurs as a result of carbondioxide in the air reacting with calciumhydroxide in the cement mortar. As a result, the pH of the concrete pore water is reduced and the concrete's natural protection of the reinforcement steel against corrosion is broken down. Since the carbonation reaction itself increases the concrete's strength, the idea emerged to re–establish the alkalinity of the concrete pore water without removing the carbonated concrete itself. In the mid–1980s, investigations were carried out to identify various possibilities of regaining lost alkalinity by:

- Diffusion and adsorption of an alkaline solution into the concrete.
- Production of hydroxyl ions (OH^-) inside the concrete.
- Electro–osmotic transport of alkaline solution into the concrete pores.

Diffusion and adsorption depend upon concrete porosity and humidity. The two latter mechanisms require the application of an electric field. Production of hydroxyl ions depends upon the resulting current flow, while electro–osmotic transport depends upon the strength of the electric field applied.
Several electrolytes were tried. It is beyond the scope of this article to describe the investigation program, but as a result, alkalinity was found to be efficiently regained by transporting a sodiumcarbonate solution into the concrete pores under the influence of an electric field.
Being an easily soluble alkaline buffer, readily available, inexpensive and easy to handle on site, sodiumcarbonate immediately became the preferred electrolyte for regaining lost alkalinity and, so far, it has been used on all commercial realkalisation projects.
Realkalisation is performed by applying an electric field between the reinforcement steel in the concrete and an anode embedded in an electrolytic reservoir, which is temporarily placed on the concrete surface. During treatment, the alkaline electrolyte is transported into the carbonated concrete. In the diagram this is symbolized by a penetrating front. Simultaneously, electrolysis at the reinforcement surface produces hydroxyl ions (OH^-), symbolized by the ring around the reinforcement, while free sodium (Na^+) and potassium (K^+) ions in the concrete migrate towards the steel. These mechanisms increase the alkalinity in the carbonated pore water sufficiently to re–establish passive conditions of the reinforcement, typically within one week of treatment.



The principle of realkalisation. Diagram by FOSROC NCT.

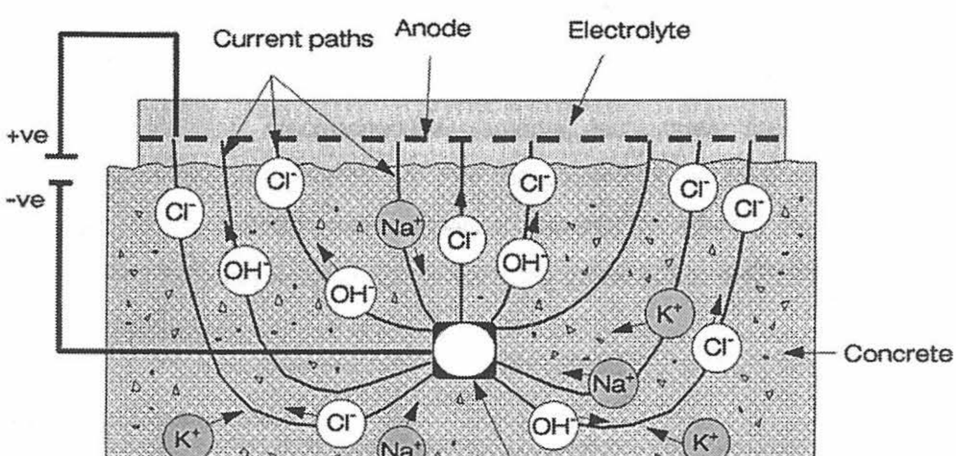
Desalination

In the early 1970s, chloride induced corrosion was recognized as an extensive and serious cause of deterioration of concrete bridge decks in the USA. As a consequence, possible methods to halt and prevent such damage were investigated. Lankard[3] and his team, for example, removed large amounts of chlorides within 24 hours under the application of a 100 VDC electric field. Due to the large amounts of energy required the method was not, however, considered feasible and work in this field was halted.

In the mid 1980s, on experimenting with a method to measure chloride diffusion in concrete, it was noticed that chloride ions can penetrate concrete rather quickly under relatively low voltages. Thus, the idea of extracting chloride ions rapidly by reversing the polarity was conceived. Laboratory tests proved successful and during the winter of 1987–88, this technology was applied on the soffit of an indoor swimming pool. The results were encouraging, with a considerable reduction in chloride content within 8 weeks of treatment.

As in realkalisation, desalination is performed by applying an electric field between the reinforcement in the concrete and an anode embedded in an electrolytic reservoir and temporarily placed on the concrete surface. The main practical differences between these methods are the electrolyte, the anode material and the treatment period.

During treatment, the chloride ions (Cl^-), being negatively charged, are repelled from the reinforcement surface and are moved out of the concrete as symbolized in the diagram by the current paths. Simultaneously, electrolysis at the reinforcement surface produces hydroxyl ions (OH^-) which increase the pH level in the surroundings of the reinforcement, while free sodium (Na^+) and potassium (K^+) ions migrate towards the reinforcement. These mechanisms are then sustained until the chloride content of the concrete has been reduced sufficiently to avoid reinitiation of reinforcement corrosion, which typically requires some 4 to 8 weeks of treatment.



The principle of desalination. Diagram by FOSROC NCT.

Practical application

Realkalisation and desalination can be performed under all weather conditions as long as the electrolyte does not freeze. These techniques are suitable for most types of reinforced concrete, but are not necessarily universally applicable. Prestressed and post–tensioned structures and any concrete with unusual characteristics require thorough investigation to assess suitability.

Structures that have been realkalised include facades of office blocks, facades and balconies of apartment buildings, water towers, and various structures with a special architectural significance, amongst them an increasing number of listed buildings. Desalination has typically been used for concrete columns, decks and soffits of bridges, abutments and car parks. Compared to other electro–chemical remedial techniques, a major technical advantages of realkalisation and desalination is that the causes of the reinforcement corrosion are removed within a defined treatment period.

The effect of the treatments is easily monitored and documented by analysis of concrete samples taken out at defined test locations before and after treatment. In addition, all electro–chemical repair techniques even halt corrosion at undetected locations.

It is important to realize that the nature of traditional concrete repair requires breaking out and replacing all contaminated concrete, also when mechanically sound, whereas with electro–chemical techniques the replacement of authentic material is limited to only those areas that are already cracked, spalled or delaminated. The risk of inducing micro–cracks during extensive break–out of concrete is reduced at the same time. In terms of architectural preservation electro-chemical remedial technology therefore offers new opportunities, that might help to maintain our cultural heritage for the future.

Guri E. Nustad is a corrosion engineer and international project manager at FOSROC NCT in Oslo, Norway.

Notes:

1. J.B. Vrable, 'Cathodic Protection of Reinforced Concrete Bridge Decks: Laboratory Phase', *NCHPR Report Nº 180, Transportation Research Board*, Washington 1977.
2. Cost 509, 'Corrosion and protection of materials in contact with concrete', Workshop, Edinburgh 1996.
3. Lankard et. al., (Federal Highway Administration, Office Research & Development), *Neutralization of chloride in concrete*, Washington 1975.

Durability of electro-chemical repair

Evaluation of a trial project in the Netherlands

Realkalisation is based on the principle to arrest and reverse the electro-chemical corrosion process by reinstalling the alkalinity of the concrete mass. An everyday apartment building is presented in this paper to illustrate the possibilities and particularities of realkalisation in practice. Two different realkalisation systems were used on galery soffits about six years ago and served as a case for a major research program on the durability of these repair methods which is now nearly completed. The results are evaluated here in a consultant's perspective, involving the quality performance and cost effectiveness of realkalisation.

by René G.J. Ackerstaff

The services provided by our company High Tech Contracting (HTC) are a combination of engineering and contracting in electro-chemical concrete repair. Our firm takes responsibility for all aspects of a work, from advance investigation and design, to process control, execution and monitoring. HTC does not only repair patches of concrete but provides complete systems to prevent corrosion and concrete damage to entire structures or building components. Ensured guarantee for ten years is standard.

A network of concrete repair contractors is supported by our engineers in executing electro-chemical repair work. Apart from the engineering support, we provide special equipment and materials to contractors. In line with the electro-chemical treatments carried by HTC, our firm uses a variety of testing methods, most of which are of a non-destructive nature. Major testing methods, such as Bloodhound potential mapping and RCT-Germann chloride testing, are represented by our firm for the Dutch market.

Typically, work is executed in co-operation with specialized concrete repair contractors though occasionally, HTC is commissioned directly by owners or building managers.

At present, we are involved in a major research program on the efficiency and durability of the *Norcure* electro-chemical repair methods, which is nearly completed. The mostly positive conclusions will be presented in a report and a practical recommendation. This paper is an introduction to some of the findings of that evaluation research.

Electro-chemical repair

Corrosion of reinforcing steel is an electro-chemical process in which steel, water and oxygen exchange electrons. Locally, the steel rebars act cathodic though at some other locations the steel serves as an anode, which is where the steel corrodes. Electro-chemical concrete repair is based on the principle to arrest and reverse this corrosion process. The repair methods can be distinguished in Cathodic Protection (CP), Realkalisation (RA) and Desalination or Chloride Extraction (CE). Both realkalisation and desalination are patented methods by NCT/Fosroc, and are available through a network of licensees.

Cathodic protection - CP forces the reinforcing steel into a cathodic potential level by using a durable external anode. This way a sufficient potential can be created at the reinforcing steel to arrest and prevent corrosion. CP is useful for constructions where extensive risk of corrosion damage is anticipated. It can be used before damage occurs to prevent corrosion in certain environments. CP is the only effective alternative against corrosion caused by bound-in chlorides, even at high concentrations. Different types of CP systems include:

- Half conducting cables embedded in shotcrete.
- Titanium mesh covered with shotcrete or mortars.
- Drilled-in anodes.
- Conductive mortars and coatings.

Conductive coatings, like the *Thoro CP anode 30* by HTC, are most commonly used in The Netherlands. Around thirty CP works have been realized so far and more are to follow.

Realkalisation - RA proves to be an economic solution in most cases when carbonation is the cause of corrosion. With a special installation a current of about 1 Amp/m2 is impressed on the concrete through an electric field between the surface and the reinforcement bars. In the concrete and particularly around the steel, electro-chemical reactions restore the alkalinity within a few days.

Desalination - CE extracts chlorides from the concrete with a similar installation. This process takes some more time than realkalisation. Depending on the initial chloride concentration, it can take several weeks to arrive at a safe level of chlorides inside the material. Since the process of desalination is most effective between the reinforcement steel and the concrete surface, it is most suitable for the extraction of ingressed chlorides due to, for instance, sea spray or deicing salts. The extraction of bound-in chlorides, for example as a result of an accelerating admixture like $CaCl_2$, is more difficult due to geometry and bonding in the cement matrix.

Concrete deterioration

Of all concrete damage 80% results from carbonation or chlorides and only 20% is due to other causes. Most damage to concrete structures in The Netherlands is due to carbonation.
In the typical high alkaline environment of reinforced concrete, steel reinforcement is passivated. Calciumhydroxyde [$Ca(OH)_2$] sustains a high pH level of 12.5-13.5. When concrete becomes dry, carbondioxyde enters the pore system and reacts with calciumhydroxyde to calciumcarbonate [$CaCO_3$] which leads to a pH of less than 9, causing depassivation of the steel and eventual corrosion if water and oxygen are available.
The presence of chlorides can cause corrosion still at higher levels of alkalinity. In most cases it brings on pitting in the steel rebars which can reduce static safety. This form of corrosion is considered quite dangerous because the reinforcement steel can be completely gone without clear visual warning such as cracks or delamination of the concrete.
Cracks resulting from mechanical forces are typically caused by misuse of a structure, for instance through excess loads. Cracks through temperature changes are mostly the result of a failing structural design. In both cases, injection or manual repair is usually the appropriate method.
ASR, Alkali Silica Reaction is a reaction between certain aggregates and alkalis such as sodium [Na]. Although this form of damage is not common in The Netherlands, it is of importance in relation to the type of realkalisation method to be selected. With the realkalisation process a vast amount of sodium migrates into the concrete and some of the aggregates might develop ASR. It is therefore recommended to carry out petrographic analyses for any structure that is due to be realkalised.
Chemical attack might occur in sewer systems and in petrochemical or other industrial plants, which is beyond the scope of this paper.

Traditional repair

Manual repair is an option for just small problems and small repairs. If used in case of widespread carbonation or chloride initiated problems, it only restores the environment on the spot of the repair. A few centimetres further the surface of the reinforcement steel will act anodic, shifting corrosion to another place. Regular repair will consequently result in a patch work.
If a structure is very disorderly built, with reinforcement steel occasionally barely covered and an inhomogeous concrete mix made with a shovel, the damage might only be limited to some minor locations. In combination with a comprehensive investigation of the entire surface manual repair might do the job in such a case, probably with an additional coating. Yet, manual repairs are typically very well visible on the 'fair face' of concrete.
To arrive at a durable result, carbonated or chloride contaminated areas must be chiseled-off completely and replaced by shotcrete or mortars. Apart from the partial substitution of original materials, this method involves a radical intervention in the building as such, as well as a severe impact on the usage of a building during the work.
The costs of extensive traditional repair are often higher than the complete replacement of components or building parts. Options for complete reconstruction or replacement of components depend on the nature and complexity of the attachments between such components and the substrate or other parts of the structure.

Inhibitors

Inhibitors prevent corrosion by forming a resistant film on the surface of the reinforcement steel. Typically, inhibitors are mixed-in with the fresh concrete in a solution of 1.5-3.0%.
It is claimed that the latest generation of inhibitors migrate through the concrete in time of days, thus opening up possibilities for the use such agents for the restoration of existing concrete work. Still, it will be difficult -if not impossible- to achieve the required concentration levels around the reinforcement steel. Moreover, the only established effect of such inhibitors is a delay of the start of corrosion with about 200 days. We do not yet consider these methods as an alternative for traditional or electro-chemical methods of repair but it would, however, provide a great solution for concrete distress in recent architectural heritage.

Electro-chemical repair

Cathodic Protection arrests corrosion as soon as the power is switched on. A CP installation is permanent and needs control and maintenance. Certainly, the conductive coatings have the advantage of simple application. If CP is compared with traditional repair, a lot of the extra costs for wiring and installation are balanced against less repair work in the future. In case of traditional repair all affected concrete has to be removed until uncorroded steel is found. With CP only those parts which are actually delaminated, detached or spalled have to be removed and replaced.
Realkalisation and desalination restore the properties of the original materials, or even improve them. Both methods share the main advantages with CP systems; the corrosion stops immediately and there is a large reduction of future repair work. The installation is

more complicated but can be reused. No maintenance is required.

Tests

Trial realkalisation and desalination work in the Netherlands involve enclosure walls, parking decks, storage tanks, a bridge, and apartment buildings. So far, we have had no opportunity to apply one of the *Norcure* methods to a designated landmark. Still, there are some candidates of recent architectural heritage, similar to those in other countries, that would be appropriate for realkalisation.
In this paper however, an everyday apartment building is presented to illustrate the possibilities and particularities of these methods. Some concrete components of the Frederikstraat condominium have been realkalised in 1990 and 1991. This work have been well documented and monitored in the context of the present research program to analyse durability of electro-chemical repair.

Frederikstraat

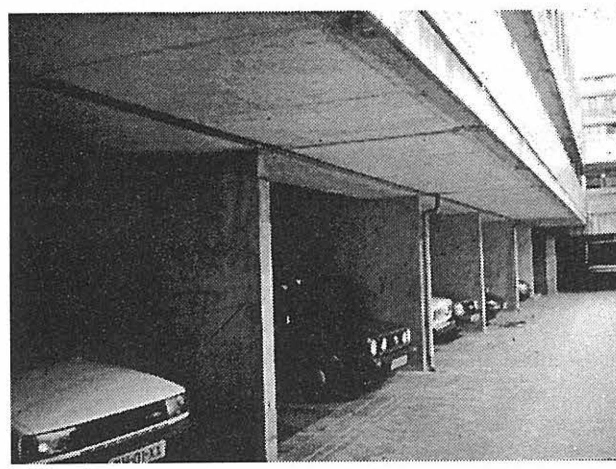
The Frederikstraat condominium is a luxurious apartment building located in central The Hague. It is build in 1976 and owned by the Aegon insurance company. Realkalisation was a part of a complete renovation project designed and coordinated by Groep 5 architects. The main contractor for the work has been Intervam, the company that originally constructed the building.
In 1990 a first realkalisation trial of 90 m^2 was performed by Torkret using an electrolyte spayed onto the surface with cellulose fibres. In 1991 the final work of approx. 2000 m^2 was done by Ervas using coffer tanks (pans) with an electrolytic solution. For both stages of the work NEBEST and TNO where involved as engineering consultants under supervision from the CUR1 Committee B46. At that time the Committee was investigating the possible use of realkalisation and desalination, which resulted in their report 'B92-6, realkalisatie en chloride-extractie van beton; state of the art'. This report provided the basis for the present research program under supervision of CUR Committee B62, that was initiated and sponsored by SBO[2] and coordinated by the author on their behalf.

Selection of method

The concrete slabs of galleries and balconies are made of 250 mm reinforced concrete, based on a blast furnace type of cement. The concrete cover on the rebars is 12-20 mm. The carbonation front was beyond the first layer of rebars at a depth of 25-30 mm. Investigations learned there was limited or starting carbonation damage. On the surface corrosion products and small cracks parallel to the rebars were visible.
The main reason to decide for realkalisation has been to reduce future maintenance costs. The tenants of these expensive apartments would not accept repeated repair work in the future. Furthermore the concrete repair was just a part of a complete improvement scheme, in which all the concrete was eventually to be painted. Aegon, an investor very active in real estate and also the owner of this building, wanted to experiment with forms of preventive maintenance to be used as tools for more economic building management on a larger scale.

Trial project

The possibility to use a realkalisation method was first tested in 1990 on an area of 90 m^2 on the soffits of the parking deck on the ground floor. At that time the usual method for realkalisation was spraying a layer of cellulose fibres to contain an electrolyte of 1 Molair sodiumcarbonate in water.
To distribute the current a steel rebar net was used in sections of around 24 m^2 each, to include one or two balconies at a time. The current density was 1 A/m^2, and was sustained for about two weeks.
The calculated total charge was 215 $Ah/m^2_{concrete}$ which is 1055 Ah/m^2_{steel}.
The spraying of the fibres caused some problems.



Frederikstraat parking decks after trial project 1990.
All photos: HTC.

Initially, the tenants were not too pleased about the large amount of fibres and dust blowing on their expensive cars on the parking decks. To get the cellulose layers well against the soffits and to keep them there, an amount of workmanship was required. With high mid-summer temperatures and the concrete very dry it appeared a precise job to keep the fibre layers sufficiently wet to ensure their electrolytic performance.

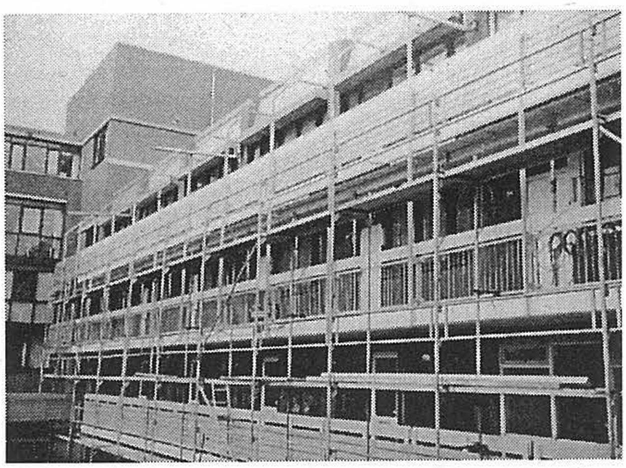
Realkalisation

Based on the positive results of the trial project it was decided in 1991 to realkalise the complete 2000 m^2 concrete surface.To avoid the experienced setbacks, mainly the complaints by the tenants, the method for realkalisation was changed to the employment of coffer tanks.
Ervas designed and built special tanks of 0.75 m^2 that were supported by wooden beams. In every unit

currents were distributed through a titanium mesh anode covered with sponges. As an electrolyte 1 Molair sodiumcarbonate in water was used.
The current density was 1 Amp/m^2. The process was planned to take a bit longer because a lower transport capacity was expected from the sodium ion in the sponges as compared to the fibres. The total charge was 372 $Ah/m^2_{concrete}$ which equals 1820 Ah/m^2_{steel}. The complete surface of these sections has eventually been coated after more than a year.
The coffer tank system proved to have advantages. The building site remained clean and tidy. Measurements and control could be arranged in smaller units. The units could be reused, and a waste of materials could be avoided. Though, a difficult point was to ensure full contact between the sponges and the concrete surface.

Durability concept

With the evaluation research a theoretical model was formulated to assess the data gathered at both stages of the project. The data involved the main realkalisation processes and aspects of durability.



The apartment building hidden by scaffolding during second phase realkalisation work.

During the process there is production of hydroxiles [OH^-] around rebars. At the same time there is migration of sodium ion [Na^+] into concrete. These two combine to [NaOH] which is able to form a high alkaline environment. In concentrations of 0.3-1 Molair in the pore water it will lead to a pH level of 13.5-14. If the concrete becomes dry again after treatment and carbondioxyde [CO_2] enters the pore system, recarbonation may occur. With recarbonation, sodiumcarbonate is formed in an equilibrium [$2NaOH + CO_2 \leftrightarrow Na_2CO_3 + H_2O$] that constitutes a strong buffer solution with a typical pH between 12.5 and 13.5. In the worst case scenario all [NaOH] becomes [Na_2CO_3] which will still lead to a pH level of about 10.8, which is sufficiently alkaline to sustain the passivation of the reinforcement steel. This means that even despite recarbonation a stable situation is installed that will prevent future corrosion of the reinforcement steel, as long as no chlorides are available. This is the basis of the durability concept for realkalisation.

Durability tests

After five to six years the first durability tests were performed in 1996. At the Frederikstraat there were three test groups available:

- Not realkalised.
- Realkalised 1990, no coating applied.
- Realkalised 1991, coated after one year.

Twelve core samples were taken with a 45 mm diameter and an average length of 80 mm. These were cut in slices representing the different zones to investigate;

- Slice 0-12 mm: cover layer.
- Slice 15-30 mm: rebar zone.
- Slice 30-45 mm: beyond the rebars.
- Slice 50-80 mm: remaining construction mass.

To obtain an immediate visual indication of pH levels and volumes, 1% phenolphthalein was sprayed on to the samples. The slices were then grinded to a powder and the amount of [Na] in the pore water was determined according to NEN 2489 3 by extraction for five minutes in water using Atomic Absorption Spectrometry (AAS). To analyze the total amount of sodium [Na] in the pore water and the cement matrix, powder samples of the same slices were dissolved in an acidic solution for total disclosure of the sodium.

Phenolphthalein tests

The phenolphthalein tests produced the following results:

- In the non-realkalised cores, the carbonated zone from the surface to a depth of 25-30 mm did not show any colouring, indicating a pH below 10. The remaining part of the concrete coloured purple, typically indicating a high pH level of 12.5-13.5.
- The realkalised but uncoated cores coloured purple indicating high pH levels, though in the first slice of 15 mm this process was slower and the results lighter as compared to the other slices, indicating a lower pH estimated at 12. This could be caused by recarbonation in the first zone.
- The realkalised coated samples all turned purple having a high pH.
- Core samples taken in 1991, immediately after realkalisation, showed similar high pH levels as well as a discolouring ring around the rebars indicating a local pH of 13.5-14, on which level phenolphthalein is disabled. This white ring is no longer visible after five years which can be understood as an indication of diffusion of hydroxyl [OH^-] into the surrounding concrete mass.

All the realkalised concrete proved to sustain a sufficient alkalinity level to maintain passivation of the reinforcement steel.

Sodium analyses

Realkalisation results in an important increase of sodium concentrations around the rebars and in the cover between rebars and surface. At least a tenfold of the original amount is typically available in the pore water.

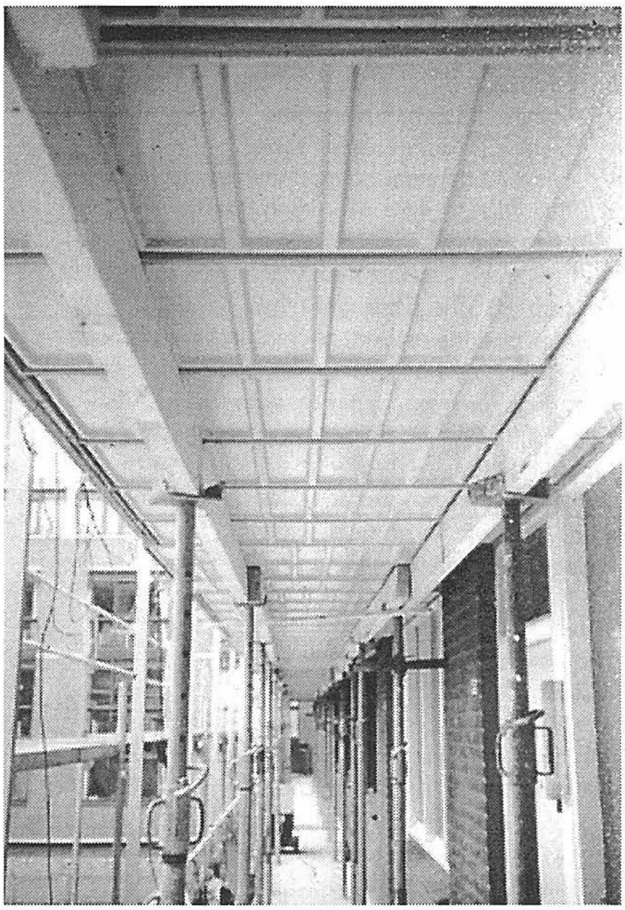
The concrete realkalised in 1990 contains around 7 $kg/m^3_{concrete}$ in these areas.

The concrete realkalised in 1991 contains around 5 $kg/m^3_{concrete}$ in these areas.

This means as well that the total amount of sodium [Na] in these samples is around the 10 $kg/m^3_{concrete}$ given a realkalisation with 1 Molair sodiumcarbonate at a charge 215 $Ah/m^2_{concrete}$.

Measure pH in suspension

In the suspension the pH levels are measured. Dilution compared with the pore water is x200. In linear conditions adding 2.3 to the measured pH would produce the original pH of the pore water. This



Realkalisation pans fixed onto the soffits of the access galleries in 1991.

Galleries of Frederikstraat apartments after realkalisation in 1991.

indicates a pH level of over 14 which is not impossible in areas where the entire high sodium [Na] content is present in the form of [NaOH]. In areas where also [Na_2CO_3] is present, it is impossible to recalculate the pH in the pores, due to the strong buffer capacity of [Na_2CO_3] // [NaOH]. In areas of recarbonation the estimated pH level is above 12.5.

Total charge in 1990 was 215 $Ah/m^2_{concrete}$, in 1991 it was 372 $Ah/m^2_{concrete}$. This indicates a difference in efficiency in migration of sodium ion between the fibre system and the sponge method of 2.4 to 1, in favour of the fibre system. Other factors such as temperature may be important too.

Water vs. acid disclosure

Water disclosure was measured after 5 minutes. Further delay would have brought in more sodium [Na] in the suspension. Comparing these results with the results of acid disclosure it could be concluded that in blast furnace concrete (BFC) around 55% of the total amount of sodium [Na] is present in the pore water of the concrete, thus contributing to the alkaline environment and the pH buffer. In Portland cement (PC) this will be more, an levels could increase to 80-100%.

Test results

From the performed tests the following conclusions could be drawn:

- Realkalisation leads to high pH levels over 13.5 around rebars and in the concrete cover.
- After 5 years this high pH is still maintained.
- Without coating recarbonation in the concrete cover occurs.
- The strong buffer [NaOH] // [Na_2CO_3] keeps pH

levels above 12.5, depending over time on the amount of [NaOH] available through the realkalisation process.

- A charge of 215 Ah/m² using fibre system brings in an amount of sodium [Na] of 7 kg/m³ (water dissolved, in BFC only 55% measured, total [Na] is 10 kg/m³)
- With a coating as applied here there is virtually no recarbonation. The measured difference has been the result of the one year delay before applying the coating.
- The anticipated period in which durability remains must be estimated as multiple of the monitored six-year period in this case.

Qualitative criteria

Primarily, the decision for realkalisation depends on the specific type and progress of damage, which must be comprehensively investigated. Realkalisation is a method to repair and prevent carbonation problems, and is most efficient in cases where there is limited corrosion, cracks and delamination.
The second question will be if there is any need for prevention. What will happen if only the visual damage is repaired, is major future damage to be expected? If the carbonation front reaches the rebars and active corrosion is detected, one can anticipate progress of damage. The increase of damage is determined by aspects such as the age of the construction, the concrete cover, concrete quality, humidity, environmental exposure and, most importantly, the internal geometry of the construction. With the same amount of patent damage, latent damage can be expected to be more advanced in case of very regularly built structures, as compared to disorderly built structures.
For building owners and managers, the exploitation horizon is an important aspect in decision making. Also, the required durability and appearance of the construction have a major impact. Short term exploitation often leads to patch repairs. A lifetime preservation policy is related with the application of structural improvements, which in most cases proves to be more cost effective.
In case of restoration some important additional questions must be considered. Are major adaptations acceptable in materials, size and surfaces, or are only minor interventions allowed? Are coatings on concrete faces already present, respectively acceptable in the future, or is the restoration aimed at a complete preservation of the authenticity in materials and surface appearance?

Costs

Finally, both the direct costs for the work and future maintenance have to be estimated and compared to those of possible alternatives. The comparison of alternatives is key and it is therefore standard procedure for HTC to provide such information to her clients. From comparing the direct investments and future maintenance costs for the various repair methods it appears that CP and realkalisation are far more cost effective than peeling-off degraded concrete or complete replacement of affected components. Expenses over time are similar to those for traditional repair.
In addition, realkalisation has the advantage of low maintenance costs, while traditional methods require financial reserves for future repairs to corroded reinforcing steel and concrete damage caused by progressing carbonation.

Conclusions

When assessing the performance of realkalisation the following conclusions can be drawn:

- Total charge > 200 Ah/m2$_{concrete}$ results in a sufficiently buffered alkalinity.
- When coatings are applied recarbonation is made virtually impossible, and pH levels stay high.
- Without a coating alkalinity might decrease to pH 10.8 on long term; at that pH level, the occurrence of corrosion depends on the concentration of chlorides.
- Advantages of realkalisation are: no radical intervention, environment-friendly, and costs effective when compared to traditional methods and integral replacement of components.

In terms of restoration of architectural heritage most important is that, with these methods, original concrete structures can be more easily preserved.

René G.J. Ackerstaff is a building engineer for High Tech Contracting in Breda, The Netherlands. On behalf of the main sponsor SBO, the author has been the coordinator for the evaluation research presented in this paper.

Notes:

1. CUR stands for Stichting Civieltechnisch Centrum Uitvoering, Research en Regelgeving, the Centre for Execution, Research and Regulations in Civil Engineering, an independent foundation in the Netherlands.
2. SBO stands for Stichting Betontechnologisch Onderzoek, an independent Foundation for Research on Concrete Technology.
3. NEN stands for Nederlandse Norm, or Dutch Standard.

HTC

DOCOMOMO seminar TU-E

Case from the Netherlands
Ir. Rene G.J. Ackerstaff
HTC, NL
April 1997

HTC HTC; high-tech-contracting

- contracting specialists in electrochemical concrete repair
- project engineering, supervision,
- research, inspection and non-destructive testing

HTC Electrochemical concrete repair

- cathodic protection
- realkalisation
- desalination

HTC Concrete deterioration

- 80% of all damage results from
  - carbonatation
  - chlorides
- 20% other causes
  - mechanical forces, temperature changes
  - chemical attack
  - ASR

HTC Concrete repair 1

- traditional methods
  - chiselling and shotcrete -
    - partial substitution of material
  - manually -
    - only for small problems and small repairs
  - rebuilding/replacement of elements -
    - renewing all

HTC Concrete repair 2

- electrochemical methods
  - inhibitors -
    - mix-in only for new constructions ?
  - Cathodic Protection -
    - protects material with coating or layer
  - Realkalisation, Desalination -
    - restores original materials

HTC Projects in the Netherlands

- realkalisation and desalination
  - walls, decks, tanks, bridges, apartment buildings
- no monumental buildings done
  - like the examples from other countries
  - but some monumental candidates for realkalisation
    - one of them is Zonnestraal, Hilversum
- this case an apartment building to illustrate possibilities
  - older project with much data on durability

HTC Project "Frederikstraat"

- general information
  - luxurious apartments in centre of The Hague, 1976
  - owned by insurance company Aegon, renovation architects "groep-5" , main contractor Intervam
- project information
  - realkalisation test by Torkret in 1990
  - and final project by Ervas in 1991
  - project size realkalisation 2000m2
  - engineering by Nebest and TNO
  - supervision by CUR committee B46

HTC Why realkalise this project?

- starting damage by carbonatation
  - ceilings of galleries, 25cm, blastfurnace cement
  - carbonatationfront beyond first layer of rebars
  - corrosionproducts and small cracks along rebars
- to reduce maintenance costs in future
  - to prevent repeating repairworks (critical tenants)
  - total improvement, project had to be painted
- experiment for preventive maintenance
  - use as tool for buildingmanagement on larger scale

HTC Testproject in 1990

- selected testsite 90m^2
- realkalisation method
  - spraying of cellulose fibre to contain electrolyte
  - 1 molair sodiumcarbonate in water
  - steel rebar net as anode
  - sections of 1-2 balconies, 24m^2
  - current density 1 A/m^2, 2 weeks
  - charge 215 Ah/m^2 concrete = 1055 Ah/m^2 steel

HTC Realkalisation in 1991

- total surface 2000m^2
- realkalisation method
  - tanks 0,75 m^2 on supports
  - 1 Molair sodiumcarbonate in water
  - titanium mesh and sponges
  - charge 372 Ah/m^{2}concrete = 1820 Ah/m^{2}steel
  - coating applied after more than a year

HTC Concept of durability

- realkalisation processes
  - production of hydroxides [OH^-] around rebars
  - transport of Sodium [Na^+] into concrete
  - forming [NaOH], 0,3~1 Molair: pH 13,5~14
- re-carbonatation in time
  - Carbondioxide [CO_2] enters the concrete
  - [$2NaOH + CO_2 <> Na_2CO_3 + H_2O$]: pH 12,5~13,5
  - 'worst case' all becomes [Na_2CO_3] : pH ~10,8

HTC Testing durability in 1996

- 3 testgroups
  - I) not realkalised
  - II) realkalised 1990, no coating
  - III) realkalised 1991, coated (after 1 year)
- samples; 12 cores diameter 45x80mm
  - slice 0-12 mm : coverlayer
  - slice 15-30 mm : rebars
  - slice 30-45 mm : behind rebars
  - slice 50-80 mm : rest of the construction

HTC Test procedure

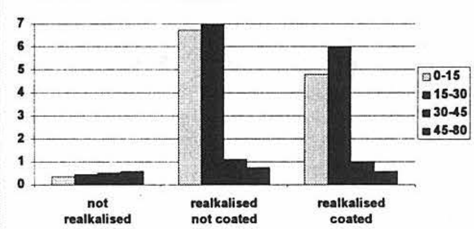
- phenolfthelain
  - visual indication on pH and volumes
- water extraction of [Na]
  - 5 minutes dissolving in water according NEN 2489
  - to determinate [Na] in porewater
  - [Na] by Atomic Aabsorbtion Spectrometrie
- disclosure of [Na] in acid solution
  - to determinate total amount in porewater and cementmatrix

HTC Results phenolphthalein test

	concrete cover	around rebars	behind
not realkalised	no colour first 25-30mm	cover 10-25mm	purple
realkalised not coated	purple (after a while)	purple	purple
realkalised coated	purple	purple	purple
directly after realkalisation	purple	purple+white ring after a while	purple

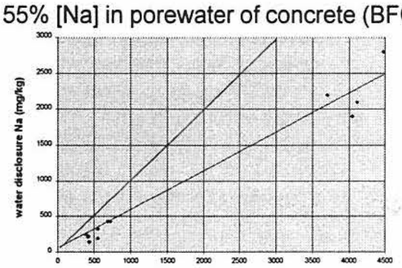
HTC Results Sodium analyses [Na]

- [Na] in $kg/m^3_{concrete}$



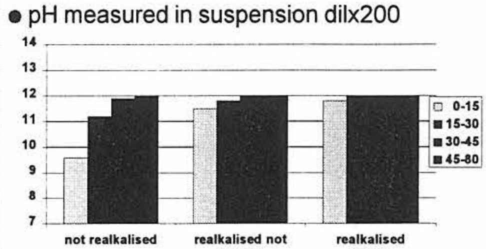
HTC Water vs. acid disclosure

- 55% [Na] in porewater of concrete (BFC)



HTC Results pH in suspension

- pH measured in suspension dilx200



HTC Conclusions from test

- re-carbonatation without coating
- with coating nearly no re-carbonatation
- charge 200~300 Ah/m^2 > [Na]~7kg/m^3
  - (water dissolved, in BFC only 55%, total [Na]~10kg/m3)
- buffer [NaOH // Na_2CO_3] keeps pH>12
- after 5 years around rebars high pH>13,5
- expected durability for many years

HTC When to decide for realkalisation?

- type of damage and expected progress
- required durability and appearance
- direct costs and maintenance
  - related to alternatives

HTC Investigate damage and progress

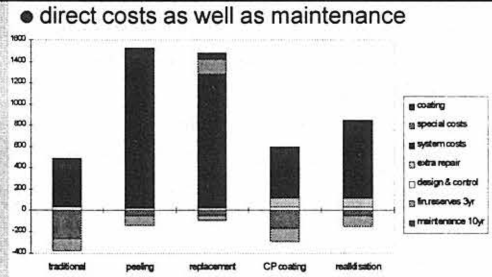
- corrosion caused by carbonatation
  - carbonatationfront reaches rebars
  - corrosion and cracks visible, limited delamination
- expected progress
  - speed determined by age, cover, concrete quality, humidity, environment
  - slow progress at disorderly constructions
  - for very regular constructions first amount of damage is often a warning for fast progress

HTC Required durability and appearance

- exploitation horizon and quality of management
  - keeping a few years or lifetime preservation
  - repair works: for once, or always
- appearance
  - larger adaptations acceptable in materials, size and surfaces
  - coatings over concrete present or possible
  - or only small changes allowed
  - or total preservation of the authenticity of materials and surfaces

HTC Calculate alternatives

- direct costs as well as maintenance



HTC Summary

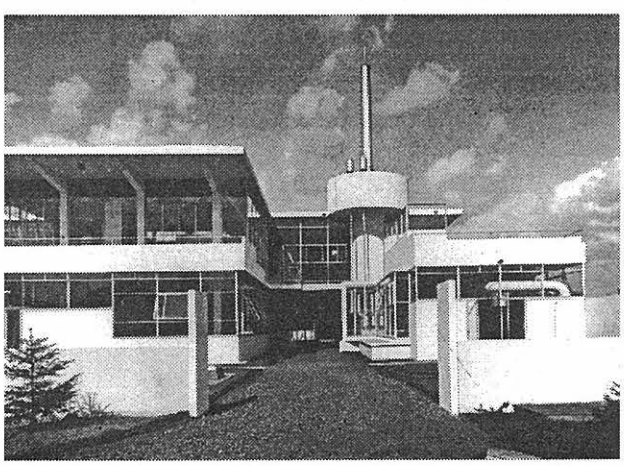
- total charge >200 Ah/m^2 ,sufficient buffer
- coated; no re-carbonatation, high pH
- non-coated; longterm decrease to pH 10,8
- friendly for man and environment
- competative compared to tradional repair
- PRESERVATION OF THE ORIGINAL CONCRETE STRUCTURES

Concrete repair and material authenticity
Non-destructive repair techniques

Among the numerous challenges that must be addressed in the conservation of modern heritage, the repair of concrete raises conceptual and technical questions about longstanding principles of material and design authenticity. This paper examines this problem as it pertains to the Zonnestraal Sanatorium, a deteriorated reinforced-concrete structure in Hilversum, the Netherlands. Case studies and an analysis of the pros and cons of realkalisation examine its viability for repairing the exposed concrete of Modern Movement structures when material and design authenticity are critical.

by Wessel de Jonge

During the Industrial Revolution, buildings and their programs became both more diversified and specifically tailored to their functions. Yet the common consequence of such specificity is a short functional lifespan. Therefore, not only the nature of the programs changed but also the period during which a building could serve the same purpose. The introduction of new materials and construction types - in the sense of building assemblies- was another major influence on Modern Movement architecture. The conservation techniques required for buildings

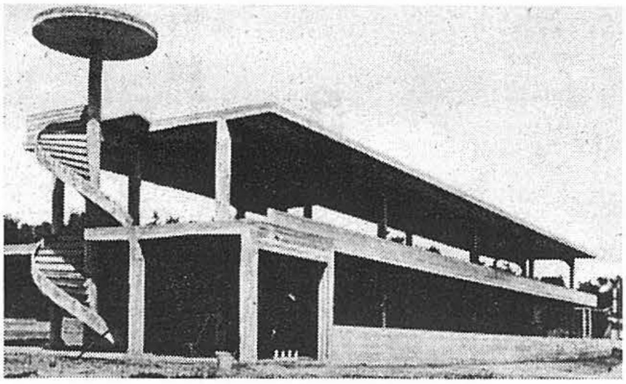


Zonnestraal Sanatorium (Jan Duiker, 1926-28) in Hilversum, The Netherlands, in its original splendour. Photo: Eva Besnÿo, courtesy of DOCOMOMO archives.

from the Industrial Age are therefore different from those appropriate to earlier buildings.
Between the two world wars, these developments ultimately led to the pioneering work and revolutionary ideas of the modern avant-garde. Around 1920 they established direct links among user requirements, design, and the lifespan of buildings. Their ideas produced the architecture of the Modern Movement. Some of these architects, such as Jan Duiker (1890-1935) in Holland, regarded buildings, by definition, as utilities with a limited lifespan, sometimes even as 'throw away' articles[1]. One well-known example of Duiker's work is the Zonnestraal Sanatorium in Hilversum (1926-28).

Transitoriness
The introduction of a structural frame with columns was a main principle of the Modern Movement, opening buildings to daylight and fresh air. The elemination of decorative elements was another feature of Duiker's architecture. Indeed, the facade of the Zonnestraal Sanatorium is nothing more than a membrane of steel and glass.
Related to the idea of varied lifespans was the practice of prefabrication, which allowed the easy replacement of deteriorated components. The prefabricated concrete spandrel panels of the sanatorium are probably the first ones to be used in Holland.
Duiker's work did not excel in proper detailing and often fail to meet present-day construction standards. Although many assume that their constructions are the result of professional ignorance, research suggests that Duiker and his colleagues were well aware of what they were doing and accepted the concept of a building's limited lifespan. In the case of the Zonnestraal Sanatorium, this makes sense, since tuberculosis was expected to be eliminated within thirty to fifty years.
Thus the 'transitoriness' of Modern Movement architecture can, in some cases, be understood as part of the architect's intentions. This obviously has an impact on our approach to the conservation of such buildings.

Spiritual economy
The architects of the Modern Movement designed buildings that were as light as possible, using minimum amounts of material. The dimensions of the concrete beams of the Zonnestraal Sanitorium, for



The slender concrete structural frame of one of the Zonnestraal pavilions illustrates Duiker's design principle of 'spiritual economy'. Photo: courtesy of DOCOMOMO archives.

example, follow the moment diagram. Duiker referred to this as 'spiritual economy'. In 1932 he wrote that the aim of optimal construction 'develops towards the immaterial, the spiritual.'[12]

Many architects and engineers of the Modern Movement experimented with materials and constructions. While they obviously lacked much of the knowledge that we have today, we do not fully understand exactly what they knew. Without such information, how can we evaluate the relationship between their constructions and their original intentions? And how can we determine what type of interventions are historically respectful and therefore responsible?

The values of historic buildings, and particularly buildings of the Modern Movement, should be based on more than their appearance. Understanding the original design intentions is critical to the conservation process. How to deal with buildings, such as the Zonnestraal Sanatorium, whose construction technology was a main expression of the original design approach? The aspect of 'transitoriness' should not be concealed by advanced technology during the conservation process, leaving an artificial memento behind. It should be possible for students, architects and others to appreciate the concept of the building's functionality after its conservation.

Concrete deterioration

The concrete structural frame of Zonnestraal Sanatorium, which is made up of two pavilions and a main building, is in complete harmony with its original function and presents a clear illustration of the architect's design approach. The frame was designed to be as light as possible: if we consider the moment diagram of the girders, the combination of 9 m spans with a 3 m cantilever is optimal, as it allowed the dimensions of structural members to be minimized and thus saved concrete (the extensive carpentry for formwork was not uneconomical when labour was cheap and materials expensive). The combination of 3 m floor spans with 1 m 50 cantilevers, which seems less economical insofar as moment reductions are concerned, allowed the use of slabs that are 120 mm thick at their supports and a mere 80 mm thick in the middle of spans and at the perimeter of the cantilevers. Despite their minimal dimensions, these thin floor slabs contain a top and bottom layer of rebar plus light orthogonal reinforcement to spread tension forces. One can easily imagine that there is very little concrete covering the reinforcing steel.

To fill the narrow and complicated formwork, the concrete was watered down to make it more fluid. The high water-to-cement ratio, together with the nonhomogeneous composition of the concrete, resulted in an extremely low compression strength in some locations; in certain columns, for example, the compression strength is similar to that of wet sand (9.4 N/mm^2). In addition, concentrations of coarse aggregate have been found, particularly near concentrations of rebar. The extreme porosity of the concrete caused the carbonation of the material to reach beyond the rebar in most cases, depassivating the basic environment of the steel. Finally, chlorides were found in the upper floorslab of one of the pavilions; these were apparently added to advance curing in winter.

After the sanatorium was abandoned around 1982, many windows in one pavilion were broken, leaving the concrete fully exposed to the elements. The damage caused by corroding rebar is enormous, and parts of the building are unsafe.

Control calculations indicate that, in theory, the pavilion has collapsed. The frame is currently supported by light partition walls which, of course, were never designed to serve as structural supports. Fortunately, the other two buildings are in much better condition.

Intention or material

If the goal were simply to respect the design intentions, the deteriorated pavilion could be demolished and reconstructed using advanced contemporary techniques, to match the original design. The appearance of such a replica will allow us to understand the original design approach, but almost all of the materials would have to be renewed. However, the 'Operational Guidelines for the Implementation of the World Heritage Convention' state that authenticity of design and materials is important and that 'reconstruction is only acceptable if it is carried out on the basis of complete and detailed documentation of the original and to no extent on conjecture.' Since the Ministry for Culture of the Netherlands intends to nominate Zonnestraal for inscription on the World Heritage List, reconstruction would probably not be acceptable.

Another option is to repair and reinforce the existing structural frame using contemporary techniques. Although this method would be more expensive than reconstruction, it would be somewhat more respectful in terms of the building's material authenticity.

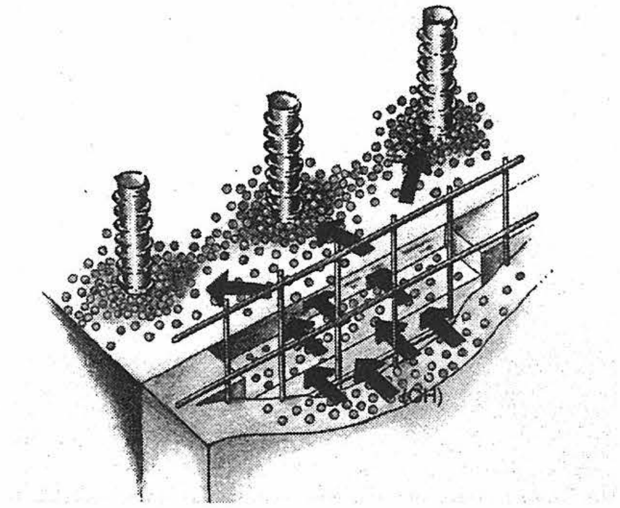


Diagram of the realkalisation process. Drawing: FOSROC/NCT.

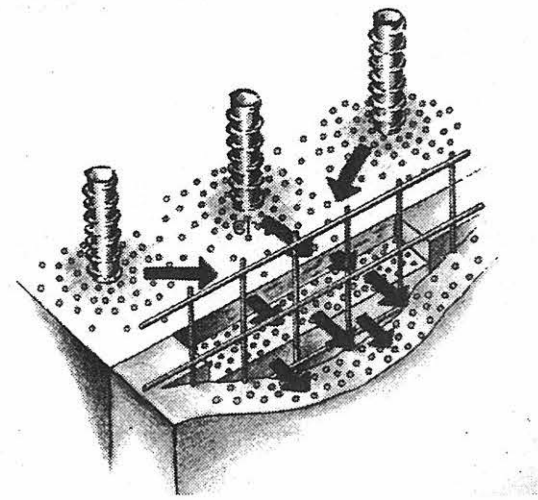


Diagram of the desalination process. Drawing: FOSROC/NCT.

However, it also involves visible changes to the building, such as the increased dimensions of its beams and columns. This would compromise its design authenticity, in particular Duiker's basic concept of 'spiritual economy'. The potential conflict between the underlying ideas of the Modern Movement and longstanding conservation principles is clearly illustrated by this example.
When considering the conservation of the Zonnestraal Sanatorium, the most economical solution would be to retain the original design virtually intact. Ideally, both the original design and materials should be respected. Since we hope to salvage at least a part of the original structure of the pavilion, a third option -involving relatively new, non-destructive electro-chemical concrete repair methods- seems worthy of consideration.

Electro-chemical repair

Electro-chemical systems for concrete repair were first developed by NCT in Norway for civil works, such as bridges, in the 1980s. The British-Norwegian company FOSROC NCT owns the license today. Apart from preventive electro-chemical treatment through cathodic protection, there are two types of electro-chemical remedial techniques: desalination and realkalisation. Most of the European experiences so far are with realkalisation. Interestingly, material scientists in North America and in Europe seem to disagree on the major cause of concrete deterioration; in the United States, concrete damage is typically attributed to chlorides and other salts, and carbonation is often denied as a primary cause, while European experts tend to agree that it is generally the ingress of carbondioxide that disturbs the basic environment in concrete.

Desalination

Chloride ions that are externally ingressed can be extracted from the concrete by desalination -or chloride extraction- using an electric field that is established between the reinforcement steel and an anode installed at the surface. It is useful for repairing structures exposed to salts, such as highways, parking garages, and seaside constructions. As it is a slow process, desalination can cause disruptions when the structure being repaired is in use. Another possible problem can be the secretion of chloride gas, which is not environmentally friendly; this can, however, be avoided through pH control or continuous circulation of the electrolytic solution in the pans applied to the concrete surface.[3]
The effect of desalination on chloride ions behind the rebar remains unclear. Since polarity is created between rebar and surface, these ions are not primarily affected. Although remigration of ions will result in a lower overall level of chlorides over time, desalination is therefore less effective for concrete that suffers from in-bound chlorides.

Realkalisation

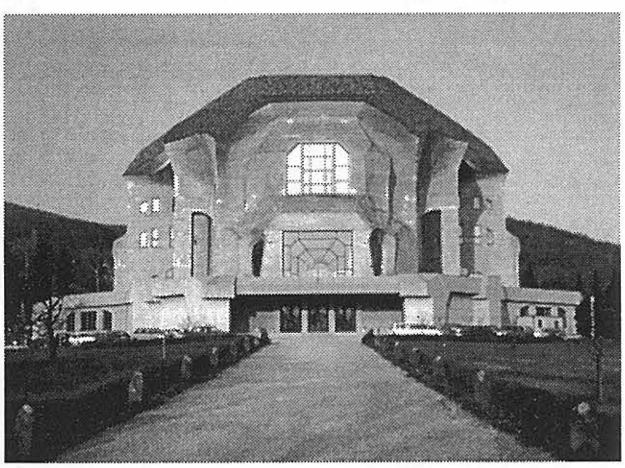
Realkalisation is performed by applying an electric field between the reinforcement in the concrete and an anode embedded in an electric reservoir and temporarily placed on the concrete surface. During

The deteriorated pavilion of the Zonnestraal Sanatorium provides an interesting case in terms of material and design authenticity. Photo: TU Delft, courtesy of DOCOMOMO archives.

treatment, the alkaline electrolyte is transported into the carbonated concrete through electro-osmosis. Simultaneously, electrolysis at the reinforcement steel surface produces hydroxyl ions [OH^-], while free sodium [Na^+] and potassium [K^+] ions in the concrete migrate toward the reinforcement steel. These mechanisms increase the alkalinity of the carbonated concrete sufficiently to re-establish the passivation of the reinforcing steel, typically within one week of treatment.
It is possible to monitor and evaluate this treatment in a series of trial projects and applications in practice. Some of these projects date back five years or more and their evaluation reports provide relevant information for the analysis of realkalisation. Four case studies have been examined for this paper from a restoration architects' point of view.

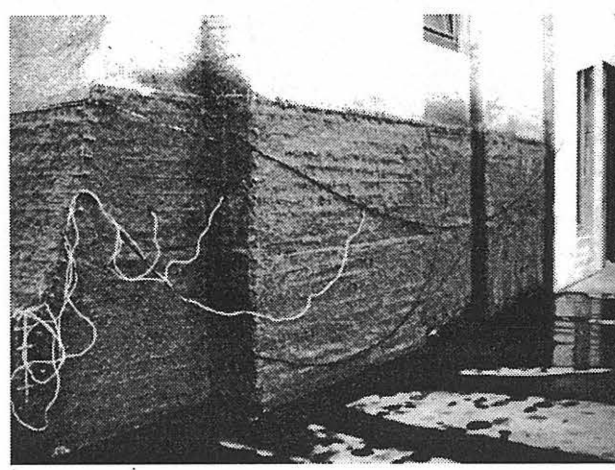
Goetheanum

Rudolf Steiner's Goetheanum in Dornach, Switzerland, became an icon of free architectural expression through concrete technology soon after its completion in 1928. In the mid-1980s carbonation was diagnosed at depths of 30 to 80 mm. In some locations, it had passed beyond the 20-50 mm concrete covering. Although the level of corrosion



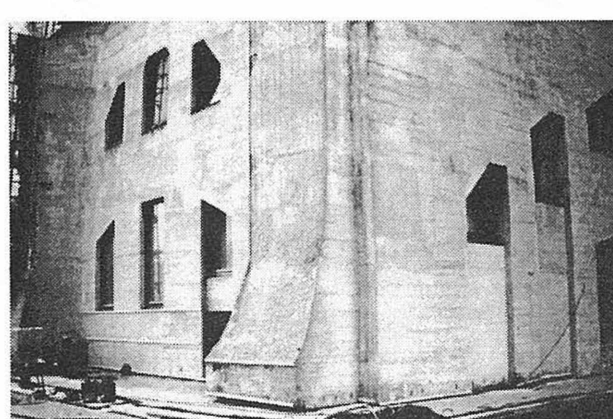
Goetheanum in Dornach (R. Steiner, 1928). Photo: J. Repiquet.

was not yet alarming, some rusted steel was visible, and this compromised the integrity of the historical fabric. A trial realkalisation project was carried out in 1988 on about 100 m² of the concrete on the building's north facade. Conventional repairs already in progress by then had involved chiseling off some of the original concrete at locations where rebar corrosion and spalling had occurred. When the client realised that these repairs were not respectful of the building's significance the work was stopped, leaving the facade with exposed rebars. When the client became aware of the principles and the non-destructive character of electro-chemical repair, trial realkalisation could be carried out.
Revaluation shortly after the trial treatment revealed that realkalisation had taken about twice as long as expected. This was due to the fact that the concrete had been impregnated earlier with a silicone-based agent, which had partially sealed the pores. As a result, realkalisation by electro-osmosis was obstructed and only the electrolysis part of the process remained effective. Phenolphthalein tests of cores indicated an alkalinity level beyond the rebars of more than 0.5 mol K_2CO_3/l_{pores}, more than sufficient to ensure durability.
Another assessment was initiated in 1995, seven years after the initial treatment, and still continues. This analysis is twofold, consisting of an electro-chemical appraisal and a purely chemical appraisal. The first of these testing programs is based on comparing the potentials and electrical conductivities of the treated and the untreated concrete. The results of this program are so far very encouraging. After seven years a significant and durable passivating layer remains around the reinforcement steel in the treated areas, and there is a significant difference between the treated and the non-treated areas. The full extent of the treatment will, however, become clear only after comparing the results to the outcome of the chemical tests.
During the trial realkalisation and the initial assessments the facade continued to suffer from increasing damage at its exposed areas, and repair

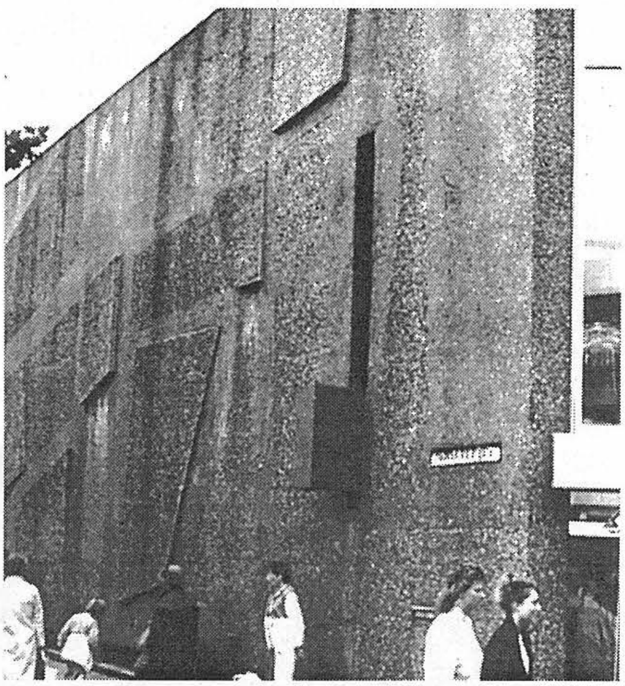


Trial realkalisation at the Goetheanum in 1988. Photo: courtesy of FOSROC/NCT.

The trial area at the Goetheanum after realkalisation. Photo: courtesy of FOSROC/NCT.

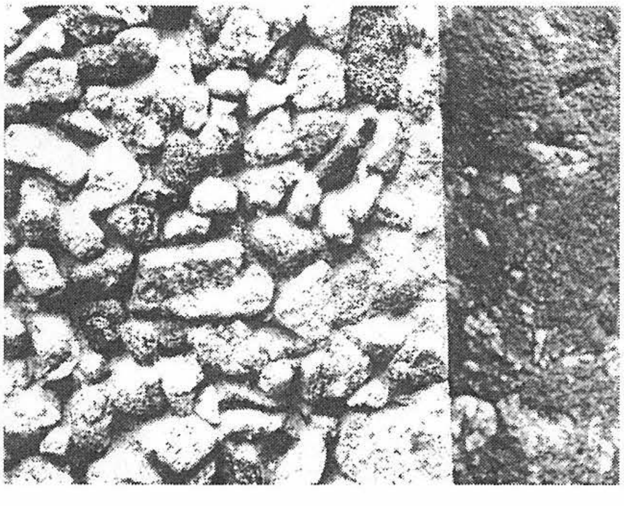


works had to be resumed in 1994, even before the test results were available and sufficiently evaluated. Over the five years after trial realkalisation various other solutions were considered, some of which involved the installation of external insulation. All of these options were rejected by the Inspectorate for Historic Buildings. For both technical and aesthetical reasons, there was no other option except the complete replacement of the top layer of carbonated concrete, that reached beyond the reinforcement steel. In order to remake the original surface texture shotcrete was rejected in favour of *in situ* concrete, with rubber moulds applied inside the formwork to remodel the original texture.[4]



One of the exposed concrete facades of the State Bank of Norway in Stavanger, with a geometric decoration of slightly projecting cubic volumes. Photo: courtesy of HTC, The Netherlands.

The dressed surface of the bank showes alternating use of smooth and chiseled concrete. Photo: courtesy of HTC, The Netherlands.

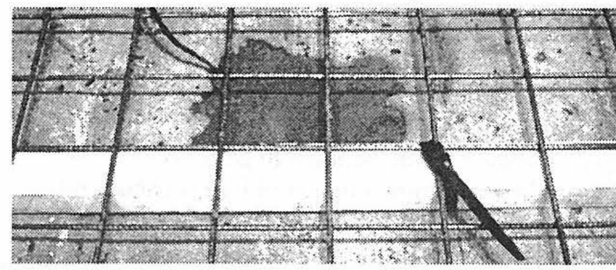


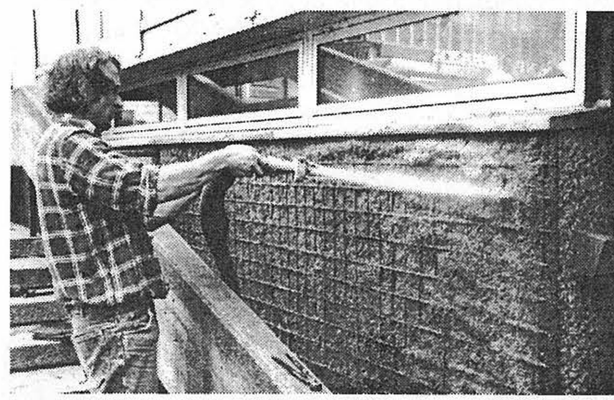
Electrode nets are installed on the concrete surface to prepare for realkalisation. Wood battens ensure the correct spacing. Photo: courtesy of FOSROC/NCT.

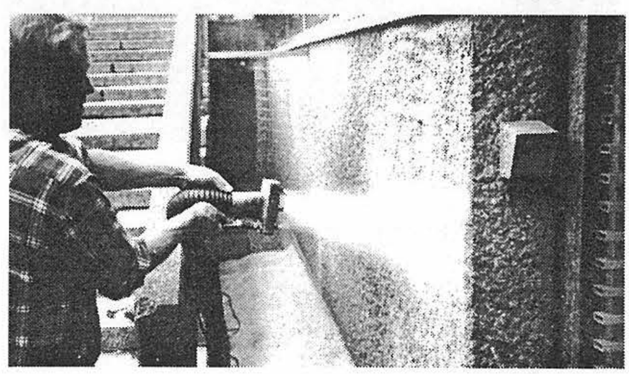
Cellulose fiber permeated with baking soda is sprayed over the steel net installed on the surface. Photo: courtesy of FOSROC/NCT.

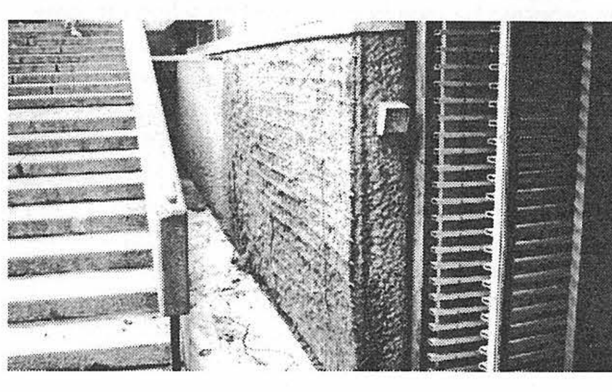
The fiber mass is applied to cover the anode net completely. This system operates on large areas. Photo: courtesy of FOSROC/NCT.

The same surface after application of the fiber-bed. Realkalisation is about to start. Photo: courtesy of FOSROC/NCT.









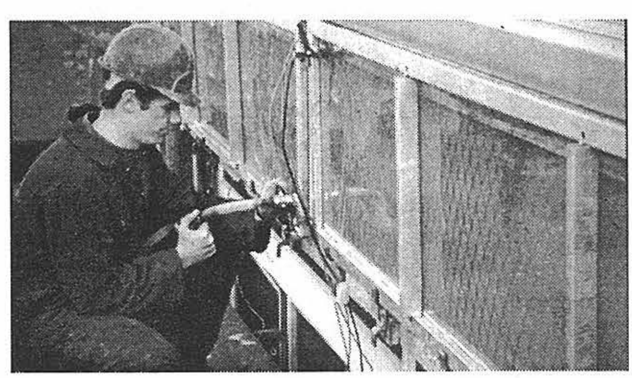
State Bank of Norway

This bank building in Stavanger, Norway, dates to the early 1960s. Its main facades are alu-glass curtain walls while some 330 m^2 of secondary facades are exposed concrete, which is hand-chiseled to create an architectural texture. One of its facades features an appealing geometric decoration with slightly projecting cubic volumes. Further decorative effects include the alternating use of chiseled and smooth concrete. In 1987 cracks and spalling were observed. A survey was carried out, which included initial visual inspection, mapping of potentials, concrete covering and carbonation depths, chloride analyses and measuring of relative humidity.
The condition of the concrete was alarming. Its covering varied between 40 and 0 mm. The facades of the building are particularly vulnerable to carbonation due to their partly chiseled surface, the dressing of which effectively caused the removal of the outer cementitious skin as well as micro-cracks in the surface. The maximum carbonation depth was 32 mm for the chiseled surfaces and only 10 mm for the smooth areas. The potential mapping revealed that 70% of the vertical rebar was corroding due to carbonation, in combination with high relative humidity levels (80% RH average). These areas required conservation, although damage was still limited. The need to arrest corrosion, avoid further chipping, and preserve the appearance of the building led to recommending realkalisation of its concrete facades.
In the autumn of 1988, NCT carried out the realkalisation of approximately 300 m^2 of the facade. A 25 mm thick layer of celluse fiber, permeated with a sodiumcarbonate solution (baking soda), which served as an electrolyte, was sprayed over a steel net installed on the surface. Wood battens ensured the correct spacing between the electrode net and the surface. Electrical connections were made and sealed off by oil-based putty. Cracks, spalls, exposed rebars, and other metal features were sealed off with epoxy putty to avoid short circuits. The electrode nets were mounted against the battens and joined by steel wire, to ensure a continuous electrical circuit, and connected to a rectifier. The resistance between the rebar and the external electrode was checked, and the section was adjusted as required. Finally, an additional 10-20 mm thick layer of fiber and electrolyte was applied.
The process was running at 12 V most of the time, providing a current density of about 0.5 A/m^2. Alkalinity tests of cores with phenolphthalein showed that the process could be terminated only after a week, due to the depth of the carbonation. The red colour of the entire core revealed that the process was complete. After removing the system, the surface was cleaned using a high-pressure water jet. All cracks and cavities were filled with repair mortar, pigmented on site, and mixed with coarse aggregates. The repaired surfaces were chiseled by hand to match the original finish. Finally, the surface was treated with an unobtrusive mineral coating to protect areas where insufficient concrete covered the rebars.
When lead [Pb] electrodes are taken as a reference point[5], the critical potential for the occurrence of corrosion of reinforcement steel is 415-515 mV. A higher potential is a typical indication that the steel is sufficiently protected, while a potential under 415 mV typically indicates corrosion. Random tests on the bank's facade revealed at least one alarming figure of only 384 mV. Just after treatment, the potential of this critical reference point measured 402 mV. Other reference points showed increase from 536-559 mV, to 541-583 mV.
In August 1990 the results of the treatment were again examined. Tests showed that the alkalinity level was similar to the level immediately after realkalisation. Potential measurements confirmed these tests. Interestingly, the one critical reference mentioned before was recorded to have increased its potential after 9 months to about 612 mV, and other low values increased as well. NTC explained this increase of potential after treatment as the natural equalization of the various potentials over time, through re-migration of ions.
One of the cores was taken at a repair at the interface between carbonated and fresh concrete. Extracts were analysed for sodium [Na] concentration. For the fresh concrete, values were below the expected typical background level. In the carbonated zone the sodium concentration was as expected after treatment with sodiumcarbonate two years earlier. NCT explains this by the limited migration of sodium and sodiumcarbonate in concrete. This observation seems to conflict, however, with their theory of potential equalization over time.

Housing Frederikstraat

This housing complex, constructed in the mid-1970s in The Hague, The Netherlands, features gallery-access flats on top of parking decks. The galleries suffered from alkalinity problems due to carbonation. About six years ago two types of electro-chemical

An alternative use of pans with an anode net and sponges, felt, or gels. After the tanks have been fixed to the surface they are filled with an electrolytic solution. This system operates in small units. Photo: courtesy of FOSROC/NCT.



treatment were applied to the most critical areas, and these were recently revaluated by means of durability tests.[6]
One of the treatment methods was similar to that applied at the Bank of Norway, while the other system made use of 0.75 m² pans with titanium electrodes and a sodium solution in sponges; a coating was applied after the latter treatment. In 1995 the durability of the electro-chemical realkalisation was evaluated. This involved the chemical analysis of samples to test the spreading and the concentration of sodium, potassium and chlorides. Samples of both treated areas were compared to areas of untreated concrete, as well as to the results immediately after realkalisation. A great difference in sodium concentration was found between the untreated and the treated material, the latter being about ten times higher than the former. Surprisingly, the sodium concentration in the uncoated, realkalised concrete appeared higher than under the coated surfaces. This can be explained by the uneven distribution of currents during treatment, as well as by differences in covering and variations in the dampness of the electrolyte bed, which prevented the free movement of ions. Uneven distribution of currents occurs more easily if large areas are treated with a single system at one time. This was the case with the fiber-bed method in Frederikstraat, where approximately 24 m² was covered with a single system. When compared to the results immediately after realkalisation, a drop of 30 to 45% in sodium concentration was diagnosed; this could lead to lower pH levels. As with the Bank of Norway, this was explained by the redistribution of ions through diffusion over time, but here the result was less favourable: although K- and Cl-concentrations were slightly reduced, their measurements did not indicate a significant difference. Calculations suggest that a significant part of the sodiumhydroxyl produced by the realkalisation process recarbonated to sodiumcarbonate, which serves as a 'buffer' with a minimum pH of between 10.5 and 10.8. In uncoated concrete this effect was only slightly higher that in the coated material. In addition, pH-values were a fraction higher in the coated concrete but over 11 in both cases. This implies that the reinforcement steel is still sufficiently passivated after four years. It seems that a great variety of results can occur within realkalised areas when large areas have been involved in the treatment. Systems that operate with larger numbers of small units produce a more evenly distributed effect. However, proper monitoring necessitates taking samples and in such cases the large amount of samples might affect the historic integrity of the fabric.

Hoover building

The Hoover factory in London, UK, was constructed in 1932 by Wallis Gilbert & Partners. After Hoover's production of vacuum cleaners was relocated in the early 1980s, this Art Deco building was vacant for eight years. This resulted in severe deterioration of the fabric. The Tesco supermarket company bought the factory in 1989, and it became a listed building in 1990.
The concrete, which had extensive rebar corrosion caused by carbonation at depths of about 70 mm, could not be repaired in the conventional manner. Breaking out and replacing the affected concrete would have resulted in serious alteration to the visual appearance of the building, and English Heritage insisted that the original concrete be preserved. The realkalisation was performed by the UK concrete repair specialist Makers, who carried out realkalisation projects earlier, such as the Desborough Water Tower in 1991.
The concrete varied in covering and had an average carbonation depth of about 30 mm. The average realkalisation time was four days. Areas up to 400 m² were treated at a time, and within 23 weeks, the total concrete area of about 4,500 m² was realkalised. Also in this case, the effect of the treatment was documented on site by using the pH indicator phenolphthalein. After treatment the surface was jetted and left to dry. A cementitious skim coat was then applied, and the concrete was finally given an elastomeric coating. Although the results were closely monitored, it is still too early to draw

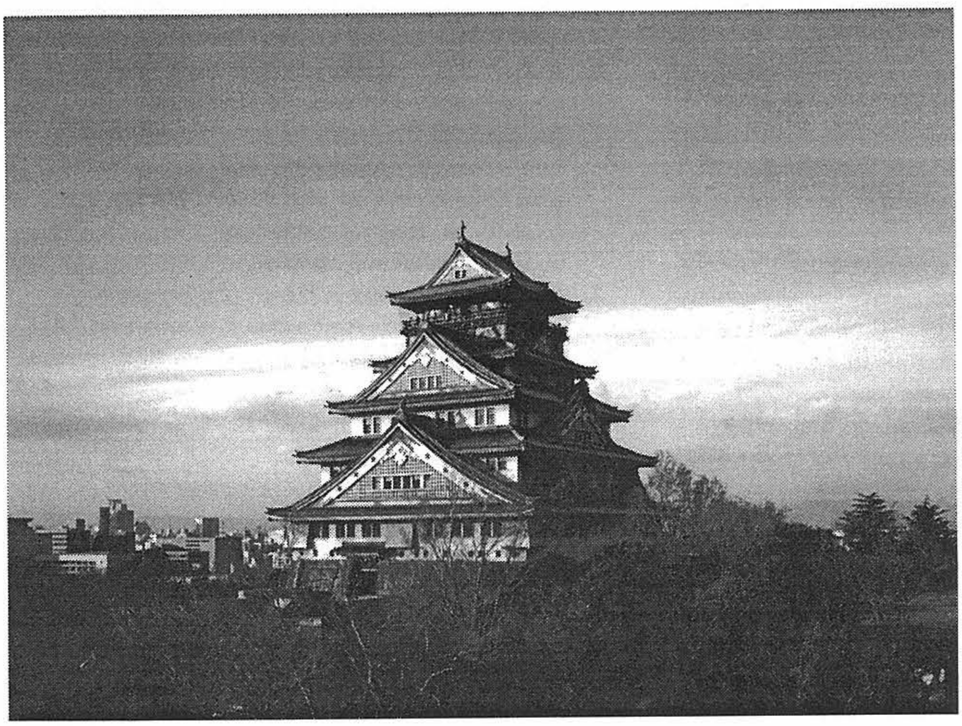
Hoover building in London after complete refurbishment. Photo: courtesy of Makers, UK.

conclusion on long-term effects in this case.
Since the treatment, realkalisation equipment used by Makers has been improved. The rectifiers initially developed by NCT consumed a lot of energy, were heavy to move, and thus required enormous lengths of cable. New, computerized rectifiers are portable and capable of maintaining the current constant by varying the voltage. They are also more accurate and faster then their earlier counterparts and do not require 24-hour supervision.

Analysis
From these case studies, preliminary conclusions can be drawn about electro-chemical treatment as opposed to traditional concrete repair methods. These can be described as the *prerequisites* for the operation of electro-chemical treatment, the practical *disadvantages* of these systems, the *questions* that remain insufficiently answered and the *advantages* of these methods.

Prerequisites
Carbonation in itself is not certain to lead to corrosion, since this depends also on humidity, oxygen and chloride levels. The performance of concrete should be examined and assessed by qualified experts.
The structure should be statically sound at least to a minimum extent. Cracked, spalled or disbonded material should be removed before treatment.
Reinforcement steel should be continuous to ensure an uninterrupted current.
Coated and/or impregnated concrete can be less suitable for electro-chemical treatment. In such cases the process can be much slower and thus might prevent the continuous use of the building.

Disadvantages
Electro-chemical treatment does not improve the static performance of a structure. Severely damaged concrete cannot be repaired only through these methods, and combinations with traditional treatments at the same surface areas implies a significant increase of cost.
Surfaces should be relatively clean before treatment. This might require grit or sand blasting and thus risk damage to the historic fabric. In some cases a finish coating is still required. This is unsuitable for architectural fairfaced or textured concrete.
Monitoring on site should be sophisticated, as drilling cores is destructive and will affect the historic fabric, especially when the concrete is fairfaced and textured. In early concrete structures, the rebar is often not continuous and the concrete must therefore be damaged at many locations in order to connect the rebar sections. In some cases, when certain mineral aggregates are present in the existing concrete, the ingress of sodium through realkalisation can cause Alkali Silica Reaction (ASR).


Osaka Castle in Japan is one of the most recent projects where realkalisation has been used. Photo: courtesy of Denka, Japan.

Questions
Variation in concrete covering can result in variations in the effect of the treatment; typically these differences are equalized over time, but they can complicate monitoring and could require more samples, causing further damage to the building fabric.
It is difficult to find 'second opinions' on the effectiveness of electro-chemical treatment; broader evaluation by practicioners and architects seems to be necessary.
Monitoring on a longer term sometimes reveals contradictory changes in performances, due to the

remigration of ions. At the Bank of Norway initial values were found to have increased, while at Frederikstraat lower values were diagnosed. Although performance remains within safe margins, and durability remains unquestioned, it seems appropriate to require improved monitoring during the first years after treatment.
Because polarity is created between the surface and the rebar, the effect on the chemical environment behind the rebar remains insufficiently clear.
The use of the treatments on post-tensioned and pre-stressed concrete poses specific problems that require qualified expertise.

Advantages

Realkalisation halts corrosion of the rebar by removing the actual cause of this problem. Even corrosion at undetected locations is arrested. In addition, its effect can be monitored immediately on site.
With electro-chemical treatments few temporary supports are required. It is less disruptive than traditional repair methods, which create more noise, dust and vibrations. It also reduces the risk of inducing micro-cracks since extensive break-out of the concrete is unnecessary.
The treatments are relatively environmentally friendly and help to prevent premature demolition. It reduces maintenance needs -and dangers resulting from the repair-at-random approach that often eventually results in damage.
Most importantly, material and design authenticity can be respected to a much greater extent than is possible with traditional repair techniques.

Conclusion

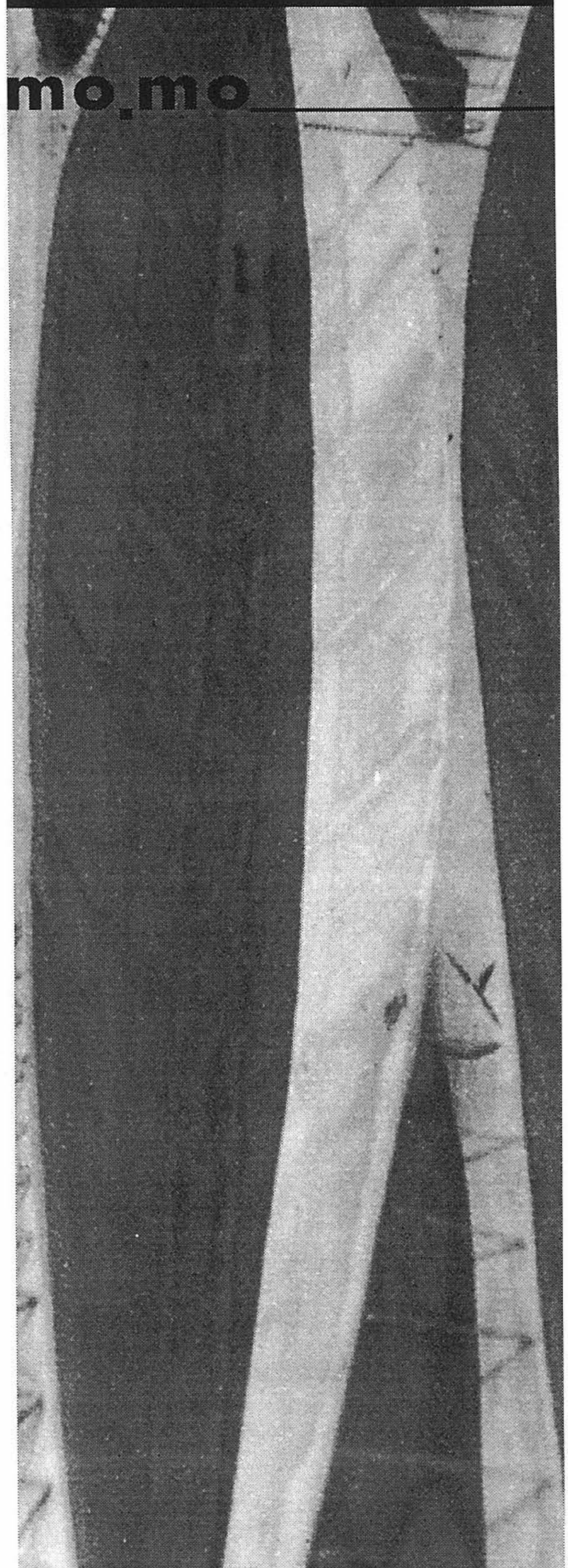
Electro-chemical treatment is a relatively new but promising approach to repairing concrete deterioration at historic structures. The use of these techniques, however, should be based on a full understanding of their prerequisites, their disadvantages, the questions they raise, and their advantages. With any new conservation technique careful documentation, monitoring, short- and long-term assessment of projects where electro-chemical treatment is being applied, and the discussion and publication of the results of case studies will benefit the conservation community.[7] In the case of the Zonnestraal Sanatorium, where traditional methods of concrete repair might compromise the building's authenticity, electro-chemical treatment is being considered as a complementary repair technique for some of the buildings, especially in cases where damage is latent rather than patent. It is essential to understand that both traditional repair techniques and the electro-chemical methods are complementary rather than mutually exclusive. The quality of any conservation strategy lies in making the right architectural judgements on the basis of an informed diagnose in each case.

Wessel de Jonge is an architect with Leodejonge Architects in Rotterdam, The Netherlands. He is the job architect for the restoration of Zonnestraal Sanatorium.

Notes:

1. H.A.J. Henket and W. de Jonge, *Het Nieuwe Bouwen en Restaureren; het bepalen van de gevolgen van restauratie mogelijkheden,* The Hague 1990, pp. 19-21, with English summary pp. 96-100.
2. Jan Duiker, 'Dr. Berlage en de Nieuwe Zakelijkheid', in *De 8 en Opbouw* ,3, 1932, pp. 43-51.
3. The fiber-bed system is therefore less suitable in such a case.
4. Vojislav Ristic' paper gives further details on the actual repair work carried out at the Goetheanum. Some critical comments on the job are included in Rudolf Pörtner's paper on the Liederhalle.
5. A potential is a relative value that refers to a selected standard, or critical reference point, in this case lead [Pb] under the same circumstances.
6. René Ackerstaff's paper gives, from a consultant's perspective, a more detailed account of the durability test program carried out at the Frederikstraat housing complex.
7. An excellent overview in French of experiences with concrete repair is provided in *Monumental* 16, March 1997, published by Monuments Historiques, France.

CASE STUDIES



Restoring brilliant ornamentation

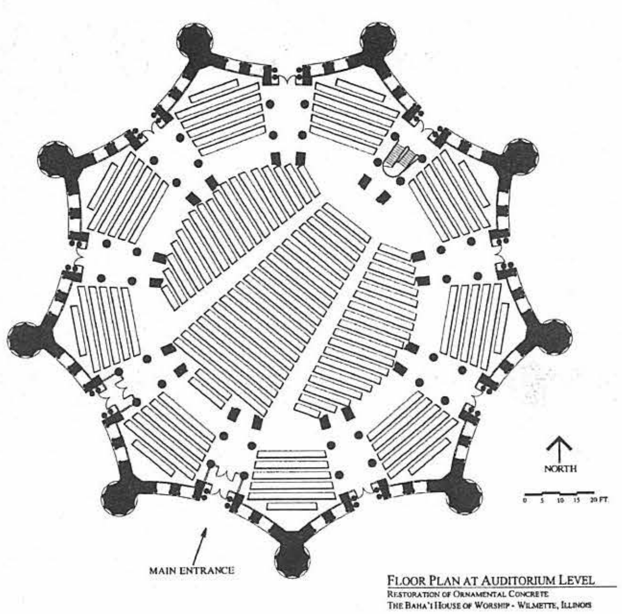
The Bahá'í House of Worship (Louis Bourgeois, 1920-53)

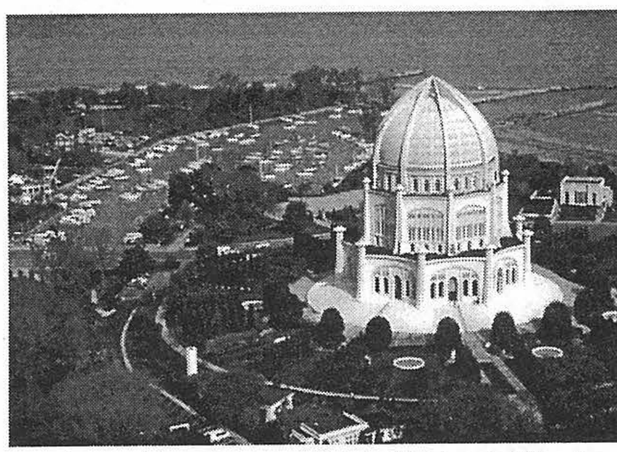
Restoration of architectural concrete presents many challenges beyond the production of high quality concrete. The aesthetic qualities of the finished material must be duplicated in the new repair. Restoration requires matching the aggregates, color, pattern, texture and shape of the original components. Correcting the underlying causes of the deterioration calls for attention to the finest details.

by Robert F. Armbruster

Architectural concrete repairs can be beautiful. Even exceptionally complex, exposed aggregate concrete can be restored to its original appearance.
Restoration of the remarkable ornamental concrete of the Bahá'í House of Worship in Wilmette, Illinois, utilized cast-in-place and precast exposed aggregate concrete of complex geometry to duplicate the existing components. The new work incorporates materials of even greater durability than the original, for the Bahá'ís intend this historic temple to serve for more than one thousand years.
The Bahá'í House of Worship is considered one of the finest examples of architectural concrete. Designed by architect Louis Bourgeois, the House of Worship is notable for its nine-sided symmetry and its mixture of architectural influences. Surrounded by gardens on a bluff overlooking Lake Michigan, the 51 m high Temple features crushed white and crystal clear

Floor plan at auditorium level showing the nine-sided symmetry.

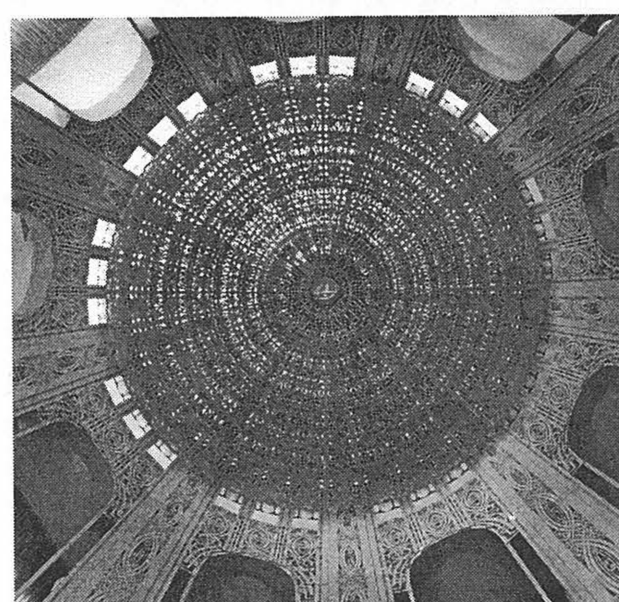


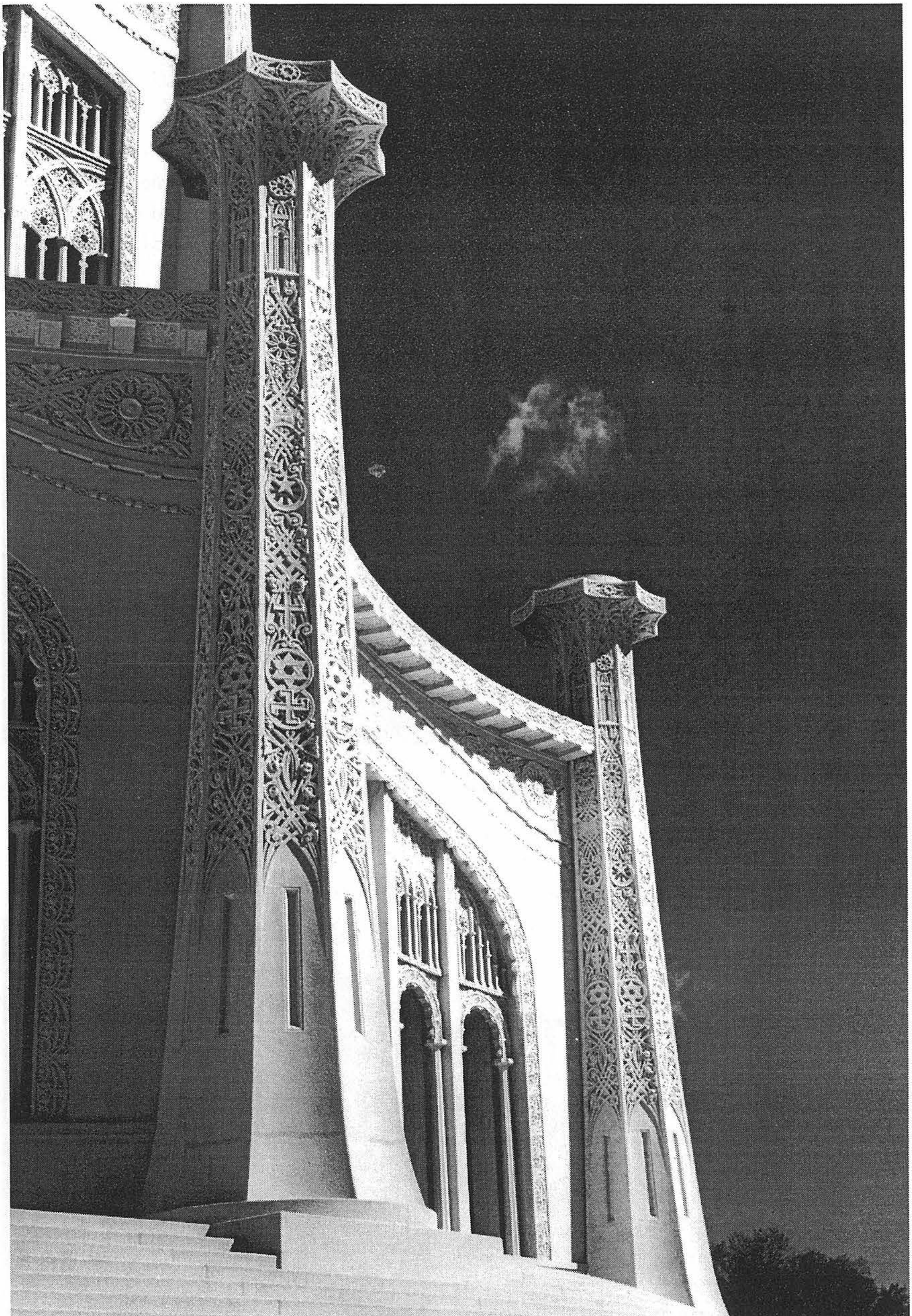


Aerial view of the temple site with Lake Michigan in Wilmette, Illinois. Photo: Bahá'í Media Services.

Next page: Detail of the temple, showing the ornamental concrete. Photo: R. Armbruster.

Interior of the dome. Photo: R. Armbruster.

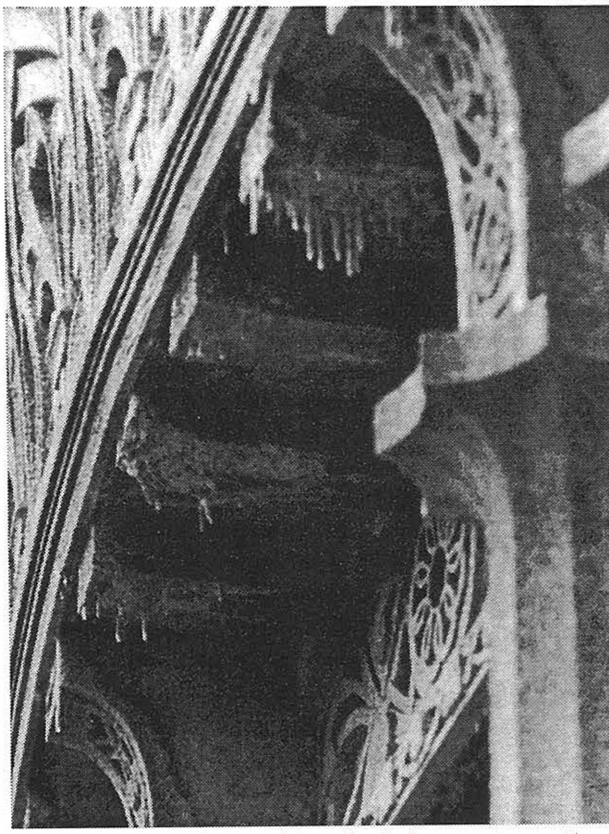




quartz concrete panels which gleam a vibrant white, sparkling in the sun. A dome of precast concrete panels with more than fifteen thousand perforations scatters light throughout the soaring interior space. Additional sunlight is filtered through filigreed architectural concrete panels screening large expanses of glass within three building levels of highly ornamented, curving walls. Construction began in 1920 and was completed in 1953.

John Early

The ornamental concrete was created by John J. Early who became known in the United States as 'the man who made concrete beautiful'. He championed architectural concrete as offering great visual beauty together with economy, design freedom and flexibility unmatched by other materials. John Early was a pioneer and innovator of exposed aggregate architectural concrete. He expanded the optical sensations of exposed concrete with polychrome color from multi-hued aggregates, cleverly devised construction techniques exploiting precast elements and intricate molds, applied coatings of exposed aggregate concrete, and used thin precast components of architectural concrete as forms for cast-in-place structural elements. Many view Early Studio's greatest accomplishment to be the ornamentation of the Bahá'í House of Worship.



Detail of the Bahá'í House of Worship before restoration. Photo: unknown.

Investigation

By 1983, this intricately sculpted concrete was suffering from weathering and the effects of water penetration. Fifty years after their construction, a few areas of the ornamental cladding showed signs of deterioration. Thirty-nine meters above the gardens, a 1 m wide gutter at the base of the dome is encased within the architectural cornice, soffit and dentils of the clerestory. In some of the nine bays, these components exhibited efflorescence, cracking and edge crumbling.

To start the restoration, the project manager formed a team with the structural engineer, contractor and key craftsmen for a unified approach to the investigation and repair. Two years were needed to determine the full extent of the damage. In addition to close-up examinations of the concrete, cores and inspection openings provided the means to explore the interface between the structural concrete and the ornamental concrete and to determine the condition of the original anchors. The source of water infiltration was verified with water testing. Petrographic examination of the cores determined the nature and depth of deterioration within the *in situ* material. Copper-coppersulfate half cell potential measurements and chloride ion analyses assessed possible corrosion activity.

Close-up after restoration. Photo: R. Armbruster, 1993.

Deterioration

A clear picture of the damage finally emerged. The weather-tight and fully functional superstructure of the building was completed in 1931. During seventeen years that followed, the exterior and interior architectural concrete was applied as a cladding. The original copper lining in the gutter extended out over the horizontal edge of the structural concrete where it terminated in a drip edge. Years later, a 120 mm thick layer of ornamental concrete was cast directly against the structural concrete face of the cornice and the copper drip edge. The copper was not modified to go over the new lip of the gutter. In addition, the ornamental concrete had a scalloped top edge projecting above the structural concrete and copper lining, thus raising the overflow point of the gutter. For decades water had entered the interface between the structural and ornamental concrete of the cornice. Trapped, with no means of draining, it saturated both materials. Cyclical freezing and thawing drove deterioration from the interface outward into the white quartz aggregate material and inwards into the plain aggregate structural concrete. Neither concrete material was air entrained. The white quartz concrete proved to be more resistant to the freeze/thaw action. Damage had not yet reached the exterior surface of the architectural concrete in some bays even though deterioration extended deep within that bay's structural concrete. Expansion of freezing water pushed the white concrete away from the structural concrete, creating a gap of up to 30 mm and fracturing the steel anchors tying them together. The building's structural steel frame had not been weakened but the integrity of the concrete cornice was seriously compromised. The condition called for removal and replacement of the architectural and structural concrete.

Versatile repair material

Simultaneous with the engineering investigation, the team developed the exposed aggregate architectural concrete material for the restoration work. Research in the Bahá'í National Archives, laboratory decomposition of material from the building, review of John Early's papers presented to the American Concrete Institute, and discussion with members of Early's original crew were helpful, but it was the knowledge and experience of the craftsmen on the team in particular that led to success through careful experimentation. More than fifty samples were made, many at full size, to refine the concrete mix proportions and the wide range techniques required for forming, casting and finishing different parts of the restoration.
The aggregate in the repair material had to match the original material in color, size, surface density (or packing), exposure and light reflectance. The repair material had to be versatile because it would serve for small patches of existing ornamentation, cast-in-place replacement of large areas, and production of precast panels. The repair concrete need to be air entrained and have a low water-to-cement ratio, yet flow into intricate molds. Materials for the concrete had to be readily available. Production of the finished concrete also had to be economical and of consistently high quality.
The final repair material for the architectural concrete contains white Portland cement, crushed quartz up to 10 mm in size for the large aggregate, finely crushed quartz around 1 mm in size, very fine silica sand, water, a clear water reducing admixture, and a clear air entraining agent. Quality assurance was integrated into every step of the process. Mixing procedures included pre-measurement and independent double checking of quantities. Slump and air content tests were performed on every batch. Cylinder samples were made, cured and tested to verify results.

Fine tuning

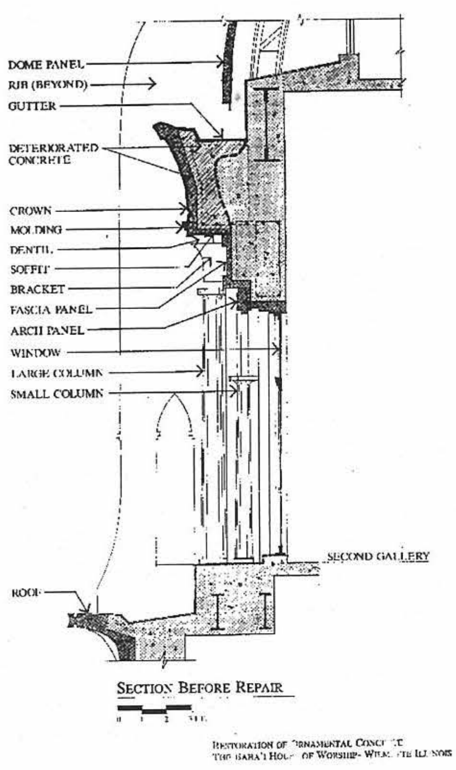
All architectural concrete was mixed on the site in 0.4 m^3 batches using portable mixers. A custom formulated retarding agent applied to the surface of the molds gave the desired exposure of the quartz aggregate. All of the new concrete was cured for three weeks within moisture tight plastic wraps.
For architectural components which had to be replaced, a rubber impression of the original was taken from the building. The impression then served as a mold to cast a positive model in plaster. Sculptors further refined this model to renew the original crispness of the ornamentation. The joints, sides and back of the pieces were shaped, additional plaster models cast, and the entire assembly aligned to fit templates of the building before production molds were created in fiberglass, urethane or wood. The project required sequential replacement of interlocking layers of curving, sculpted elements which had no parallel planes or edges. Dimensional control was transferred between layers as work progressed. For accuracy and production efficiency, a series of templates and jigs were created. Full size mock-ups of complete repair assemblies were built in the shop for testing and fine tuning to the project's exacting tolerances. Specialized hoists and access systems were designed, built and tested.

Different designs

Construction began with replacement of the monumental stairs at the entrance of the Temple. Deicing salts had accelerated cyclical freeze/thaw deterioration. The original cast-in-place upper landing and precast stairs were removed. A new waterproofing membrane was applied to the sloping structural concrete deck below the stairs. To melt future snow and ice, a hot water heating system was installed below the new precast stairs. A cast-in-place landing of exposed aggregate quartz concrete completed restoration of the original appearance. Repairs at the clerestory and crown varied in extent on each of the nine sides or bays. The original concrete in one bay was in excellent condition and the only intervention was the installation of concealed anchors between the architectural concrete and the underlying structural concrete. Restoration of the remaining eight bays involved the complete removal and replacement of all unsound concrete and the copper gutter. The varied depths of deterioration required three different designs for structural concrete repairs below the same architectural concrete repair scheme.

Seamless repair

Workmen removed the weakened white architectural concrete with seven kilogram jackhammers. Core samples were then taken and analyzed petrographically to determine the depth of deterioration. Meanwhile, the crew continued to remove unsound structural concrete, which sometimes



The ornamental concrete before repair. All drawings: Wiss, Janney, Elstner Associates, Chicago.

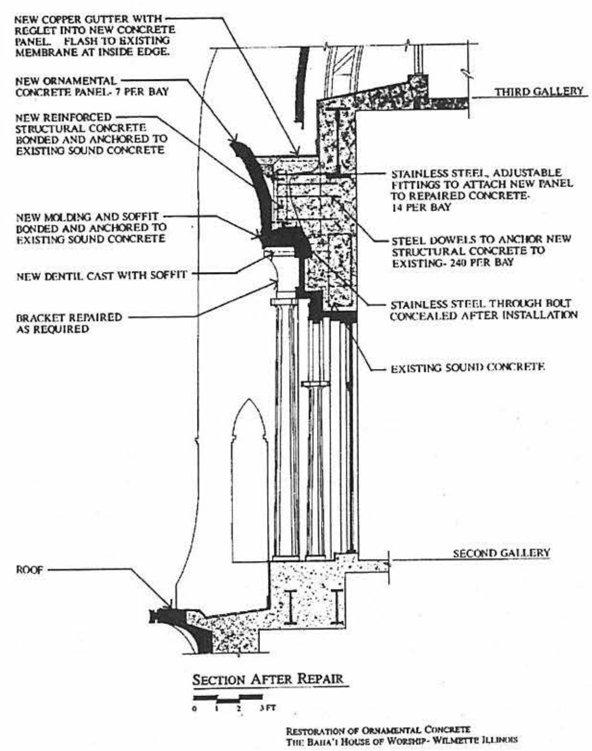
extended 1 m deep. The laboratory results verified the craftsmen's hands-on feeling that sound material had been reached. In some places the petrographic examination also revealed cracks well below the apparently sound surface so the new anchors were extended beyond the cracks.

In each bay, 240 structural anchors were installed approximately 300 mm apart across the remaining *in situ* structural concrete. Epoxy coated steel reinforcing rods were added to follow the curving wooden forms of the structural concrete repair. The craftsmen prepared the existing substrate and then placed ready-mixed structural concrete into the forms. After the forms were removed the concrete cured for three weeks under a plastic wrap.

The crown had rotated outwards due to water freezing within the interface. This movement damaged the projecting ends of the architectural brackets below the soffit. A few fascia panels also suffered deterioration from cyclical freeze/thaw action. The brackets and fascia were patched in place, keeping as much of the historic concrete as possible. After carefully trimming away unsound material, stainless steel reinforcing was added. Flexible urethane molds fit into the remaining ornamental surface to create a smooth transition between the repair and the original concrete. Retarder on the mold exposed the aggregate. The technique created a seamless repair.

Precast panels

To replicate the architectural concrete in the 9 m long

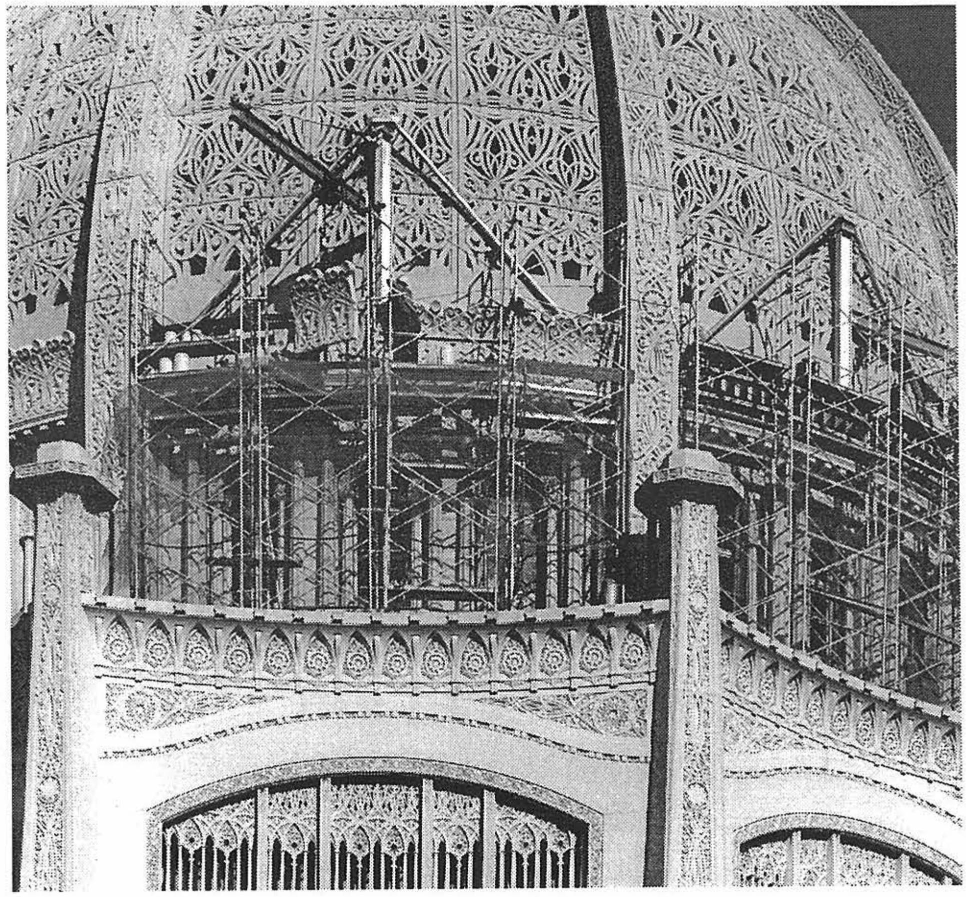


The ornamental concrete at the Bahá'í Temple after repair.

soffit and dentil section, white quartz concrete was cast-in-place using flexible molds carefully fit between the original architectural brackets and fascia panels that remained. The inside surface of the molds was coated with a retarder so that the quartz aggregate could be exposed the next day when the forms were stripped. White quartz concrete was also used for cast-in-place repairs of cracks and freeze/thaw deterioration in the flat architectural panels of the clerestory.

Precast architectural concrete panels were selected to replace the cast-in-place ornamental face of the cornice. By using precast panels the repair could maintain the highest consistency in materials, use an optimum curing environment, provide a free draining internal weep system in the crown, and more easily

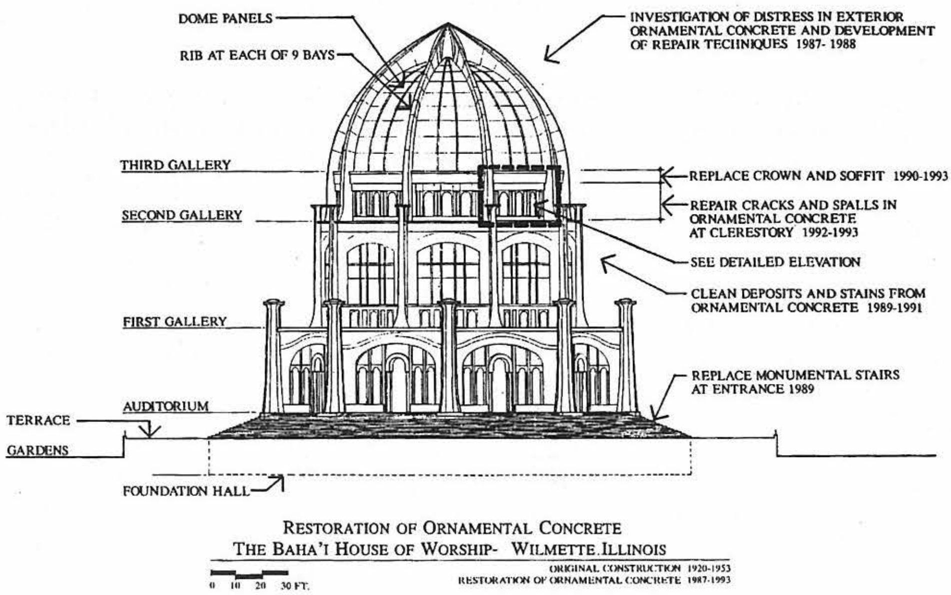
Restoration works in progress. Photo: S. Corrie.



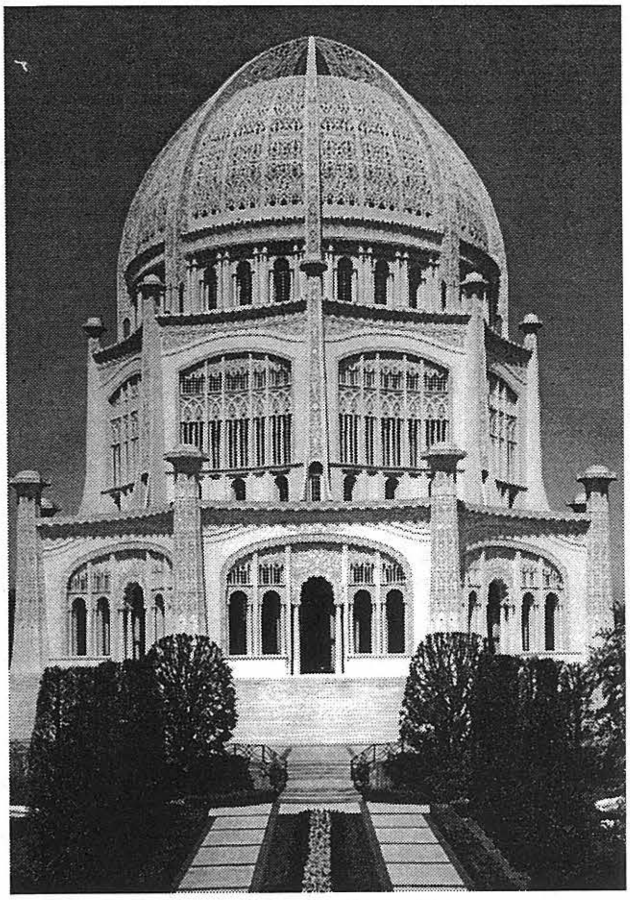
allow for replacement of architectural panels if necessary in the future. Although a cast-in-place repair of the ornamental concrete face would have been simpler to carry out, precast panels offered flexibility in scheduling production, minimized the effects of inclement weather, and reduced material handling high on the building.

The craftsmen produced the precast panels within the Temple's shop with multi-part fiberglass molds. A retarder on the molds let the crew expose the quartz aggregate the next day. The panels were cured before lifting them up to their final position and attaching them to the structural concrete with stainless steel angles and expansion anchors. For the one inaccessible corner of each panel, a concealed, through-panel anchor was invented. The panels were set with 10 mm wide, open joints on the sides and the bottom to provide clear weeping of the cavity behind the panels.

The back of the precast panels included a reglet for tight termination of the new copper lining in the gutter section. Drains were added and the bottom pitched in



Overview of the temple, showing the restoration projects between 1987 and 1993.



Overall view of the temple. Photo: W. Lembke.

every bay of the 95 m long gutter to further improve on the original system.

Future maintenance

The Bahá'í House of Worship always remained open during the seven year project. Having doors on every side of the Temple helped, but a good logistics and staging plan was key. Customized hoisting and access systems provided safety for the hundreds of thousands of visitors to the Temple, efficiency for construction, and protection for the existing fabric of the building. The equipment was designed and built with future maintenance of the Temple in mind. All anchors into the building are stainless steel, recessed and hidden below the surface while remaining permanently available. Equipment is stored at the House of Worship in crates with complete documentation and operating manuals.
From the service driveway and Temple workshops on the ground, a large stationary trolley hoist lifted materials up to the first story roof. Roof platforms permitted the movement of materials around the building on carts to the bay under construction. Small aluminum cranes mounted on the dome then lifted equipment and material between the first roof and the gutter. Curving scaffolding set on the highest roof had adjustable outriggers to give the craftsmen and engineers incremental access to the work. As the crew completed a section they relocated the cranes and scaffolding, leapfrogging equipment around the dome. Another significant part of the architectural concrete restoration consisted of cleaning the exterior and interior surfaces of the House of Worship. Decades of Midwestern climate and urban pollution had darkly weathered the once brilliant ornamentation. The exposed white and crystal clear quartz aggregate lay veiled behind a greasy film with dust, lichen, algae, and calciumsulfate crusts. A three year program of conservation quality cleaning safely removed the deposits without damaging the architectural concrete.

Long term perspective

Early Studios worked for seventeen years creating the beautifully sculpted architectural concrete details on the House of Worship. The Bahá'í National Archives has the architect's full size sketches of the ornamentation and many shop drawings from Early Studios. Yet, the only three dimensional record of the architectural concrete was the Temple itself. So, as an element of the restoration project, a photogrammetric survey was performed so that any point on the surface of the architectural concrete can now be located in three dimensions within 1 mm. If ornamentation needs to be replaced in the centuries ahead, this data could be compiled in a computer-aided design system. Individual architectural components could be defined and a computer-controlled milling machine could create an accurate model for future mold makers.
The restoration of the Bahá'í House of Worship was based on a long term perspective, unified teamwork, and a dedication to excellence. The historic work of Early Studios was respected while developing repair solutions offering economy together with the highest quality. The original architectural concrete has been faithfully reproduced in the finest artistic manner while using advanced technology and refined materials to extend its life far into the future.

Robert F. Armbruster served as director for the House of Worship restoration, for the National Spiritual Assembly of the Bahá'ís of the United States. A licensed professional engineer, he is a consultant from Glencoe, Illinois. Over the last 20 years he has successfully provided project management, design and engineering for a wide range of projects - from Art Deco skyscrapers to New England inns, from shrines in the Holy Land to a home by Tadao Ando.

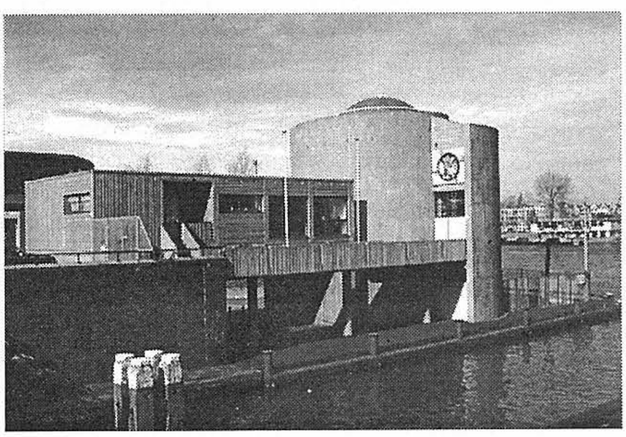
An unobtrusive treatment

Pumping station Parksluizen, Rotterdam (1968)

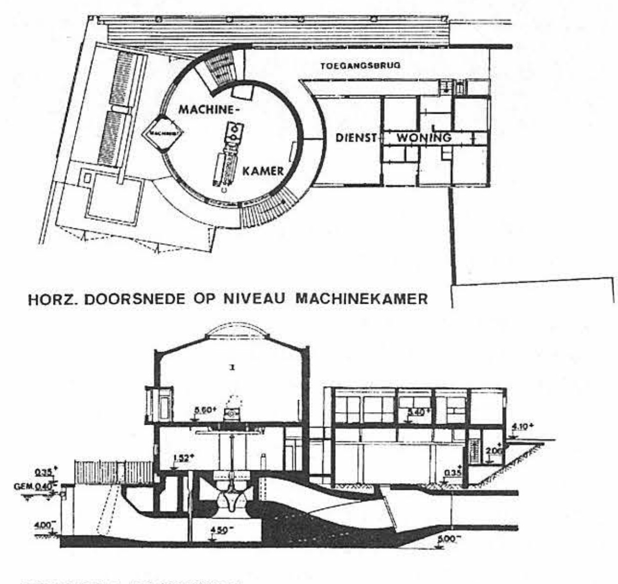
The Parksluizen pumping station was designed as a snail shell, expressing the form of the pumping engine inside. The fairfaced facades of board marked concrete are charasteric architectural features. Regular repairs had turned the face of this remarkable building into a patch work. When a comprehensive remedial program was proposed by the owner in 1994, the municipal Review Committee for architecture and historic buildings demanded greater care for the architectural qualities of this postwar building.

by Heide Hinterthür

The Parksluizen pumping station and the attendant's house, that serves as a bridge between the nearby dike and the station itself, have been designed by Van der Grinten & Heijdenrijk in 1968. The station is designed as a spiral, as an expression of the form of the centrifugal pump that is accommodated in the building. My involvement with the renovation of the pumping station dates from early 1994, as a member of the municipal Review Committee for architecture and historic buildings ('Comissie voor Welstand en Monumenten'). The committee belongs to the Building Department of the municipality of Rotterdam, and is in charge of reviewing the architectural merit of all construction works in the city, whether newly built or renovation jobs. The pumping station and the adjoining attendant's house are entirely constructed in exposed concrete. The board marks on the concrete surface are highly specific for the architectural expression. The surfaces show great differences in profile, which is why at some locations the concrete covering on the reinforcement bars was not sufficient. The concrete surface is rather open and porous and shows many concentrations of coarse aggregates. Damp easily penetrates the walls which leads to corrosion of the reinforcement. The building managers were fed up with the frequent maintenance the building required and wanted a final solution to this technical problem. At the same time, the owner wanted to have it refurbished, as the facades looked extremely weathered and showed many traces of patch repair. The building managers' initial proposal to coat the repaired facade either by a render or by an opaque coating in a colour of the RAL–range was backed up by piles of technical reports trying to convince our committee that there was no other option.



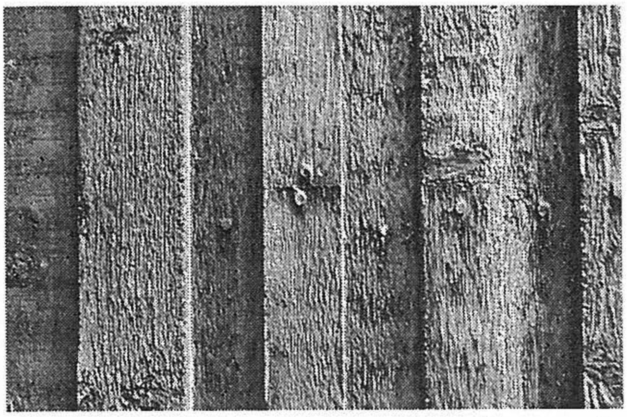
The pumping station seen from the nearby dike. The attendant's house creates a bridge to the engine hall. Photo: W. de Jonge.



Plan and longitudenal section, showing the snail shell of the underground pump being echoed in the plan of the building. Drawings: Van der Grinten & Heijdenrijk.

Brilliance and colour

Almost everyone in Rotterdam knows this building, although many think it is a church. The Parksluizen station is not only well known because of its special



The characteristic board-marked surface of the building caused insufficient concrete covering on the rebar at many locations. Photo: W. de Jonge.

location, elegantly situated at the waterfront, but also because of its specific shape and architectural expression. The building is an outstanding example of late postwar modernism. The year of design, 1968, marks the end of a period in which much care was given to the texture and surface of concrete in general. Because of the technical defects, these beautifully profiled surfaces tend to disappear from the concrete design vocabulary.
In my position with the municipal committee I have often been confronted with the aspects of concrete being vulnerable – not only in the technical sense but also from an aesthetic point of view. Again and again, exposed concrete components on buildings, such as eaves, balconies, plinths or the edges expressing floors or crosswalls, are being painted to hide the marks of repair.
Today, Portland cement is the most commonly used in the construction industry. In repairs however, the blue-gray tone of Portland cement does not match with the sandy tones of the cement that was used in the early postwar period, which was a by–product of the steel industry ('Hoogovencement').
In the majority of cases, an extensive survey to find a matching mortar, with an appropriate design of aggregate mix and colour is beyond the regular budgets. This is the prime reason why mostly standard mortars are used, resulting in contrasting patch repairs that are eventually painted away – often with poor results.
To find the right colour for a paint is one of the main problems. Generally, a blue-gray colour is used instead of the gray–brown or greenish gray of the original concrete, that harmonizes naturally with the tone of other facade materials like the brickwork of the infills. Also, the even tone of paintwork is dull when compared to the typical colour gradations of the original walls.
Painting causes not only a difference in colour, but also a different texture. Often disregarded during the preparation process but hard to overlook when the work is done, is that a painted surface often remains smooth and shiny, instead of the roughness and irregularity of the original texture. The brilliance of the surface after treatment makes the production errors and irregularities much more apparent, and takes away the natural character of the concrete that once provided the right context to make such marks unobtrusive. The brilliance makes the paint coat show itself, rather than the material of the substrate.

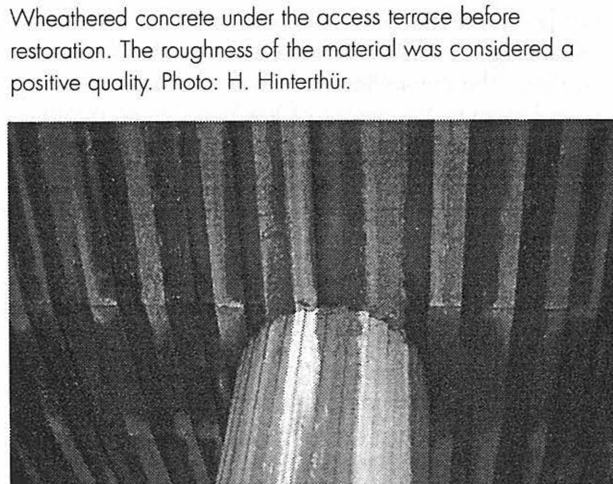
Perception of concrete

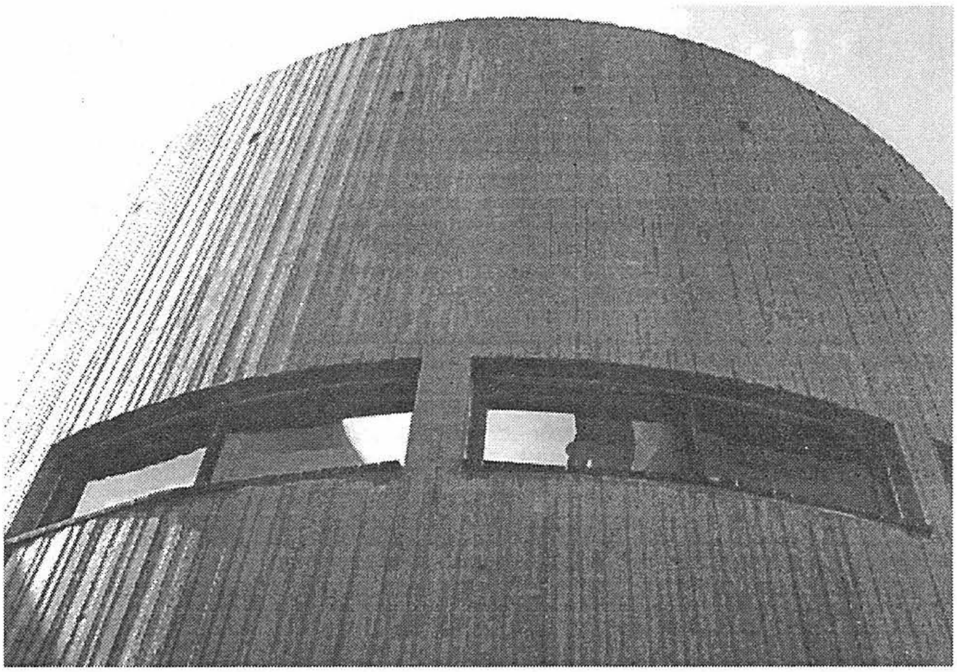
Such changes of the surface can certainly have their effect on the total composition of a facade. The contrast between painted and unpainted parts shakes the balance and, more importantly, the addition of colour can have a great impact on the environment of a building. For instance, by painting the plinth of a building the smooth and natural interrelation with the environment can be lost. The building then becomes a detached and isolated object.
Apart from technical requirements, the decision to paint concrete walls is often purely aesthetically inspired. In the postwar period concrete was a modern and beloved material, though typically rendered to hide the imperfections that resulted from shortcomings in production techniques. Today, the natural colour of concrete is commonly perceived as tame and connected with an image of a construction material.
It is obvious that, to my mind, the coating of concrete is not the first thing to do. For the renovation of the pumping station we have looked for another way. For me, this job has become a pilot project in a survey to find alternative ways and products for concrete repair.

Aesthetic requirements

The first advice of the Review Committee concerned the patch repairs. These were done with an epoxy based mortar which was too smooth and fine in texture and too dull in colour. The committee proposed to redo such repairs employing a more suitable mortar.
The second advice dealt with the rough and irregular face of the facades, which is a characteristic feature

Wheathered concrete under the access terrace before restoration. The roughness of the material was considered a positive quality. Photo: H. Hinterthür.





Surface texture of the concrete surface still enhances the architectural expression of the round volume after restoration. Photo: H. Hinterthür.

of the architecture but at the same time the main cause of technical failure. Our intention was to see whether it would be possible to retain the characteristics of the surface and simultaneously reduce carbonation progress, that was caused by the high porosity of the concrete in combination with the poor covering. In aesthetical terms, the roughness of the material was considered as a positive quality. In the case of the pumping station for instance, this texture had allowed the influences of weathering to show, which adds to the beauty of the building as a whole today. Wind, rain and pollution had painted the concrete surfaces in various ways and these patterns enhance the expression of the roundness of the main volume. Any coating would have prevented further weathering in the future. The committee's proposal was to employ a kind of stain that would be transparent and matt, with just a bit of pigments. The pigments were to hide the patches, the transparency to retain the subtle colour gradations of the original concrete, and the dimness to hide the coating itself. All in all, the committee is very pleased with the way our proposal has been taken up, particularly regarding the absence of brilliance of the transparent coating. The committee therefore has to make a compliment to the owner of the Parksluizen pumping station for turning a purely technical treatment into a restoration job. It has constituted a great reference that will have its impact on the rich concrete heritage of Rotterdam.

Heide Hinterthür is a partner in Topaz Architects in Delft, and was formerly with the Review Committee for architecture and historic buildings in Rotterdam, the Netherlands. She has mainly been involved in material and colour consultancies for a number of buildings, and is the author of several publications on the subject.

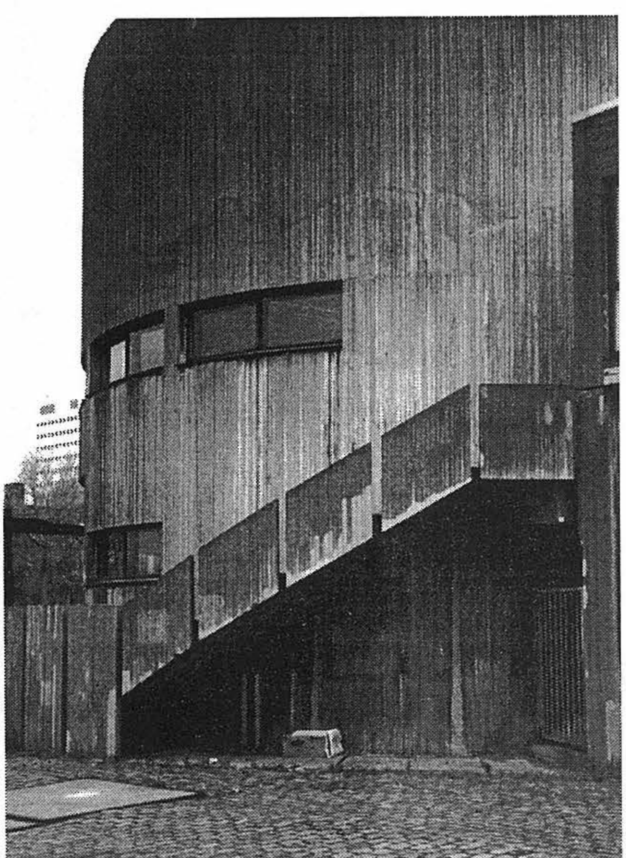
A *brilliant* match
Pumping station Parksluizen, Rotterdam (1968)

Water management is vital to Holland, and this little building is one of the many pumping stations that keeps the *polders* around Rotterdam dry. The characteristic board marks on the concrete faces of the building are decorative, but a major cause of carbonation and concrete damage. Patch repairs did not solve the problem and left an undesirable image. Building manager Van der Zanden went to great lengths to find a remedial treatment that would stop carbonation and would come up to the demands of the Review Committee to match the original architectural qualities of the surface.

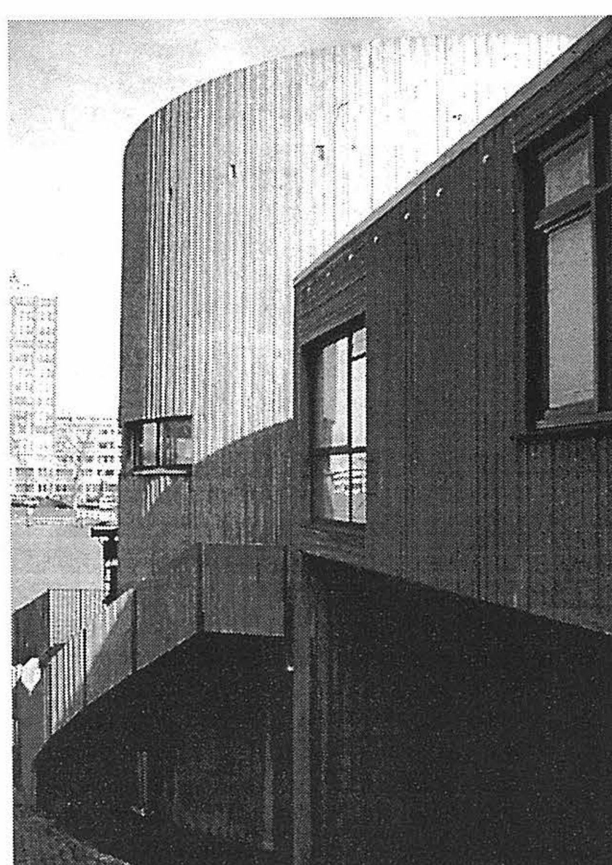
by Koos van der Zanden

The Parksluizen pumping station and the adjoining attendant's house date from 1968. The pumping engine is to carry off the surplus of water from the ring canal of the Delfland polders into the river Meuse.
The station is fully made of fairfaced concrete, producing a rather characteristic texture through the board marks of various sizes all over the face of the building.
Because of the construction method and this surface texture, the concrete covering on the reinforcement was insufficient to protect the steel. At some places, the covering was only 6 mm, causing corrosion of the rebars and, as a result, extensive spalling of concrete.

The round volume of the engine hall before restoration showing extensive patch repair. Photo: K. van der Zanden.



The engine hall after restoration. Photo: H. Hinterthür.



Durable remedy

Until January 1993 regular repairs were done with epoxy based products. A drawback of this method was that the facades soon looked like a patch work. The yellow tone of the repairs did not match the original colour, and the result was not very elegant. Also, the real problem was not solved since the disease was not cured but only concealed. After some time, the disease did reappear at the surface again somewhere else. In February 1994 the Construction Department of our office started a survey to see how the concrete envelope of the building could be renovated so as to reduce annual maintenance to a minimum. We solicited advice from FOSROC and Bouwcentrum Consultancy, and both proposed almost the same treatment:

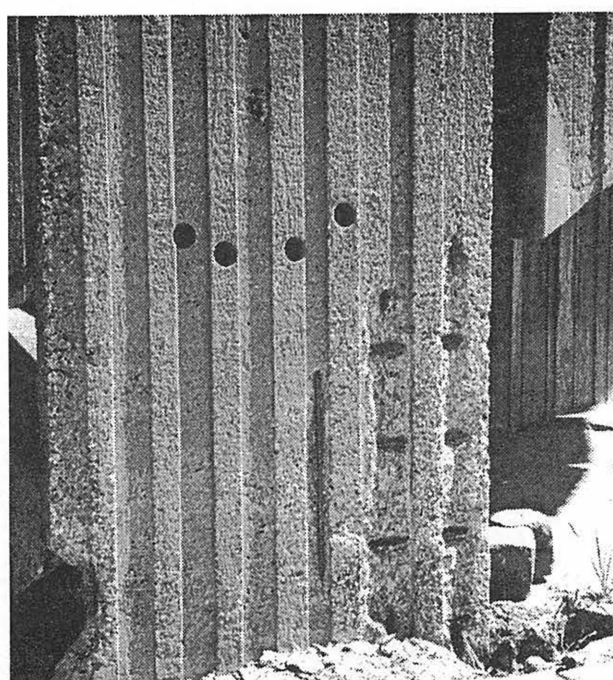
- To blast the facades.
- To break out bad parts.
- To treat the exposed rebar.
- To repair the broken out areas (Bouwcentrum proposed a cement based mortar modified with synthetic resin, while FOSROC proposed a cement based product).
- To coat the full surface (Bouwcentrum proposed a paint coat of either poly–siloxan or an acrylic paint, while FOSROC proposed a thick silan–siloxan primer, plus a methyl–acrylatic topcoat that could be produced in most colours of the RAL–range).

Fickle appearance

The two proposals were presented on site to officers of the city's Review Committee for architecture and historic buildings ('Commissie voor Welstand en Monumenten') and a month later to some committee members themselves. Shortly afterwards, the committee wrote us they disapproved with the repair works as done so far. Although they realized that the treatment did comply with our technical demands, it did not meet restoration standards. In particular the colour and the texture of the repair mortar were to be taken into account. Still, the committee admitted that the building would never become 'spotless'. But they did not favour that either. Quoting from their letter we read: 'The "aged" and fickle appearance of the building is exactly what lends it its character. This character of the building is due to the special texture of the facade surfaces: the direction and relief of the poured concrete and the resulting range of textures are unique. They define the identity of the building'. The committee underlined that the actual texture had to be preserved and carefully repaired. An even rendering, repair with shotcrete, and the application of a coloured coating were strongly advised against. To us it seemed as if the construction failures of 1968 were now regarded as part of the architectural character of the building. Concentrations of coarse aggregates were to be respected and day joints had to remain visible. In our view, the Review Committee took the issue in a very aesthetic way, largely neglecting the very real problem of carbonation and the need for structural repair.

Invisible coatings

FOSROC's initial proposal could fully meet the committee's demands with just a few modifications, and we took that as a starting point. Their repair mortar could be slightly toned so as to conceal the marks between existing material and repairs. Through working on the freshly applied mortar, the existing texture left by the wooden boards could be reprofiled and even the uneven concentration of coarse aggregates might be remade by adding some pebbles every now and then. The full surface was then to be finished with a colourless coat Dekguard Topcoat Transparent. Again we consulted the committee officers about FOSROC's reworked proposal but their concern remained that the original texture would be lost. The proposed repair mortar had a grain of 1 mm aggregates, which was considered too fine to match the existing texture. Moreover, they disapproved the proposed coating



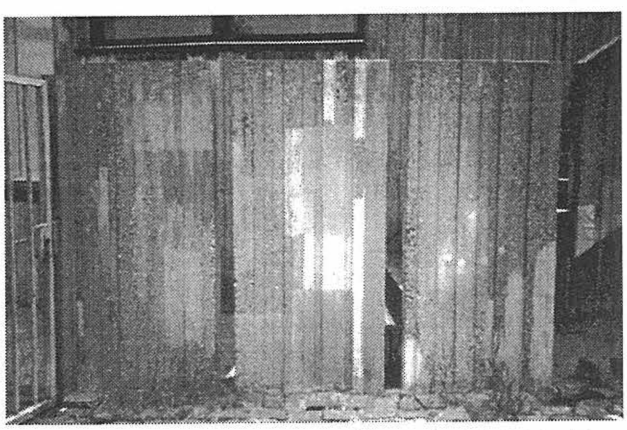
Sample area at the base of the exterior stairs, after removal of carbonated concrete. Photo: K. van der Zanden.

system. Despite the producer's specifications for the surface as matt, the officers considered the result still too brilliant. The proposed alternative, an 'anti–graffiti' coating which is supposed to be completely invisible, appeared from the specs not to solve the carbonation problems.
Committee officers decided to explore other solutions

with the Dutch agent for the German Keim products, and Sigma. Neither could provide a fully transparent coating because a minimum of 20% pigments always remains – which can be an advantage since they might hide older repairs quite well. The mineral products like Keim were rejected altogether because they allow carbondioxide through the coat and do not stop carbonation. Despite the slight colouring, the officers were positive about the Sigma products. The principle of an invisible coating seemed thereby to be abandoned, and also Sigma was invited to propose a remedial program.
Our office decided to invite a third proposal from the Dutch branch of Sika, with which we had very good experiences. Their range include a colourless coating that prevents carbonation progress. All three suppliers submitted a comprehensive proposal in terms of quality and costs. A careful evaluation learned that the quality, the guarantees and the costs of all three were roughly the same, so we asked them to put up samples on site, which they accepted to do.

Three samples

In July 1995, almost fifteen months after our first contacts, committee officers came again to see the

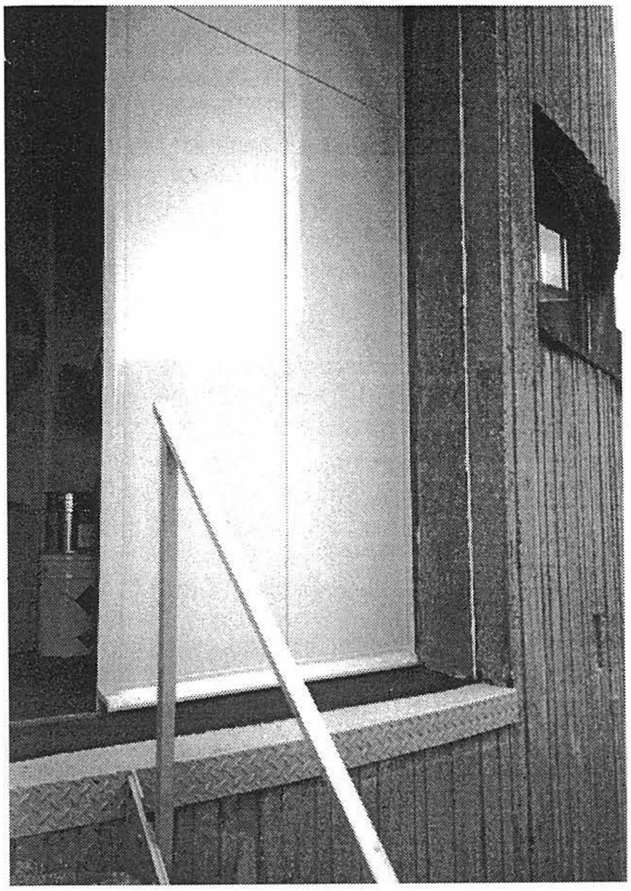


Test repairs by Sigma (left), Sika (middle) and FOSROC (right) showed a potential risk of patchwork effects, similar to previous at random repairs. Photo: K. van der Zanden. *See also colour section.*

samples. All three were turned down and they came back to their first demands: a matching mortar and a fully transparent coating. Frankly speaking, also my office and the invited firms themselves were not pleased with the samples. The story therefore continued, and the firms were offered a final chance to meet to the demands. This time, they were less enthusiastic in offering their help again.
At last, the Review Committee was satisfied with FOSROC's transparent coating, but did not approve the colour of their repair mortar. FOSROC then produced about 15 sample grouts in their labs by experimenting with various colouring additives and the company remained positive to produce the right colour still with a full technical guarantee.
Sika, on the other hand, decided not to tone their repair mortar because the authentic material on the building showed already much variety in colour.
They decided that the basic colour of their mortar should do the job, in combination with a coating. Upon demand, the coating still could be pigmented –before and after treatment. Sika put up a new sample using Monotop 620, that was slightly blasted after curing, and then coated.
Sigma did not want to water down their initial proposal to level the texture with a render, that would produce an even surface. The firm considered it useless to apply an anti–carbonation agent only here and there instead of a full treatment. Their point was, that damage would re–occur on other locations in such a case. Although they were able to match the colour of the mortar and to provide an acceptable coating, they insisted a full rendering was essential to arrest carbonation. The Review Committee could not accept this proposal because the fair face of the concrete would be fully lost. In the end, Sigma decided to propose another levelling render still suitable for patch repair, covered by a colourless coat.
All in all, the three firms met the demands made by my office. Apart from the brilliance and the carbonation–arresting effect, also the permeability was important due to the humid conditions both inside and outside the building. They all offered solutions with a breathing, anti–carbonation treatment, that came up to all regulations and guarantees.
In November 1995 we agreed with the officers on the method and products of FOSROC. The repair mortar eventually used was Renderoc HB 25, that was toned on site. Each 18 kilo bag was mixed with 200 grams Titanium White, 10 grams Yellow Oxide and 5 grams Red Oxide to match the colour of the sample area very closely. The ratio of this mixture was determined in the FOSROC laboratories.

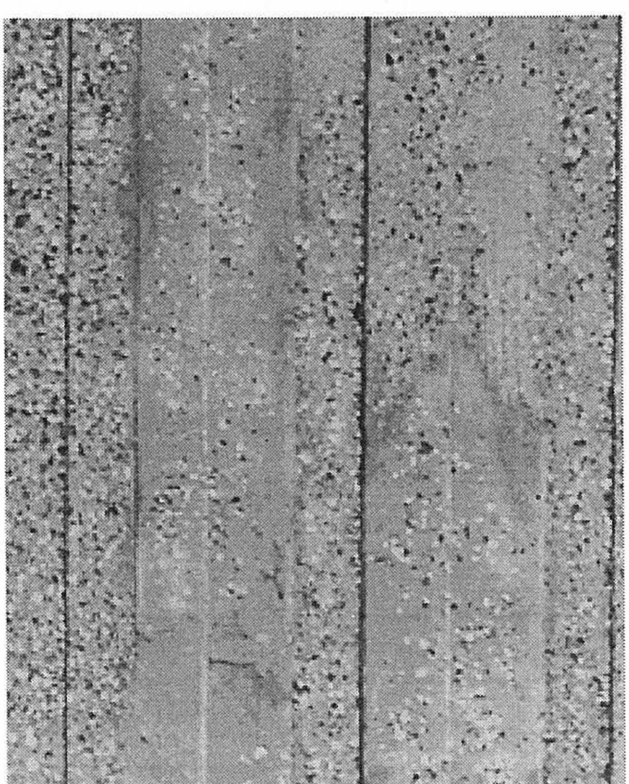
Final compromise

However, the natural variety in colour of the original concrete was so wide that it appeared unfeasible to make the exactly right colour for each patch. This was impossible both technically and financially. For this reason some patches are still visible, while others are almost invisible.
The transparent topcoat Dekguard Topcoat Transparent S was especially imported from Britain. The Dutch version of this product is slightly more brilliant as compared to the British one, which works for 40% as a hydrophobic agent that penetrates the concrete. The remaining 60% serves as a coating and the result is almost invisible.
By inviting five certified companies to tender we could still arrange a contract procedure in concurrence, despite the supplier and the repair method being specified.
To get the job properly done, it was necessary to develop a repair strategy in close cooperation



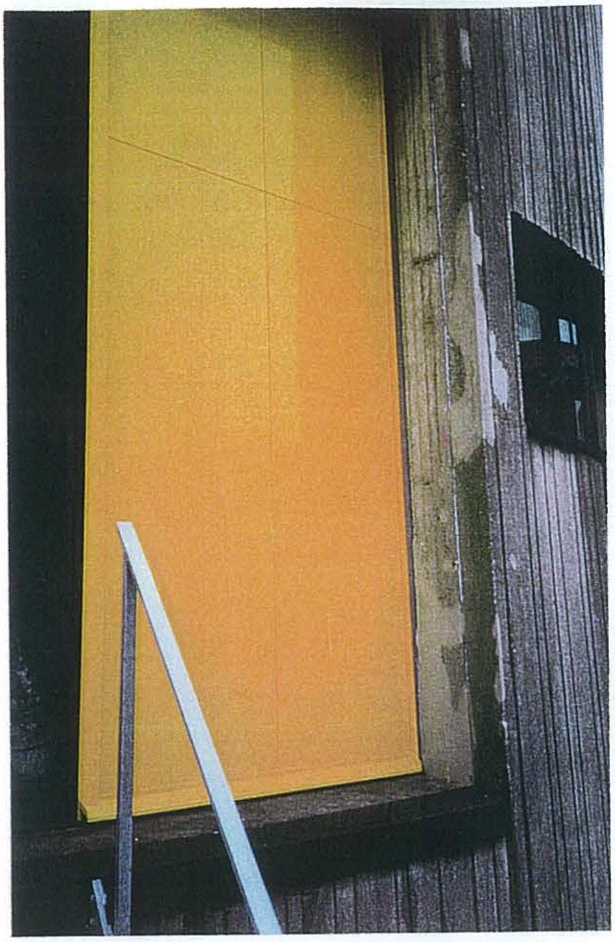
At most locations the repairs match perfectly with the existing material. Almost one-third of the concrete next to the doorpost is renewed invisibly. Photo: K. van der Zanden.

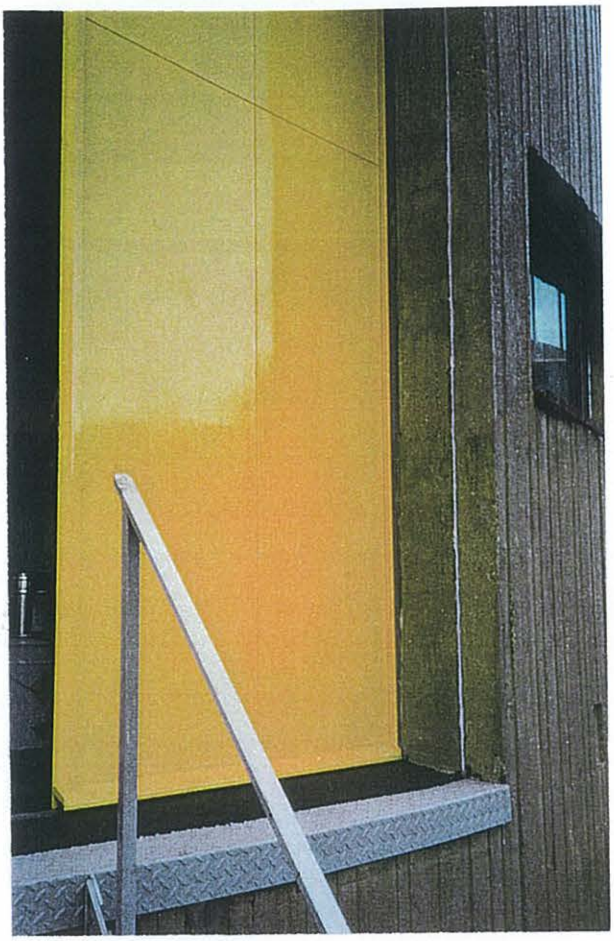
At other locations the substrate appeared different from the sample areas, resulting in a contrast with the repair mortar. Photo: W. de Jonge. *See also colour section.*

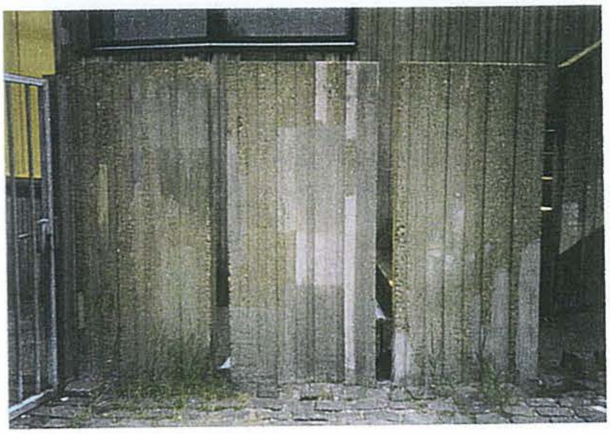


between supplier and applier. In doing so, the guarantees for both the products and the application would be secured. Also, the strict demands by the Review Committee could be more effectively countered if all parties were informed accordingly. The most economic offer was a fixed price for the complete job of Dfl. 300,000.— (V.A.T. included). The job was done between May and July 1996, with FOSROC products as specified.
It is obvious that the interest of a Review Committee might differ from the interest of a client. This case study illustrates that we, as a client, were willing to make more than one effort to meet their demands, although not at all costs. A main problem for my office has been that the preparation period for –what seemed– a simple job extended to over two years. Still, with the applied repair system we managed to find a compromise between the technical and economical demands of the Construction Department of my office, and the aesthetical demands of the Review Committee, without disregarding quality standards in any respect.

Koos van der Zanden is with the Construction Department of the Hoogheemraadschap *water authorities of Delfland, the Netherlands. As a building manager he has been in charge of the concrete renovation of the Parksluizen pumping station. Text translated from the Dutch by the editor.*







Previous patch repair of exposed concrete at Parksluizen pumping station involved materials that were unsympathetic to the original material regarding colour and texture (top, left). Three repair contractors were invited to produce trial repairs that were then evaluated by the municipal Review Committee for architecture and historic buildings; left to right Sigma, Sika and FOSROC (bottom, left).
At most locations the new repairs match perfectly with the adjacent original material (top, right). The original concrete showed a natural variety in colour shades. The repair mortar was carefully designed to match the trial area but did not always meet the original colour on other locations. The finishing FOSROC Dekguard Topcoat Transparent S is virtually unobtrusive (bottom, right). Photos: K. van der Zanden and W. de Jonge.

Investments in an invisible future

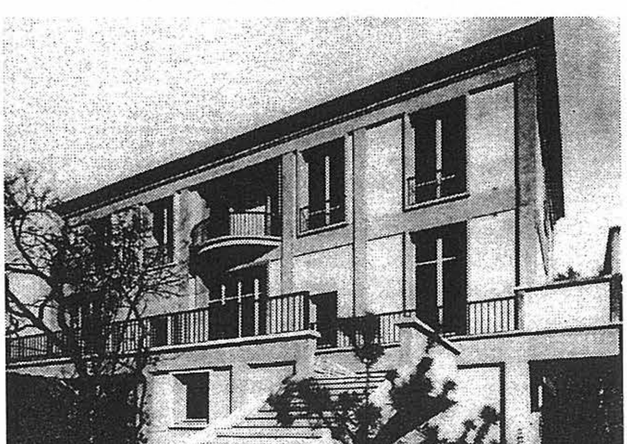
The Nubar Bey Villa at Garches (Auguste Perret, 1931)

Back in November 1995, Perret's Villa Nubar Bey was empty, cold and gloomy and in an advanced state of decay. Renovation work had barely begun -the garden had been torn up and turned into mud, there were piles of debris everywhere and the pipework was exposed. Meanwhile, work on the site had been halted and the architects' enthusiasm sapped by the public transport strikes paralysing the whole of France. Unfortunately, it wasn't only the strike that was holding up the work -the estimated cost of renovating the concrete exterior had caused the client to hesitate. Today, however, the restoration work by the Brussels' architects George and Bernard Baines is finished successfully. The villa, which has experienced a whole series of mishaps over the years, has come through the ordeal of its renovation in spite of strikes and the client's financial concerns.

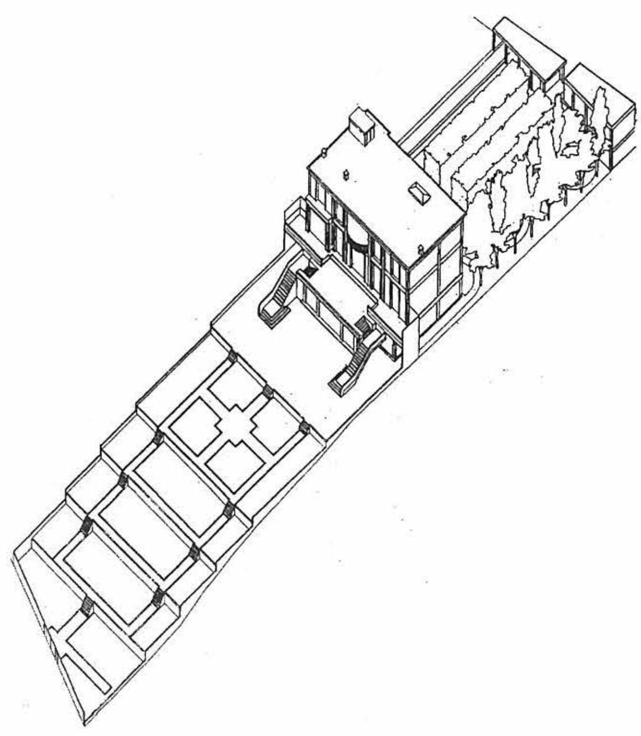
by Valérie Ortlieb

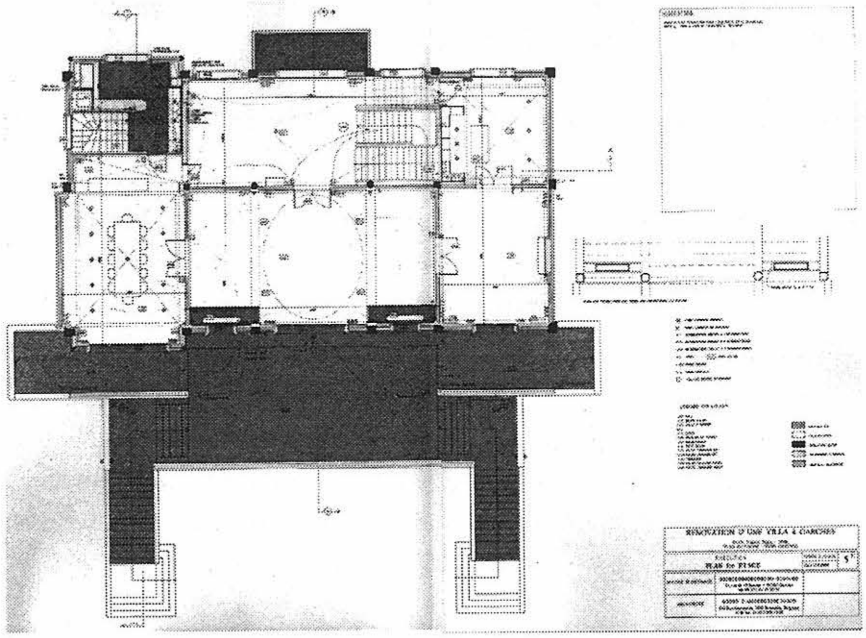
Auguste Perret built the villa in 1931 for the Egyptian 'bey' Arakel Nubar. It is located in the hilly suburbs to the west of Paris at Garches, near Giò Ponti's villa L'Ange Volant (1926) and less than a kilometre from Le Corbusier's Villa Stein de Monzie of 1927. The main house is located in the centre of a long, narrow plot. It is built on three levels and covers a total surface area of over 900 m^2. The rectangular building is flanked by an impressive terrace to the south and a cornice of the kind that is typical in Perret's work. The first floor has the entrance hall, an oval antechamber and a summer room, all in a row, plus the servants' areas. The second floor is a *piano nobile*, given over entirely to reception rooms with a 4.9 m high ceilings. The top level has the bedrooms and two bathrooms. The remainder of the plot consists of a long garden and terraces to the south, symmetrically planted with pine trees. The caretaker's quarters are located on one side of the entrance gate to the north and a three-car garage, opening onto the street, on the other. The structure is conceived around a concrete skeleton of posts and beams, that is bush hammered on the exterior, flooring blocks and internal partitions in *mâchefer* tiles.[1] The facades are articulated by the visible skeleton. The infills of the

A period photo of the garden terraces, as published in *l'Architecture d'Aujourd'hui*.

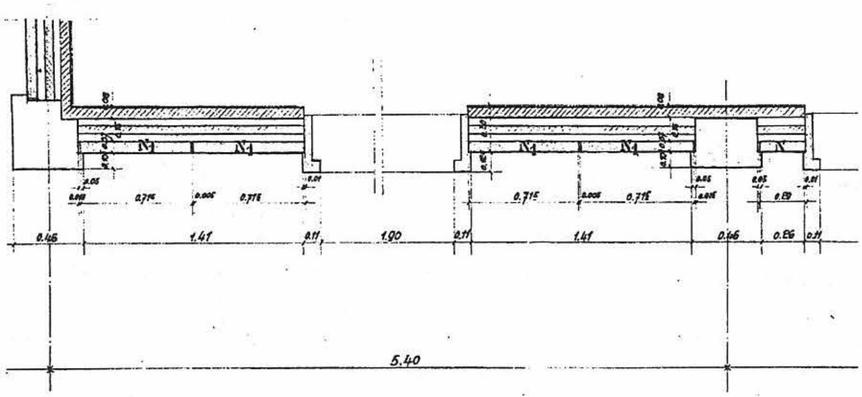


Axonometric drawing of the villa by Perret dated June 1930. The terraced garden to the south was sold and built on. Drawing courtesy of IFA Archives, Paris.





Second floor plan of the Villa Nubar Bey. The floor areas shaded in grey were redone. Drawing: Baines architects.



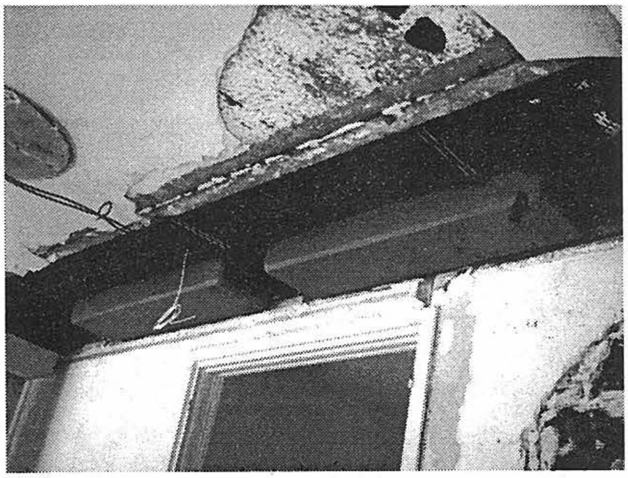
COUPE a= a

Perret's plan indicating the various details for the external walls. The posts are of bush hammered concrete, the slabs numbered N1 are in stone and the two interior walls are clad in *mâchefer* tiles. Drawing courtesy of IFA Archives, Paris.

exterior are done in three layers separated by cavities: there are two interior layers of *mâchefer* tiles and an external layer of stone slabs for the main elevations to the north and the south, and slabs of bush hammered concrete for the side elevations.
The windows are uniformly vertical, an approach which Perret, unlike Le Corbusier, was happy to explain: 'The vertical window frames man, it matches his figure [...] the vertical line is the upright position, it is the line of life.'[12] With horizontal windows, by contrast, the 'light is badly distributed, the floor is left in the shade -beautiful parquet, tiling, mosaics and carpets are sacrificed- and the ceiling remains in shadow, too.'[13] The casings of the single-glazed windows are oak, fixed to frames of bush hammered concrete which are themselves attached to the skeleton. The metal shutters are also fixed to the concrete frames and are drawn back inside them. An identical approach is found in other Perret constructions, including the dwelling and office building in Rue Raynouard in Paris.

Adaptations

The villa has experienced a number of modifications. The previous owner sold half of the southern part of the plot, robbing the property of its terraces. It was shortly after this, in October 1976, that the villa was given protected status in the *Registre Français des Monuments Historiques*. The same owner altered the first floor by removing some of the partitions between the servants' bedrooms and installing his library there. He also removed one of the two curved walls around the oval antechamber.
At the outset of the restoration project, the architects established a guideline to determine which elements to restore to their original state and which to alter. The articles written by Perret, careful examination of the villa itself and a study of the Perret archive at the *Institut Français d'Architecture* (IFA), which includes around 200 drawings and a set of correspondence, were of great assistance in this process. Perret drew a clear distinction between a building's 'permanent conditions' (which determine the structure) and 'transient conditions' (changing human functions).[4]
He created a sharp hierarchical relationship in which transient conditions were made subordinate to permanent ones. He wrote: 'Reinforced concrete has to be used virtuously. The skeleton has to be studied so that it remains visible and fully legitimated -the building's loveliest ornament.'[15] The facade especially

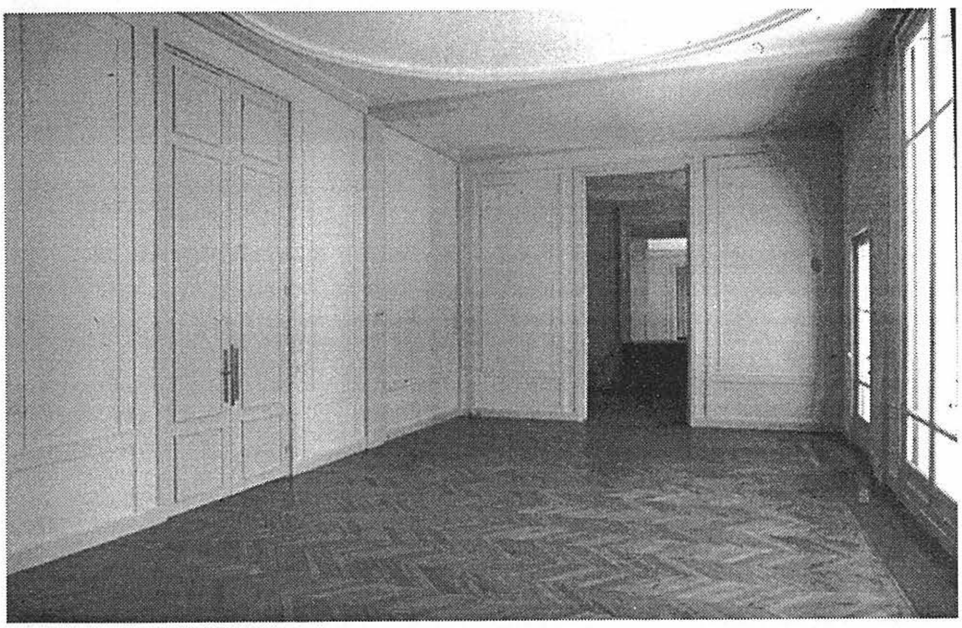


The new underfloor convectors of the main lounge on the first floor, as seen from the ground floor before the false ceilings were reinstalled. Photo: B. Baines.

rooms Perret provided -including sleeping quarters for several servants- were no longer required.

Fitting in the installations

On the first floor, the curved wall of the antechamber was restored. The idea of the library, however, was retained and a window in the exterior wall was even added to match the original ones. The sanitary facilities on this lower storey were entirely replaced. The walls were recovered with stapled *Botticino* marble plates. The existing white stone floor tiles of mottled *Larrys* limestone were sanded down and extended to cover virtually the entire first floor.
On the second floor, the layout of the rooms was again retained. The main change was the removal of two cast-iron radiators in the main lounge, which were replaced with four underfloor convectors below the parquet, taking advantage of a free space in the



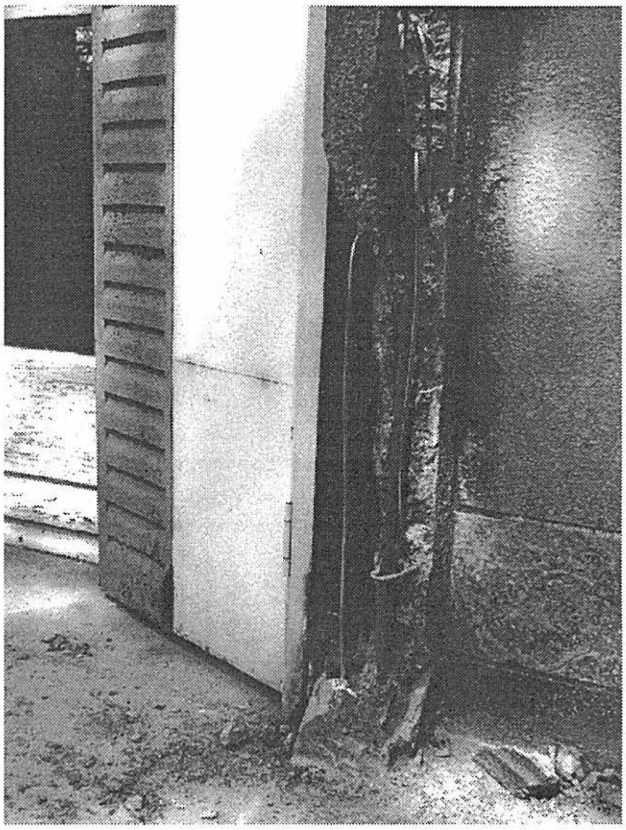
The main lounge on the second floor after restoration. The oak grilles cover the convectors. Photo: B. Baines.

was viewed as a kind of 'outer clothing that imposes its sense of order on the successive alterations made to the interior regime.'[16] This confirmed that although the facade and the representative spaces clearly needed to be restored as faithfully as possible, the servants' quarters could be altered and brought up-to-date without harming the ensemble. Unlike the alterations carried out at Le Corbusier's Villa Stein, which was split into several apartments, this time circumstances were more favourable with a client who wanted a dwelling for his sole use. Nevertheless, the villa had to be adapted so as to meet the demands of modern living and the client's specific wishes, particularly with regard to sanitary facilities, heating and electricity. Although Perret was fully aware of the constructional innovations of his time and applied them with great interest and ingenuity, he made few concessions to comfort in this villa. The bathrooms were particularly dull, covered in ceramic tiles of the most common type with visible pipework. The heating was also inadequate and some of the

false ceiling of the first floor. On the third floor the two bathrooms, which were absolutely not to our client's taste, were totally transformed. The main bathroom was significantly enlarged by the incorporation of an old dressing room. It was totally lined with 'open-book' marble. A second bathroom for a guest room on the north side replaced a former servant's room. The number of radiators was virtually doubled, the water piping entirely replaced, as was the electrical wiring and home automation system. The most laborious task however, was to trace out, on site, possible solutions for the installation of new conduits, ducts and cabling to minimise potential damage to the wall coverings, including the wood panelling of the main lounges on the second floor.

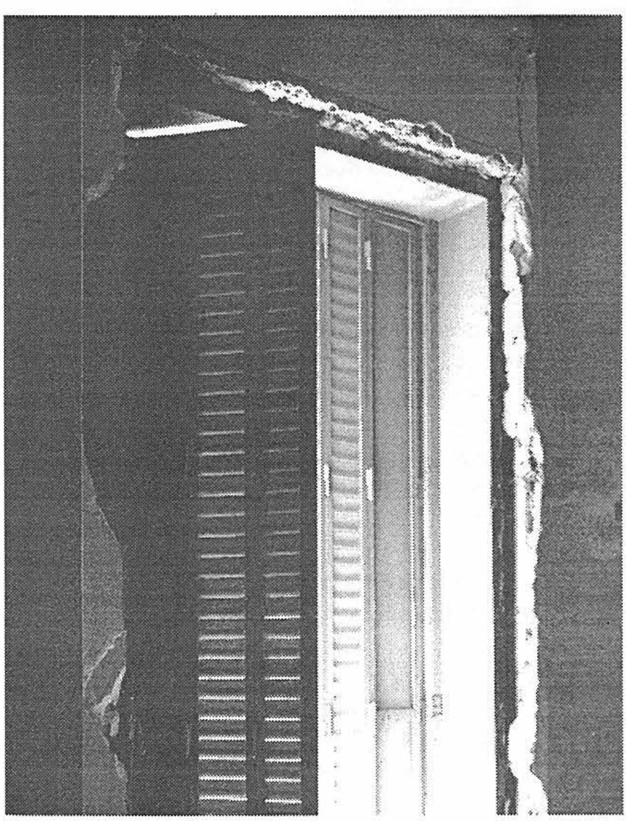
Excellent concrete

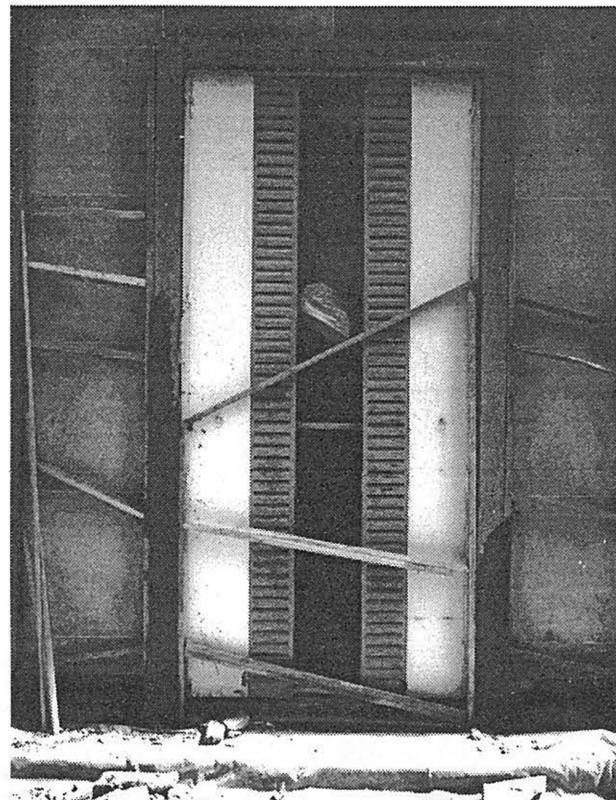
The exterior work proved the most delicate aspect of the job as far as the lasting quality of the villa was concerned. It was also the most difficult aspect to sell



Repairing defective concrete on a window frame. The existing reinforcement element has been treated with a passivating agent, while the new ones are made of 'zintane'. Photo: B. Baines.

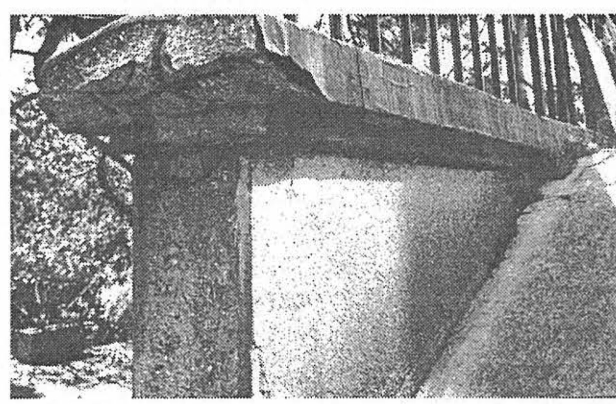
The interior walls were badly damaged during the removal of the window casings. The fibrous plaster cornice collapsed in one of the main lounges. Photo: B. Baines.



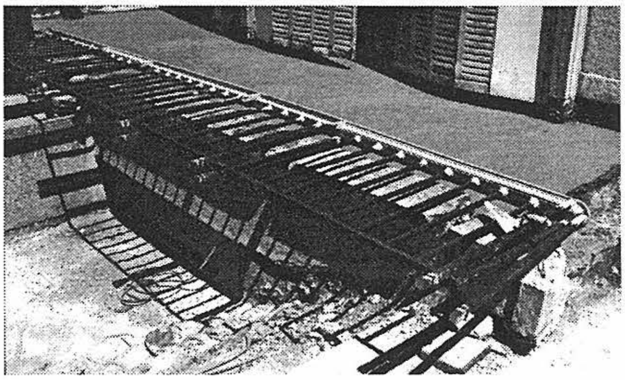


Repairing defective concrete at a window frame. The two existing steps from the lower to the upper terraces are under the plastic sheets. Photo: B. Baines.

End of the low wall of the main terrace during restoration. The handrail leans outward, the upper part of the wall has been shifted by thermal expansion of the terrace pavement. Photo: B. Baines.



to the client, in that a great deal of money was required for results that were not particularly dazzling. The job included the restoration of the concrete window-frames and metal shutters of the external walls and the complete repair of the terraces and balconies, which were allowing water to seep into the interior. The restoration of the concrete exterior walls was undoubtedly the most difficult item to estimate.
Close inspection of the state of the concrete surfaces was slow and only revealed part of the true extent of deterioration. At first sight, it appeared that rusting reinforcement was only threatening to cause some



The terrace wall fell apart when the handrail was removed. In the background, the state of the metal shutters before restoration is also apparent. To the right, the new kerbs run the length of the wall. Photo: B. Baines.

minor spalling of the concrete surfaces. Perret used concrete of excellent quality which, when all said and done, has served its purpose very well. Some of the reinforcement elements were located barely a centimetre from the bush hammered surface and several cracks had been concealed by painting.

Cosmetic patina

An architect specialising in the restoration of Perret's concrete work, who had just completed the restoration of the church at Raincy (Auguste Perret, 1922), was then invited to draw up a cost estimate and specifications for the works. The estimate was extremely high, calculating that 90% of the concrete window casings would have to be demolished and remade, employing stainless steel reinforcements. The client rejected this solution and the works were suspended. After discussion, it was agreed to restrict the intervention to a lighter, 'cosmetic' renovation of the exterior. The specifications were based on a photographic survey which allowed areas in need of repair to be located and assessed. The invited firms were all recommended by the *Conservatoire des Monuments Historiques*. The successful tenderer was the same firm that had carried out the restoration of the church at Raincy for *Monuments Historiques*.

The defective concrete was removed by hand to expose the reinforcement which was brushed and treated with a passivating agent. Where it was missing or too badly damaged, it was replaced with elements made of 'zintane' - an alloy of zinc that is more flexible than stainless steel and can be welded, and is fixed with zinc wire. A new concrete, matching the existing aggregate texture and tone, was framed, poured and bush hammered. A patina was then added to match the new sections with the conserved ones. More fundamental work had to be performed on the garage. For safety reasons, the car doors, which opened directly onto the crossroad, were moved to the garden side. Grit-blasted facade tiles identical to Perret's were used to close off the original doors.

The overall result of the concrete repair work was satisfactory, although there is a risk of repeated deterioration in future years which will have to be treated in a similar manner. This approach was, however, more in line with our client's budget and the objectives of the commission.

Changing levels

The problems encountered during the waterproofing of the terraces and balconies and the reinstallment of the *Magny* stone pavement were somewhat different. The pavement of the main south terrace had to be protected from excessive thermal expansion which had caused shifting and distortion in the low south wall, leading to cracks and hence water penetration.

The south terrace after restoration. One of the two steps has disappeared. The new kerb is running all along the south wall, against the stone slabs and the low ends of the concrete window frames. Photo: B. Baines.

A complicating factor was that new French building regulations concerning curbs and slopes of flat roof constructions had to be met, in order to obtain a ten-year guarantee from the contractor.
The stone on all the terraces and balconies was carefully removed, and so were the old membranes and slopes. New slopes in cement, reinforced with welded rebar nets, were then installed. Several layers of waterproof membranes followed by 20 mm thick units of a water-repellent insulation material were put on. Over a layer of sand *the Magny* stone units were then put back in place with lime mortar, and repointed. Four new rainwater drains were installed. The new regulations demanded a minimum curb of 100 mm from the membrane up, and a minimum of 50 mm between the finished pavement and the curb level. This constraint required to raise the entire low wall. To achieve this, it was intended to remove the handrail, and to demolish the wall and repour it, increasing its height with 150 mm. During removal of the handrail, however, the concrete already fell apart. It was remade according to the new dimensions, after which the handrail was remounted and a new copper flashing installed. This regulation obliged to change the levels of terraces and curbs to such an extent, that also one of Perret's two steps between the two small side terraces and the main terrace could not be kept.

Window sills

There was no curb directly under the windows overlooking the terraces and balconies. Creating one entailed the complete removal of the jambs and posts of the oak window casings, the removal of the original cast iron sill, the construction of concrete curbs of sufficient height and the reinstallment of the original sills. The new kerb had to be protected by a meshed facing and turned out thicker than anticipated, unfortunately projecting out as compared to the adjacent surfaces. The window casings then had to be replaced, having been duly shortened. The problem of the window sills remained with us throughout the project. A great many problems and constraints of varying type arose, rendering our work particularly difficult.
It was only after a joiner of sufficient calibre was found that it became possible to find solutions that met the wishes of the client and French building regulations as well as the project's objectives and the desire to respect the exterior of the building.
The single instance in which the rebates depth had to be increased to allow for double glazing units to be installed in a frame of only 46 mm thick and 42 mm high proved particularly tricky. None of the many other joiners that were encountered was prepared to take on such a difficult job. A great worry was that the concrete frames of the window openings would collapse during the removal of the window casings. Their slenderness posed a severe challenge: how was a bush hammered concrete profile 45 mm high and no more than 60 mm thick at its narrowest points to support oak window casings and heavy metal shutters after suffering the elements for 60 years?

Future interventions

These fears were renewed when the time came to work on the metal shutters. The largest ones could no longer be used because of their weight, while others were rusted fast. One of the first solutions considered was to cut them down, leaving only the final part, which is visible when the shutters are folded up. This was not a satisfactory answer, however, because some protection from the sun was still needed. It was finally decided, in consultation with the client, to deal with the most pressing problems by fixing the shutters that were about to fall down with metal fasteners attached by screws, which were glued chemically into the concrete frames. The shutters were brushed off to remove the rust and then painted with an anti-corrosive agent. This is certainly not a permanent solution and especially the large ones of the shutters treated in this way remain extremely difficult to operate. Nevertheless, they have been salvaged from the scrap-heap and may be restored on some future occasion.
Throughout the renovation process the same basic principle was followed that future interventions had to remain possible. The garden in particular needs sorting out. The file containing our plans has been placed in the Institut Français d'Architecture together with a series of site photographs, to suggest further work on the villa to be done in the future.

The project for the Villa Nubar Bey in Garches was prepared by the Brussels' architects firm George and Bernard Baines from May 1994 to July 1995. The works were executed between July 1995 and February 1997. The author has been an assistant architect for the job, and is now an architect in Switzerland. Translation by Ted Alkins, CT Belgium.

Notes:

1. Type of thin, plaster tiles made from the iron ore ash produced by blast furnaces and tensioned using copper wire.
2. August Perret, 'Habitations', *Miroirs du Monde*, no. 318, 1936, p. 5-11.
3. Auguste Perret, 'Les besoins collectifs de l'Architecture', *Encyclopédie Française*, Volume XVI, section 58, 1935, p. 6-12.
4. See Robert Gargiani, *Auguste Perret*, Gallimard/Electa, 1994, p. 96-115.
5. Auguste Perret, 'Les agglomérés', *Encyclopédie Française*, Volume XVI, section 20, 1935, p. 12.
6. Note accompanying the competition for the refurbishment of the Galeries Lafayettes in Paris, 1930.

A delay of decay

Notre Dame de Royan (Guillaume Gillet, 1955)

Since its construction, the Notre Dame de Royan has been a symbol of liberty for a city devastated by war. The sculptural expression of the elliptical cathedral is enhanced by an extensive use of exposed concrete, that characterizes as well the interior. In 1986, concrete failure had proceeded to such an extent that the bells of the church had to be silenced. Previous patch repairs appeared insufficient and a long term remedial program was initiated in 1989, carefully matching the original textures and colours. A first phase of the works has been concluded and last year, Royan could again enjoy the sound of the bells of the Notre Dame. But architect Philippe Oudin questions the long term effects of the repairs, that might only delay further deterioration. A critical report.

by Philippe Oudin

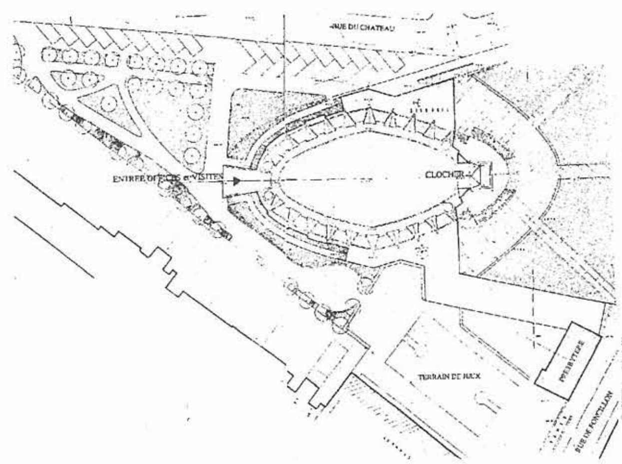
The urban plan for the reconstruction of the city of Royan after the raids of April 1945, was conceived by Claude Ferret. His scheme was aimed at an entirely new urban image, as a symbol of a new liberty. The reconstruction of the church of Notre Dame was commissioned to Guillaume Gillet after a competition in 1953, and it was built between July 1955 and July 1958. The cathedral represents an important step in the history of construction and religious architecture of the 20th Century in France. It was listed as a Historic Monument on February 10, 1988. Both the inside and the exterior of the church of Notre Dame presents a characteristic fairfaced concrete with exposed granulates.

An aerial view of the Notre Dame in the urban context of Royan. All photos courtesy of P. Oudin.

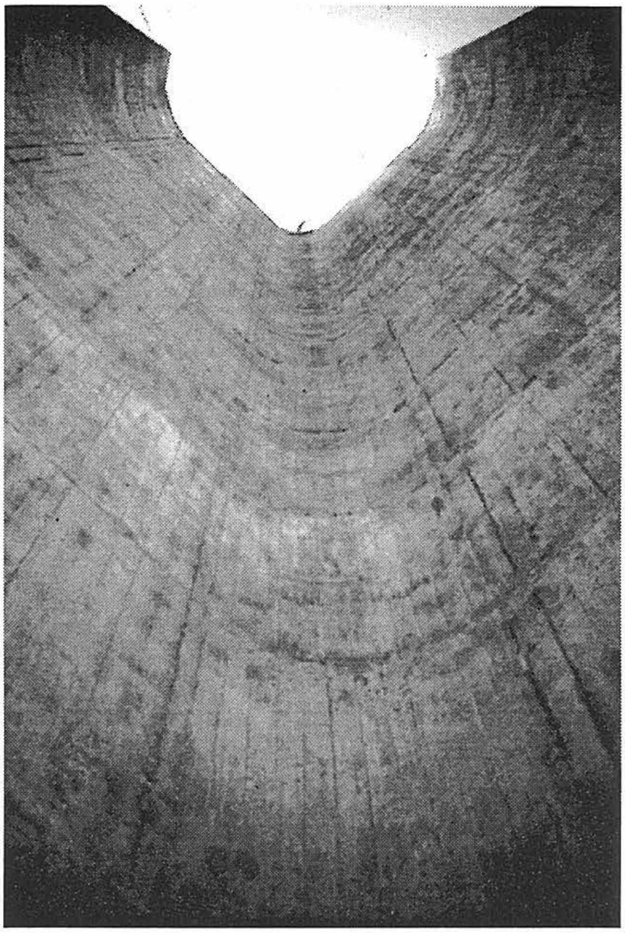
Horse saddle

In coordination with the engineer Bernard Lafaille, Gillet designed the plan of the church as an ellipse, which allowed for the roof to be designed as a hyperbolic paraboloid: a double curved shell like a horse saddle. The supporting structure of the church consists of thin concrete, V–shaped columns along the perimeter of the ellipse. These columns are retained at the lower end by the thin concrete vaults of the inclined ambulatory roofs. The facade segments are then joined and braced by two passerels –an upper and a lower one– that follow the elliptical shape of the church, and by a concrete ring on top. The magnificent glazings in between the columns, that predominate the interior atmosphere, are the work of the glass painter Henri Martin Granel.

The hyperbolical shell is very thin and less than 100 mm thick. It rests directly on the concrete ring. The double curved roof alternatingly solicits tension and compression, depending on the axis considered. Along the East–West axis, from bell tower to choir, the roof works as a suspended canvas resisting tension forces. The suspension cables are anchored in



Site plan of the Notre Dame showing the elliptical plan and the V-shaped facade columns. Drawing: P. Oudin.



One of the mighty V-shaped facade elements.

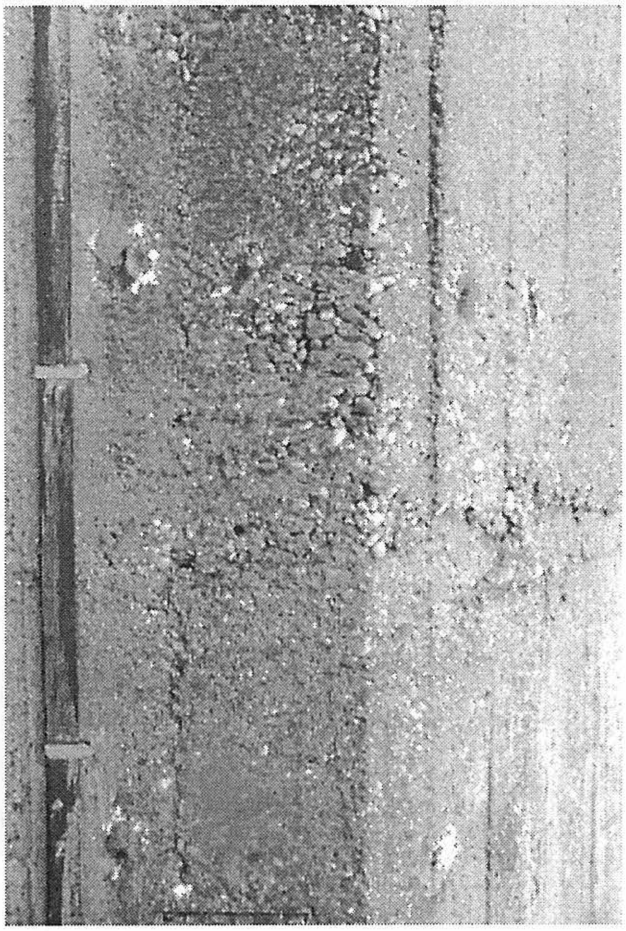
The church interior with upper passerel.

The facade columns are retained by the concrete vaults of the inclined ambulatory roofs.

a crowning arch that is supported by the concrete columns.
Along the North–South axis, the roof works as a vault resisting compression, necessitating a steel tension rod at its base. The bell tower in the East, consisting of three similar columns, predominates the general structure. The concrete frame of the belfry is inscribing these structural members. It is detached from the main structure of the tower and supported by corbels that project inward from the concrete columns. The room between the belfry and the three columns accommodates louvre–boards to amplify the sound of the bells.

Heavenly waters

The cathedral was constructed in a very short time and with a low budget. This explains the cut backs in dimensions as compared to the initial project, in order to reduce costs. Soon after the inauguration on 10 July 1958, the building presented its first defects already in 1960, due to water tightness problems that caused leakages. In 1967, water infiltrated along the frames of the stained glass as well as along the perimeter of the concrete roofs over the ambulatory, the baptistery and the holy water basin. In 1972–73, works started to waterproof the concrete but this appeared insufficient to solve the problems.
The steel reinforcement of the concrete started to corrode and caused the concrete to crack and spall, thereby accelerating the steel to deteriorate. Series of patch repairs with resin–based mortar never produced satisfactory results, neither in static nor in aesthetic terms.
It were typically the free ends of the V–shaped columns that suffered most. At these locations the concrete was seriously cracked, and the corrosion of the steel rebar had resulted in the spalling of large pieces of concrete, sometimes over 200 mm wide. Due to the rebar then being fully exposed, the steel further corroded at an even higher rate. In 1986,



The original concrete has not been vibrated and aggregates are poorly enclosed by concrete mass, The exposed surface is board marked both outside and in the interior.

Previous patch repair with a mortar that differs in texture, colour and application method.

concrete distress at the belfry had accelerated to such an extent, that the bells could no longer be used for tolling.

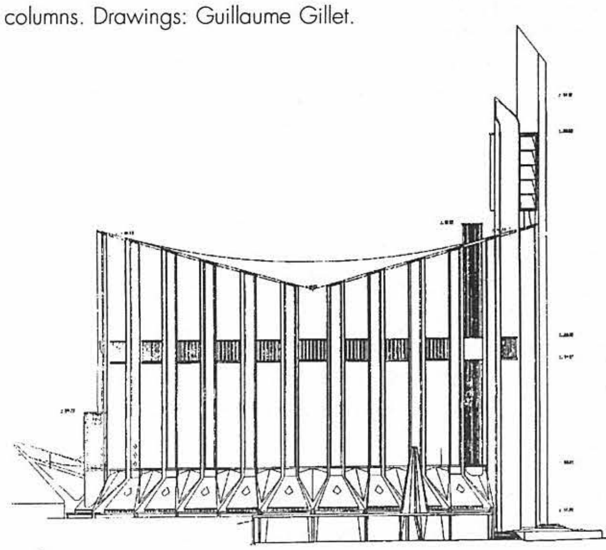
Provisional studies

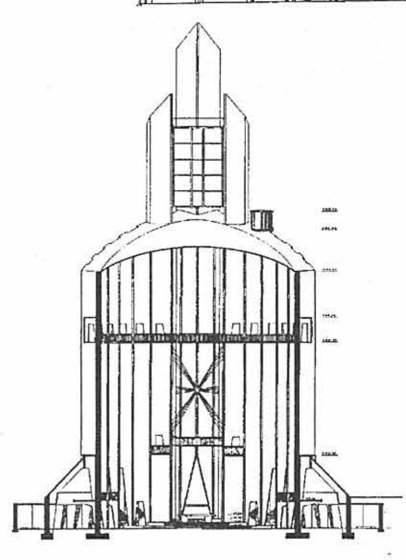
The first preliminary studies for restoration works were commissioned to the engineers Lucient Boudet and Veritas in the next year. A very detailed and systematical recording of defects was performed. Scaffolds were used for close observation of the defective areas:

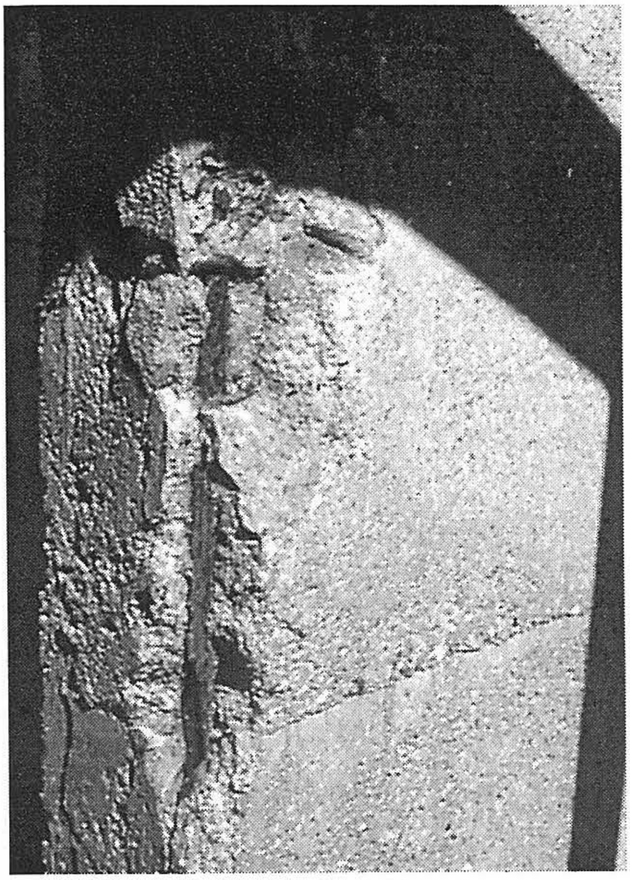
- The envelope of the building and the affected members of the structural frame were closely examined.
- The interior lay out of the rebar inside the concrete was carefully mapped by use of over three hundred X–ray exposures, presenting a life size view of the reinforcement patterns.
- After measurements, samples of the concrete were carefully taken out for physical and chemical analysis in a laboratory.

The official Provisional Study *(l'Etude Préalable)* that we undertook in December 1989 summarized the

South elevation and section showing the saddle roof and the concrete vaults of the ambulatory that retain the facade columns. Drawings: Guillaume Gillet.

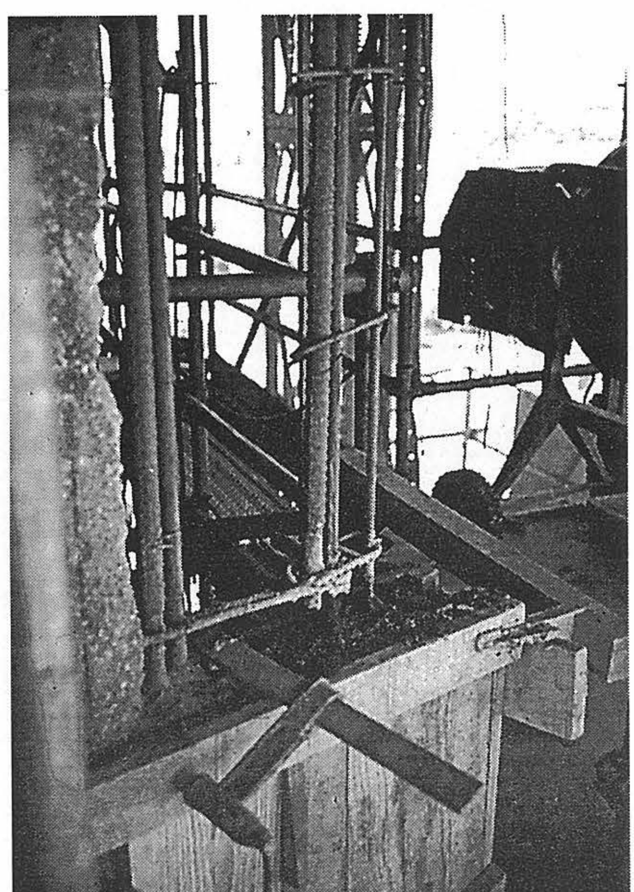






The thin ends of the columns had suffered most from concrete disorders, causing spalling of the material (left). Test repairs were performed to match colour and texture of repair mortars with existing material (right).

Repair of the thin ends of the V-shaped columns involved partial recasting. The concentration of rebar posed problems regarding the concrete covering on the steel.



results of such earlier investigations and analyses, and proposed a restoration method in technological terms, as well as a time table to execute the works in various phases.
To respond to the most urgent needs first, it was decided to start with the works on the belfry, since the lack of stability of the bell tower was of particular concern.

Analysis and methodology

Additional testing was then scheduled, complementing all those that had been done by the City of Royan before the listing of the building. These analyses were commissioned to the Laboratoire Régional de l'Est Parisien de l'Equipement, under the supervision of the CETE of Bordeaux. Tests were performed at four zones of the bell tower that were accessible.
The analyses concentrated on assessments of permeability, carbonation, and electric potential of the rebars.
The conclusions drawn from these tests indicated that:

- The concrete was generally very brittle and of a non–hygroscopic nature.
- The carbonation depth and the level of chlorine measured were mostly not of such a nature, that the rebar was expected to be depassivated in zones with sufficient concrete covering.

- The measurements of potentials as well as the visual inspections that were made beforehand, supported this assessment.
- All reinforcement steel in carbonated zones as well as exposed rebars showed corrosion or were about to corrode.

This last investigation confirmed our approach as far as the restoration principles were concerned, as included in the Provisional Study, to establish the Architectural and Technical Project *(Projet Architectural et Technique)* for the restoration of Royan Cathedral. It appeared necessary to treat or replace all the rebars that were certain to corrode in carbonated areas, either covered or completely exposed.
Consequently, in the affected zones, the concrete that was cut out was to be remade. Unaffected rebars still sufficiently covered were not expected to pose a risk on short term.

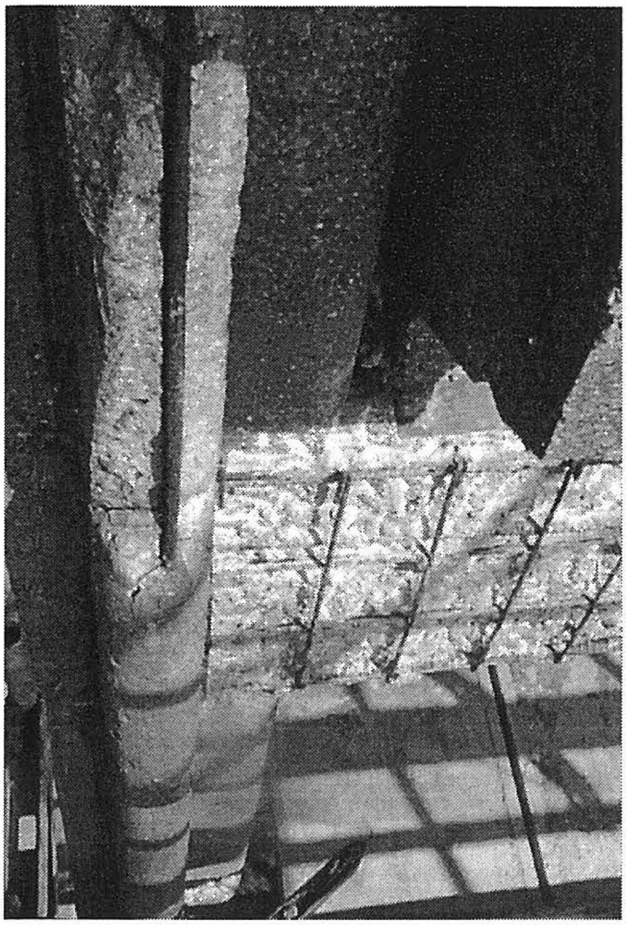
Day joints
The methodology for the remedial works was determined by the above investigations, complemented by the results of a program monitoring the ageing process at the earlier repairs with resin–based mortar. A complete examination of the concrete structure was commissioned before actual intervention to the Degain enterprise as part of a contract.
A systematic assessment of the condition of the facade columns was performed by pachometric measurements, carbonation testing and sclerometric indications, which were done by CEBTP of Niort, again by use of scaffolds. Results of the study were directly marked on the building face, so that the craftsmen would always have the information on site during the works. The test results were precisely recorded for all sections of the facades. Analyzing the results learned that sections could be identified by differences in quality that could be carried back to execution circumstances, mainly the production of the high columns in various pourings during construction. The sections were defined by the day joints, according to the number of pourings for each elevation segment, the respective heights of the scaffoldings during construction and so on. However, in general the concrete appeared homogenous, but had carbonated zones. The typical concrete covering on the steel rebars was about 35–40 mm.

Tower
The main works on the columns of the tower concerned the following:

- A complete water blasting to eliminate the chlorines on the surface.
- A mechanical blasting to clear the steel rebars of the rusted coat, in all the zones where the concrete was cracked, spalled or carbonated, as well as in zones where corrosion was suspected.
- The steel rods that were too heavily corroded, were replaced by pretreated bars of the same section.
- The reconstruction of the cut out parts was made with a micro–concrete bonding agent to secure adhesion to the mineral coating around the steel.

These works were performed carefully according to the original drawings of the formwork, regarding the size and the patterns of the boards, the type and size of granulates, the design of the mortar regarding colour and so on, in order to harmonize with the existing part of the building.
For the thin columns of the tower, small scale works were performed using custom mortars for patch repair. Small elements like the railing of the passerels and the balcony balustrades were completely redone. The stained glass windows were taken down for a careful check of the lead sub–structure, and put up again after appropriate treatment and the installment of compression bands to ensure total waterproofing.

Belfry
For the belfry the approach to respond to the occurring distress was different. The restoration was focussed on and limited to structural problems. The damages affecting the concrete were related to structural deformations due to insufficient stirrups in the reinforcement.
The concrete frame of the belfry suffered from serious failures: exposed steel, open cracks and spalling of concrete, especially at the connections between members. The lower corbels that supported the belfry were expected to have suffered most. The wooden blocks on the supports appeared to have been reduced to thin wedges. The restoration of the belfry consisted of the repair of the reinforced concrete structure and the replacement of all the deteriorated elements. The first works done on the concrete concerned locations that were not visible from the outside. This way we got the chance to define more precisely the remedial treatment for the restoration of the concrete surfaces, the quality requirements to be made to the formwork, the mortars to be used for patch repairs, and the selection of proper granulates. Calculations of the stability of the belfry showed that it was placed eccentrically on its foundations and that the entire structure of the tower was slightly slanted towards the west mainly due to the weight of the louvre–boards. It was decided to reinforce the belfry, which was necessitated by the static requirements to accommodate the bells, and by doing so, to slow down the deterioration of this part of the building. Additional static elements like prestressed cable, or frames of IPE steel profiles, as were recommended by the studies and calculations of the technicians, would have completely changed the original character. Therefore, we decided not to modify anything but to add a new and completely independent timber structure inside the lower part of the tower. In addition, we changed the axis of the bells to a new direction, along the longest span, so that the belfry



would be more appropriately loaded. The corbels projecting out of the concrete columns were remade and covered with neoprene to mute certain frequencies mechanically.

Top and left: Small scale repair work with custom mortars were performed at the thin columns of the tower.

Progress

This first phase of the intervention on the belfry also allowed us to restore the mechanical properties of the materials. The pursuit of the work on all the concrete segments on the other facades are scheduled for 1997.

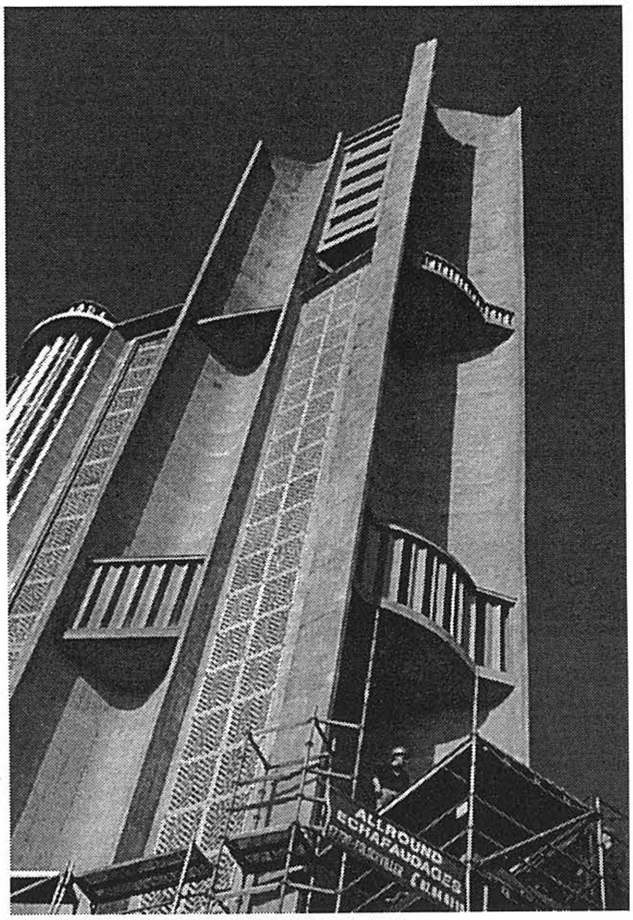
Still, it is appropriate to question ourselves regarding the structural evolution of the ageing concrete that is not yet repaired, and that remains exposed to carbonation and its implicated risks.

Similar works as done to the tower in this first phase will improve conditions for the entire structure. They will slow down and possibly arrest deterioration in the passivated layers, but will only delay further deterioration and ageing.

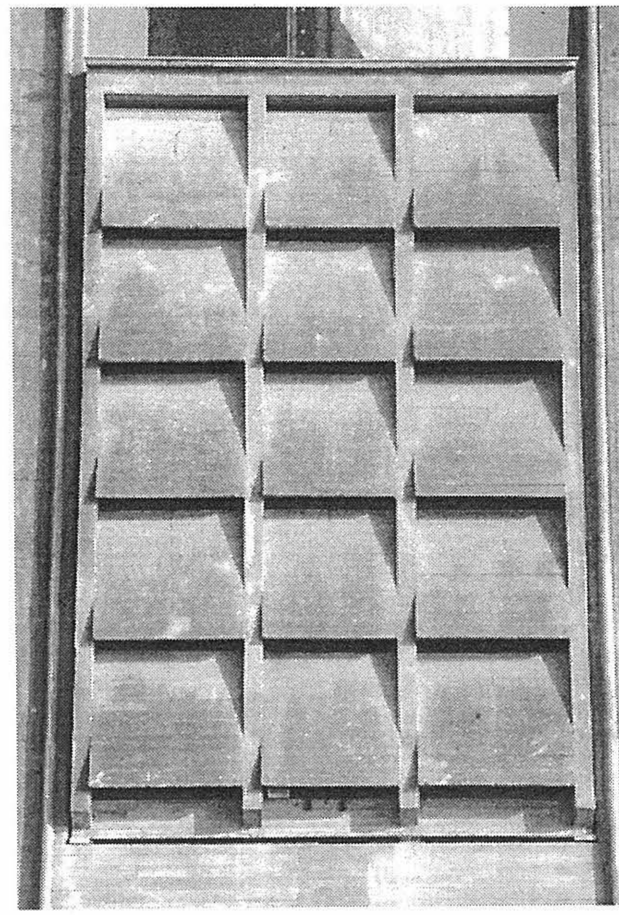
It seems that the more recently developed chemical processes as applied in many restoration cases abroad today, could be the answer to our problems. This 'NOVBETON' system, as it is called in France, employs electro–chemical processes to realkalize concrete, and this might effectively protect the steel reinforcement and restore its original properties.

This will most probably be the solution we will use for future remedial work to ensure that the bells of the restored Notre Dame de Royan can sound for the next decades.

Philippe Oudin is chief architect for Monuments Historiques in France and in charge of the restoration of Royan Cathedral. Text translated from the French by the editor.

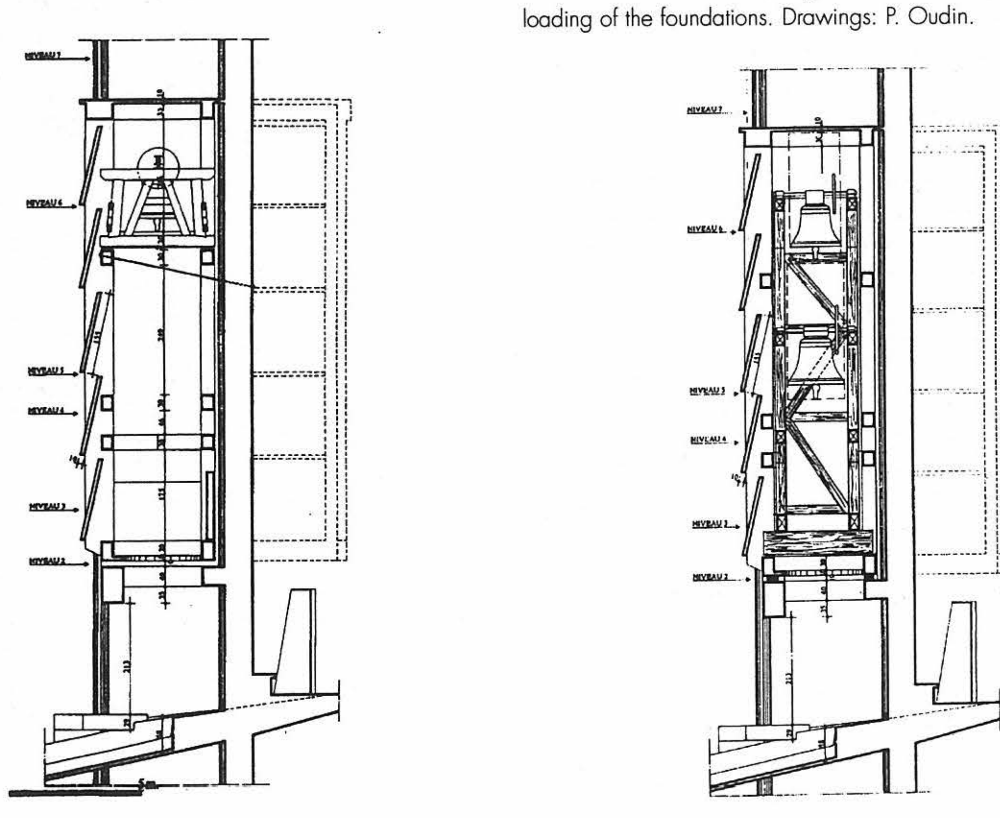


The bell tower during the works. The concrete-framed, stained glass has been taken down for repair.



The louvre boards of the bell tower after restoration.

Section through the belfry before (left) and after the restoration. The axis of the bells was changed over 90° to correct excentric loading of the foundations. Drawings: P. Oudin.



Spiritual architecture in concrete
Antonius Church (Moser, 1927), Goetheanum (Steiner, 1928)

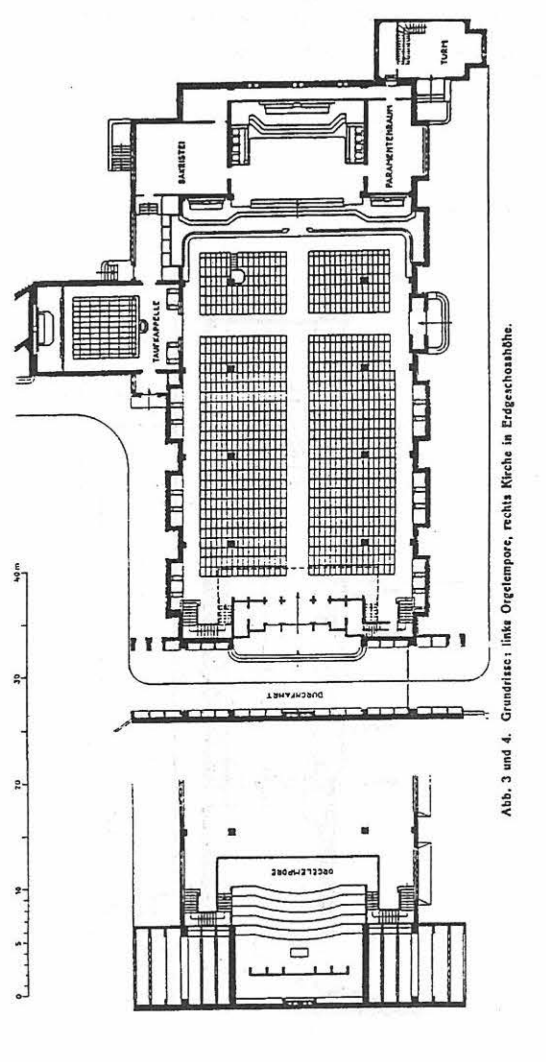
The St. Antonius Church in Basel was the first sacral building in Switzerland to be constructed in concrete. The board marks in the exposed concrete facades witness how the building was made, and are essential to the architectural expression of the building. The particular quality of the concrete work in the church caused large scale distress and visible damage. After extensive testing programs and analyses, the engineering firm Eglin Ristic AG from Basel proposed an unusual repair strategy. To avoid patch repair the carbonated outer skin of the church was completely replaced by a new coat of concrete, that was then carefully moulded to match the architectural character of the original. The debate on whether such an approach is appropriate in historic terms, particularly with respect to material authenticity, was again fueled when a similar cure was proposed for Rudolf Steiner's Goetheanum.

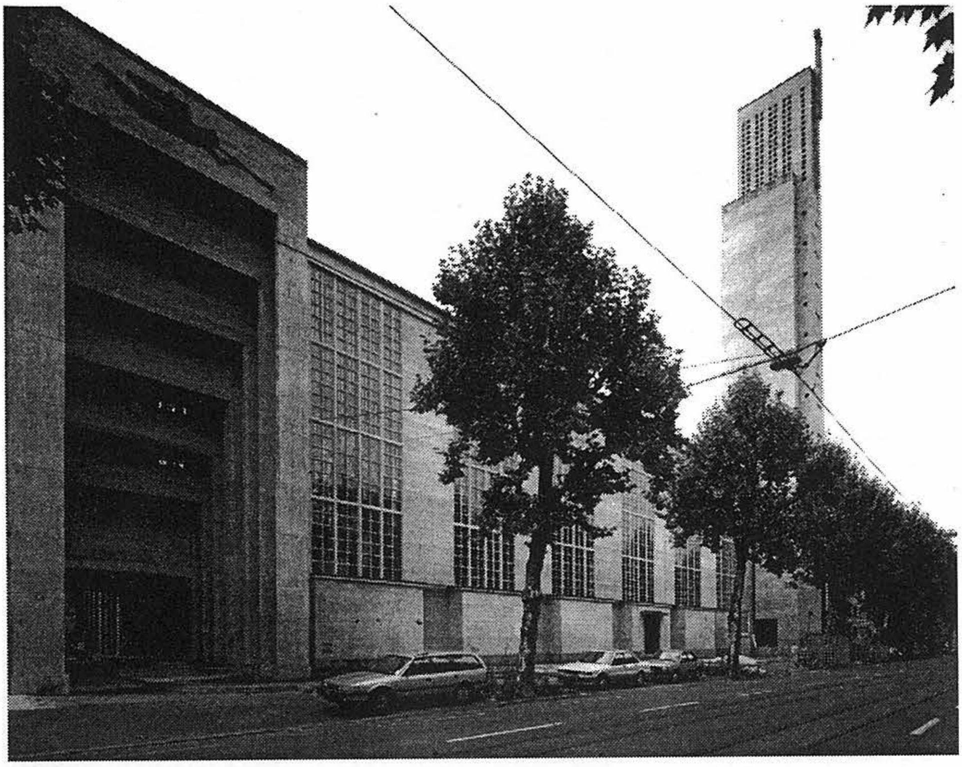
by Vojislav Ristic

The St. Antonius Church in Basel has been constructed between 1925-1927. As a major construction material architect Karl Moser employed reinforced concrete, which represented a new technology at that time. The result was an architectural monument of historic value, which fame transcended regional borderlines. The St. Antonius Church was the first sacral building constructed in reinforced concrete in Switzerland, and only preceded elsewhere in Europe by Auguste Perret's church of Le Raincy, near Paris, built in 1922-23, that has recently been restored as well.
The central aisle of the St. Antonius Church is covered with a coffered concrete vault, supported by 18 m high columns. The horizontal thrust of the vault is transmitted through the decks over the side aisles to the lateral walls. Both lateral facades consist of 400 mm thick double concrete walls, containing hollow terra cotta units for insulation, alternated by large concrete windows. The three mullions and transoms, that further divide the 4.8 m wide and 13.8 m windows into sixteen units, transmit the wind loads to the facade walls.
For the first time in Switzerland, concrete was employed as an architectural material by leaving all the concrete work unclad inside and out. The exposed concrete bears the marks of rough wooden boards that were used for the formwork, as a visual testimony to how the building was made.

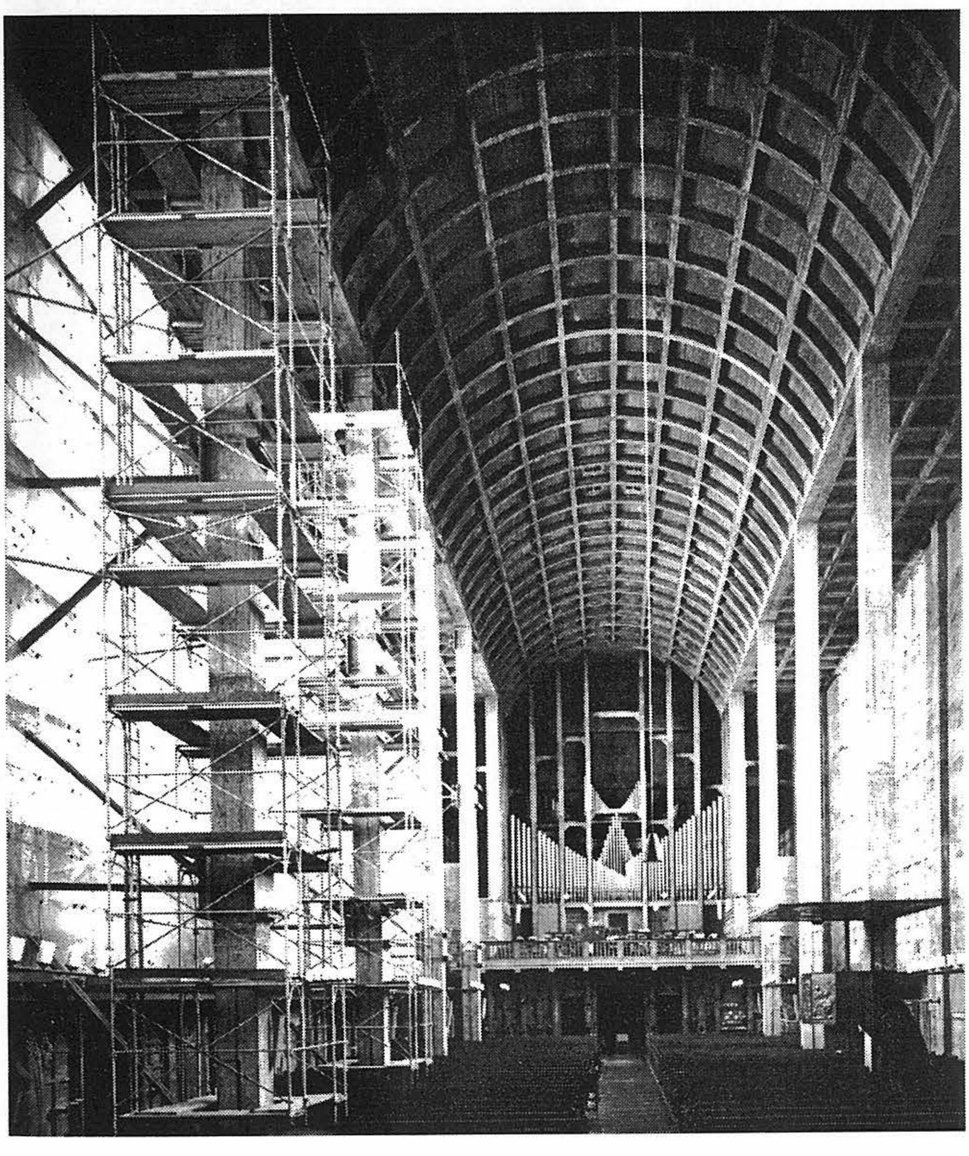
Recurring defects
As early as the 1940s, concrete deterioration in the bell tower was reported. In 1950 the tower had to be repaired in order to avoid danger for pedestrians. At that time, the repairs were carried out with shotcrete[1].

Plans of the church. The lateral walls are double concrete walls alternated by large concrete windows over the projecting confessional boxes. Period drawing.





The east facade of the St. Antonius Church at Kannenfeldstrasse in Basel. Photo: E. Schmidt, 1991.



Interior scaffolding to support the facades during renovation of the church in 1989-1991. Photo: E. Schmidt.

Meanwhile, also the facades had weathered considerably and the building was restored for the first time in 1962-63. Cracks were recorded and repaired with patch mortar and the west facade was treated with a sealant, which evaporated within two years however. Again in 1973, the tower underwent considerable repair work, which covered almost 60% of the facade surface.
The recurrence of damage in the following years forced the owner of the church, the Roman Catholic Church of Basel, to devise a concept for the complete restoration of the entire structure, the scope of which included:

- Analysis of the condition of the concrete facades.
- Development of a restoration concept.
- Determining the urgency of performing the restoration work.

In June 1983, our office was commissioned to provide these services.

Research program

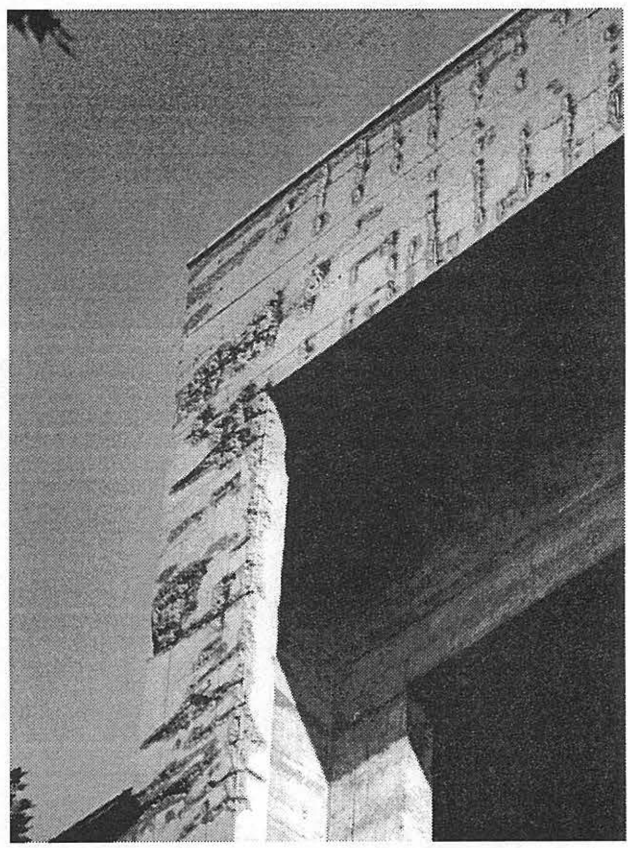
Because extensive deterioration to certain structural elements was recorded, the load bearing capacity of the structure was brought into question. To clarify this issue, extensive tests were conducted on site as well as in the laboratory.
On site investigations included visual inspection of the entire facade in order to pinpoint damage, deterioration and cracks. An extensive photographic documentation was prepared. On site testing involved:

- Measurement of the depth of carbonation.
- Measurement of the concrete cover of the reinforcement.
- Bond-strength testing with glued steel rings, 50 mm in diameter.
  Laboratory testing of concrete core samples was performed regarding:
- Analysis of the chemical constituents (calcium, silica, aluminium, iron, sulphur), conducted at the Institute of Mineralogy and Petrography at Basel University.
- Measurement of the quantity of gypsum contained, conducted at the Institute of Inorganic Chemistry at Basel University.
- Measurement of the module of elasticity (EMPA).
- Analysis of structural strength; measurement of sulfuric salts, depth of carbonation, and

petrographic analysis of particles under 4 mm were performed by the Materials and Methods Laboratory (LPM), Beinwil am See.
Also, a structural analysis of the existing building was considered essential in developing the restoration concept. Both the damage due to deterioration and temporary weakening of the structure during restoration work had to be taken into account. Special analysis was conducted to determine the static reserve capacity of the 18 m high wall panels, the window mullions and transoms. Reserve capacity appeared to have been drastically reduced due to extensive cracking and spalling of the material.
The extensive test programs and structural analysis allowed for various diagnoses to be made for the respective parts of the church, which are presented in the following paragraphs.

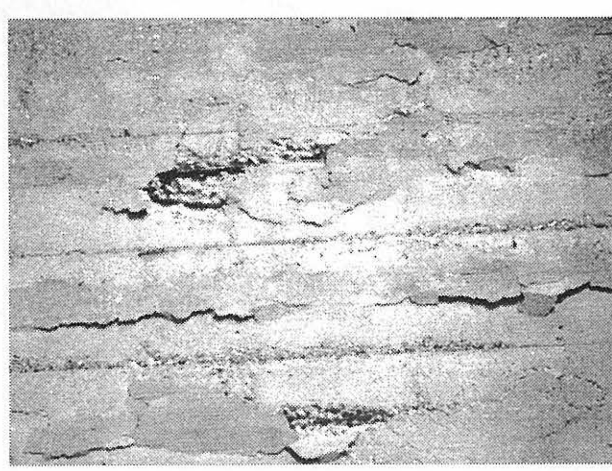
Facades

The unclad concrete had undergone considerable spalling due to corrosion of the reinforcement steel. Damage had also reoccurred at locations that had been restored previously. Extensive damage in the



The outside portal over the main passage after the removal of spalled concrete. Photo: Eglin Ristic AG, 1983.

Spalling in a previously repaired area. Photo: Eglin Ristic AG, 1983.



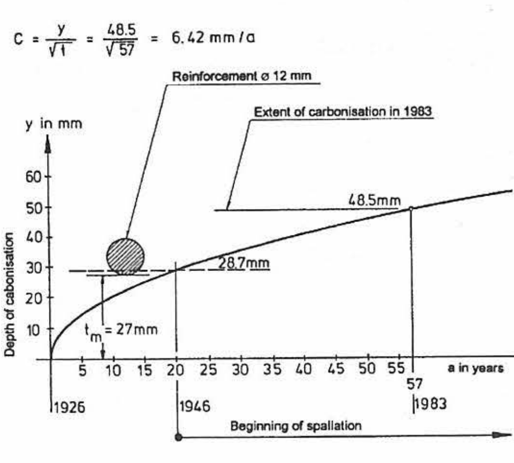
The structural safety of the window frames was reduced beyond repair due to major spalling. Photo: C. Baur.

form of concrete spalling was found on the outside portal over the main passage in the lateral facade. Apart from the scheduled restoration work, loose concrete pieces had to be immediately removed from this location as a safety precaution for passers by. The window mullions and transoms had suffered considerable deterioration on the exterior. Almost all patches applied in 1962-63 had again chipped off. Because of this, the load bearing capacity of the window frames was rendered insufficient. All damage had been due mainly to carbonation of the concrete which was advanced through the relatively high porosity of the material as well as by ecological conditions.

Carbonation

Aided by humidity, penetration of CO_2 from the atmosphere had caused the concrete to lose its alkalinity, with a typical pH level of 12.5. Through carbonation the pH level had dropped to 9.0 and the alkaline environment was neutralized (depassivated). Comparison of the average depth of carbonation (48.5 mm) with the average thickness of the concrete cover (27.0 mm) clearly indicated that the carbonation front had almost completely passed the reinforcement. The extensive spalling of concrete confirmed these findings. In the advanced state of

Carbonation over time. All graphs: Eglin Ristic AG.



carbonation as found in the exterior concrete surfaces, the concrete had completely lost its alkalinity and, hence, its protective capacity with respect to the passivation of the reinforcement steel. Nothing stood in the way of continuous corrosion of the steel. The chart showing data taken from the west facade illustrates this point.
The calculated coefficient of carbonation C in the above chart shows that carbonation progress in the west facade had been 6.42 mm per year. High porosity of the concrete was identified as the main cause of these extensive defects. Even by 1946 carbonation had apparently already reached the reinforcement -an assumption supported by the necessity for repair in 1950.

Concrete strength

Values calculated for the modulus of elasticity indicated an average compressive strength of 24600-32600 N/mm². The average density of concrete was calculated at 2270-2250 kg/m³, which could be judged as sufficient. In contrast, the compressive strength varies from a maximum of 54.0 N/mm² to a minimum of 21.4 N/mm².
Bond-strength testing provides reliable data concerning the quality of the tensile strength of a concrete surface without damaging the concrete itself. In practice, concrete showing values less than 1.5 N/mm² cannot be treated by coatings, and only complete replacement of the surface remains as a possibility for repair. The existing tensile strength found in the St. Antonius Church appeared to be sufficient for a coating to be effectively applied, thereby furnishing another repair option.

Chemical analysis

The Institute of Mineralogy and Petrography at the Basel University tested four concrete core samples for quantities of the main chemical constituents of cement, which are calcium (Ca), silica (Si), aluminium (Al), iron (Fe), and sulpher (S). From the laboratory report it could be drawn that the outer 1 to 10 mm of the concrete surface had undergone various chemical changes.
The soft, corroded surface showed reduced calcium content and, as a result, increased levels of the constituents Si, Al and Fe. Extreme levels of sulphur were recorded, which had also led to increased levels of gypsum. Testing also showed that the cement had a rather coarse grain structure, which typically results in a slow hydration process. Coarse aggregates secrete small supplies of alkaline reserves over the years, which slow down the carbonation of concrete. Although concrete spalling is typically due to expansion of rusting reinforcement steel, the well known deterioration effects of gypsum in natural stone suggested the analysis of the concrete for gypsum ($CaSO_4$) as well.[2] Sulphate levels were tested on core samples. A 5% calcium additive had originally been used in the concrete mix as a

retarder, which could be of influence on the determination of gypsum deposits, and also high levels of sulphate (SO_4) were found at the outer surface as a result of penetration from the atmosphere.[3] The deterioration of the concrete itself appeared, however, not to be due to SO_2 deposits.

Concrete quality

The concrete core samples tested showed absolutely no cracks or other structural defects. This was mainly due to the excellent static design of the load bearing system. Pouring concrete in successive phases avoided stresses due to shrinkage of concrete.
Still, the concrete was excessively porous (about 21%) due to the following factors:

- High water-to-cement ratio of 0.58 to 0.80.
- The concrete was not compacted (vibrated) but merely stamped into the formwork.
- Stamping was difficult due to the hollow terra cotta units.
- Leaks in the formwork.

Tests regarding concrete quality showed that the Portland cement content was about 290 kg/m³; higher than the required value of 250 kg/m³. The high water-to-cement ratio was the main reason why the concrete was overly porous, and the primary factor for the deep carbonation of the concrete.

Structural analysis

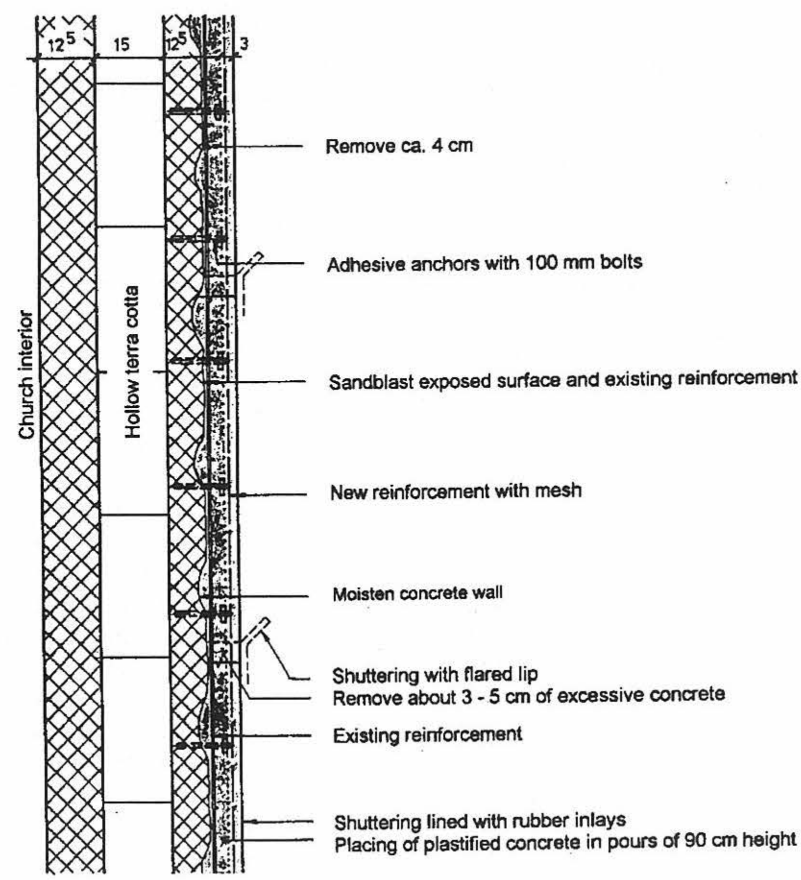
The structural analysis of the existing construction, especially concerning the 18 m high walls, showed that spalling of the concrete had not reduced the load bearing capacity of the walls. Further checks indicated that the required safety factor would still be met if the removal of the top layer of concrete, which was necessary to perform the restoration work, would be limited to 40 mm.
Other structural elements, such as the walls of the entrance portal, were less critical. On the other hand, the window members (mullions and transoms) were so badly deteriorated that the required safety factor could not at all be guaranteed.

Research conclusions

All tests conducted showed that the damage evident in the form of spalling was caused by carbonation of the concrete. The high porosity of the material due to the high water-to-cement ratio had caused the advanced carbonation of the concrete structure. As a result the depassivated zone had passed the outer reinforcement years ago. The extent of damage was extreme and restoration of the structure was urgent.

Proposals for restoration

Preservation of the architectural and historic value of the church has been a primary concern. As far as possible, the structure should be passed on to the next generations in its original form and configuration. Now that the problem of ongoing deterioration had been recognized and diagnosed, the causes of damage could be countered. Two solutions were offered: a renovation variant and a restoration variant. In both cases, it was planned to replace the concrete mullions and transoms of the windows



Section showing the renovation of the concrete facade at St. Antonius Church.

completely, because the static problems could not be solved otherwise. With the restoration variant, repairs would be executed only on damaged areas, while the non-damaged areas would be retained as they were. In view of our negative experience with mortar patch work in aesthetic terms, our office decided to search as well for alternatives that would avoid such patch repairs.
With the renovation variant, the carbonated concrete surface was to be removed from the entire facade and replaced by new concrete. An completely new method was developed involving the complete replacement of the outer 40 mm layer of carbonated material by a new 50 mm layer of concrete -not with patching mortar, but rather with new *in situ* concrete. Care was to be given to reconstruct the original surface pattern and texture by means of rubber impressions that were applied inside the formwork as moulds. Our office favoured this variant, which was considered more appropriate to respect the cultural integrity of the church.

Preparatory tests
Due to lack of experience with the proposed variant of both the contractors and our office, a series of tests was conducted. This allowed to evaluate the suitability of the specified materials at the same time. In the summer of 1984 the following issues could this way be clarified:

- Method of surface preparation.
- Matching new with old concrete regarding colour.
- Matching new with old concrete regarding aggregate textures.
- Scheduling of formwork.
- Curing.
- Bond between old and new concrete.

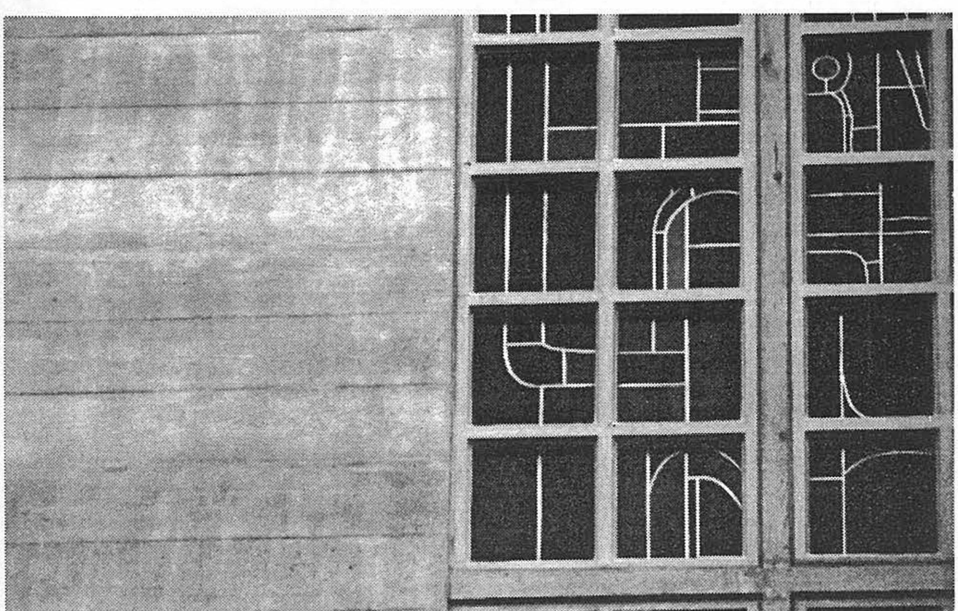
The five products chosen for impregnation and carbonation arrest were tested in the laboratory to obtain reliable data regarding:

- CO_2 ingress.
- Water penetration and damp ingress.
- Impregnation depth and alkaline resistance.

The tests confirmed the suitability of our procedure. In 1985, at a colloquium organized by the Basel Department of Historic Preservation, the investigations and studies were presented. After discussion on various detailed issues, the renovation variant was finally approved for execution.

Execution
The first phase of the renovation project, involving the sacristy wall and window, was executed during the summer of 1985 to the complete satisfaction of all concerned. This phase provided as well the data necessary to estimate costs for the complete job. After the estimate of SFr. 9,200,000 was approved, tenders were called for in 1987 and the contract was awarded to the consortium BBG - Glanzmann AG Jean Cron Ltd. The renovation was executed in four phases: in 1988 the courtyard facade, in 1989 the street facade, 1990 the tower facade, and finally in 1991 the bell tower and crucifix. Through this renovation the following goals were achieved:

- The face of the concrete facade today is set off 10 to 20 mm further outside as compared to the original situation; a concrete cover of at least 30 mm for all reinforcement could be guaranteed.
- A 50% increase in tenacity of the concrete surface with corresponding increase in resistance to atmospheric corrosion.
- A reduction of overall porosity of the concrete to less than 10% providing a corresponding decrease of damp ingress, through the application of a concrete with a 50% higher density.
- Higher proportion of cement (440 kg/m^3



A window and a wall section of the church after renovation. Photo: Eglin Ristic AG.

instead of 290 kg/m³) providing an increase of about 40% of alkaline reserves.

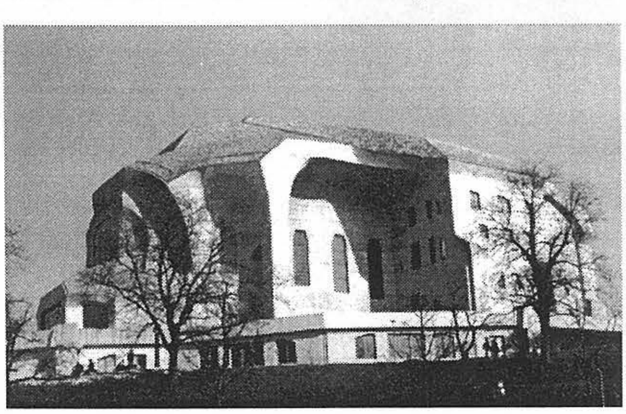
- The use of rubber moulds in the formwork solved the problem of sealing the formwork against existing older concrete without the use of adhesive tapes.
- The specified curing period of 7 days reduced shrinkage of the concrete to a minimum.
- Reduction in rate of carbonation by a factor of 8.4.

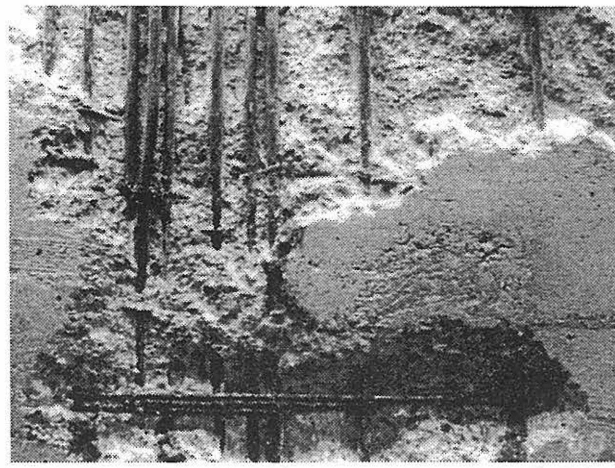
By ensuring the quality of the concrete to PC-350 with a controlled water-to-cement ratio of 0.45, dry aggregate graded between 0 and 16 mm, and addition of 1.2% of a super plastifier, the need for chemical impregnation or surface sealing was also eliminated. This significant and challenging project achieved full success only through the professionalism and dedication of all the parties involved.

Goetheanum

The Goetheanum, located in Dornach, Switzerland, is the international centre for the anthroposophic *Weltanschauung*. The building accommodates, among other functions, a university for spiritual science. After the original Goetheanum of 1913 was destroyed by fire, a second Goetheanum was built in concrete between 1925 and 1928. With this building, Rudolf Steiner tried to develop a new architectural style to express the anthroposophic conception of the spiritual and moral effect of architecture on the human mind. He achieved his goal with this large sculptural form, which is entirely constructed in concrete. Therefore, the building is a significant example of the exceptional architectural approach of Rudolf Steiner. He proved to be one of the first in the history of architecture to demonstrate that concrete can be used far more imaginatively than previous engineering works had shown. In that respect, the Goetheanum presents a unique example of architecture in concrete and remains a key building to illustrate one of the most important general architectural developments in the early 20th Century. After repeated patch repairs in a piecemeal manner over the past decades4, the Goetheanum was subject to a thorough investigation by our firm.

A south view of the Goetheanum. Photo: Eglin Ristic AG.

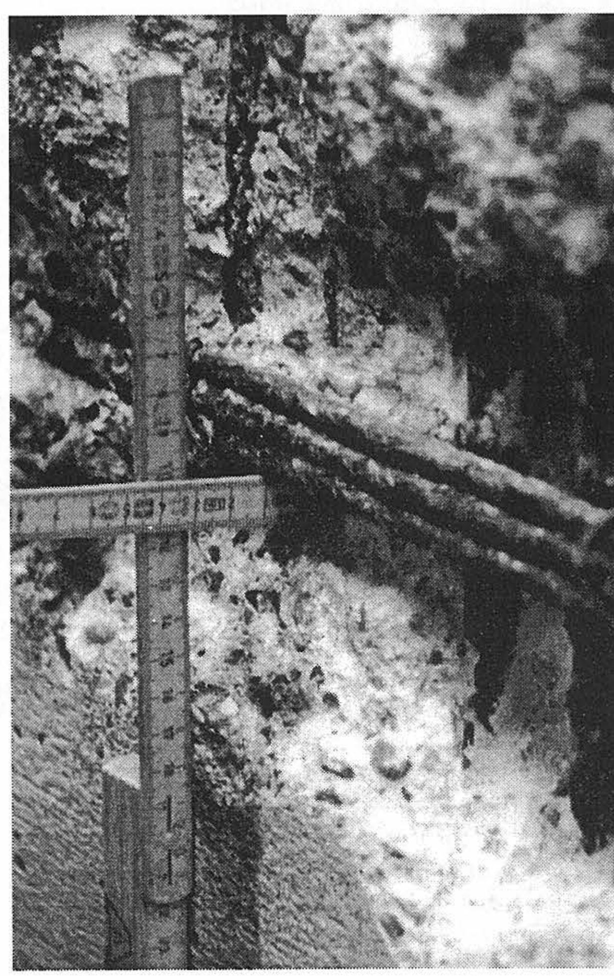




High porosity caused carbonation and, eventually, spalling of the concrete surface at the Goetheanum. Photo: Eglin Ristic AG.

Alarming damage was recorded. Up to 90% of the steel reinforcement was found in the carbonated zone of the concrete and was subject to -still hidden- corrosion. Eventual spalling was just a matter of time, and would lead to dangerous spalling of the concrete and reduction of the stability of the structure. The pattern of damage, the depth of carbonation, and the quality of concrete found at the Goetheanum were all similar to those found at the St. Antonius Church.

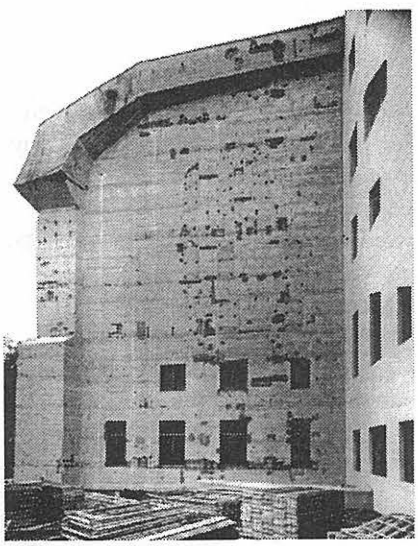
At the Goetheanum, covering on the reinforcement before restoration was typically 27 mm. Photo: Eglin Ristic AG.



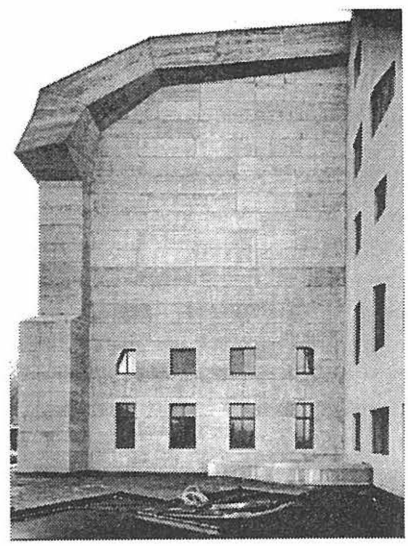
Peeling off the skin

In view of the national and international significance of this architectural monument, the administration of the Goetheanum decided to invite selected European experts to Dornach for a symposium on the restoration of the concrete facades. After the symposium and further discussion with the cantonal and federal authorities for historic preservation, the client decided to initially employ the method of renovation used at the St. Antonius Church on the eastern section of the Goetheanum. The outer 40 mm of carbonated concrete was to be removed and replaced by an alkaline coat of concrete of about 50 mm thick. The original surface texture produced by the wooden boards would be reproduced on the new facade, again by means of rubber moulds applied inside the new formwork. Through this method, the structure and its appearance could be maintained in the most authentic condition possible.

The northeast, east and southwest facades have now been restored to a satisfying appearance. The next phase will include some surfaces which are warped, and it is not clear yet how these are to be renovated. This decision will depend upon a detailed investigation, which will result in an appropriate renovation proposal.



The north-east facade of the Goetheanum before restoration. Photo: E. Schmidt.



The north-east facade of the Goetheanum after restoration. Photo: E. Schmidt.

Alternative renovation

During renovation of the St. Antonius Church and the Goetheanum, major concrete deterioration was found. At the church, damage was so extensive that the structural stability was compromised. Hence, the entire facade surface had to be restored radically to secure static safety and stability. The new means of Cathodic Protection and Realkalisation would therefore not have been the right solution -even if they would have been readily available already at the time the works were to be executed. The method that our firm developed for these works was the best way to secure the architectural qualities of this building to be saved for future generations.

Our firm is also about to finish a comprehensive testing program on the realkalization of concrete, in collaboration with the Swiss Federal Technical University (ETH), the findings of which will be published. Only after the conclusions of this research will have been evaluated, further recommendations concerning the application of electro-chemical repair methods are to be defined. The results may prove to be applicable to the sections of the Goetheanum that remain to be renovated.

Voijslav Ristic is a principle of the engineering firm Eglin Ristic AG in Basel, Switzerland.

Notes:

1. Shotcrete is mortar or concrete pneumatically projected at high velocity onto a surface.
2. Direct deterioration as a result of $CaSO_4$ is common to natural stones. Based upon our experience with many types of non-reinforced concrete, we can say that the deterioration of the concrete itself was not due to deposits of SO_2 in this case.
3. To avoid effects on the gypsum analysis, the calcium additive had been chemically bonded and was made insoluble before testing. Though sulphates from the environment had penetrated the pores and cracks of the concrete, sulphates were concentrated mainly near the surface. The results showed that the surface zones up to a depth of 30 mm had high sulphate salt contents. $CaSO_4$ levels on the surface were up to 43 times higher than inside the wall (for instance core sample no. 4: external 3.9%, internal 0.09%).
4. Note from the editor: Apart from the inadequate traditional patch repair referred to by the author, also realkalisation has been tested on the Goetheanum in 1988. See paper by Wessel de Jonge.

Patch repair leaves architectural integrity

The Beethoven hall of the Stuttgart Liederhalle

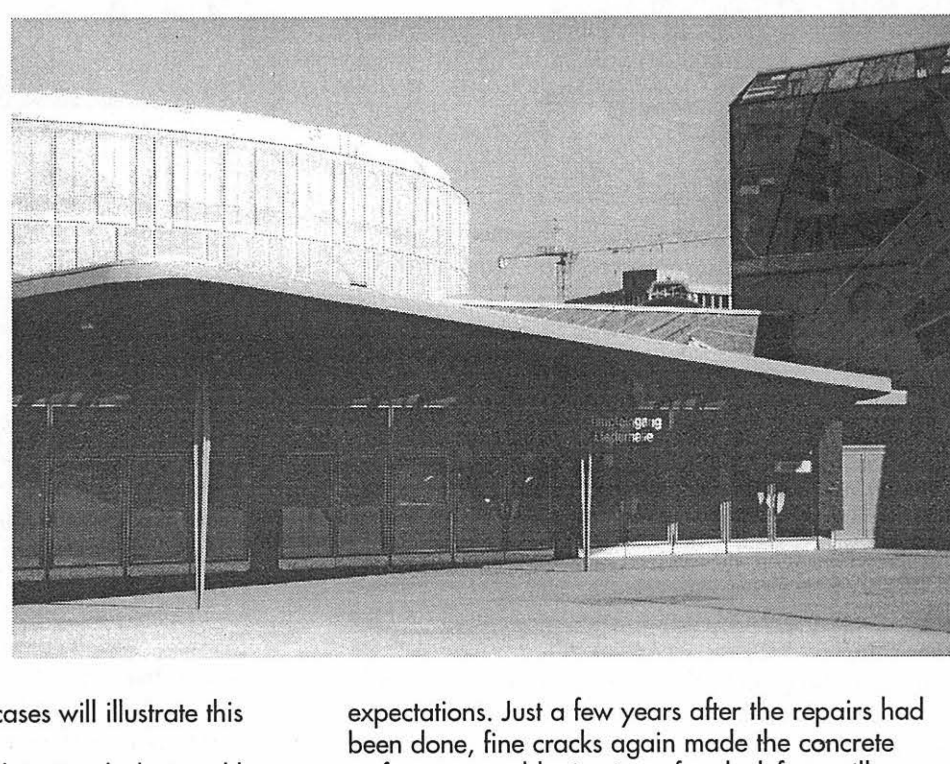
Present standards for concrete repair suggest not to limit remedial work to isolated damage spots, but advocate overall preventive measures. The common solution to apply a protective coat over the full surface of fair faced concrete facades in distress is exactly what would have destroyed the unique architectural character of the Liederhalle. The renovation of the facades of this remarkable postwar building in Stuttgart, Germany, is exemplary for careful repair of textured concrete though –or even because– the technical standards for concrete repair were not strictly met.

by Rudolf Pörtner

The general one sided alignment of most of the present concrete repair systems with the requirements of concrete technology has a history of its own. In retrospect, it were the repairs to reinforced concrete in traffic structures that resulted in a need for strict norms regarding concrete repair. The renovation of architectural heritage in reinforced concrete, however, requires more consideration than just the arguments of concrete technology. Equally important are the architectural characteristics, as well as static and constructive aspects. A few cases will illustrate this point.

In 1925, the Antonius Church in Basel, designed by the architect Karl Moser, was constructed as a fair faced concrete building. Over the last decade, all of the facades were refurbished. The intention was that the building would not look as if an even layer of mortar had been applied but rather, it was to feature a concrete surface with a visible texture of marks left by the formwork. For this reason shotcrete technology was rejected, and new concrete was applied directly to the surface. The applied materials were to satisfy the most extreme requirements in concrete technology. The concrete recipe was optimized and designed in such a way that, according to calculations, the carbonation front is to reach the reinforcement only after 500 years.

Unfortunately, the method did not come up to these expectations. Just a few years after the repairs had been done, fine cracks again made the concrete surface permeable. In view of such defects still occurring, the complete loss of the original fair faced concrete surface must be regretted even more. The only remaining authentic part of the exposed concrete facade was a recessed niche presenting the year of construction that, in a way, provided a window to

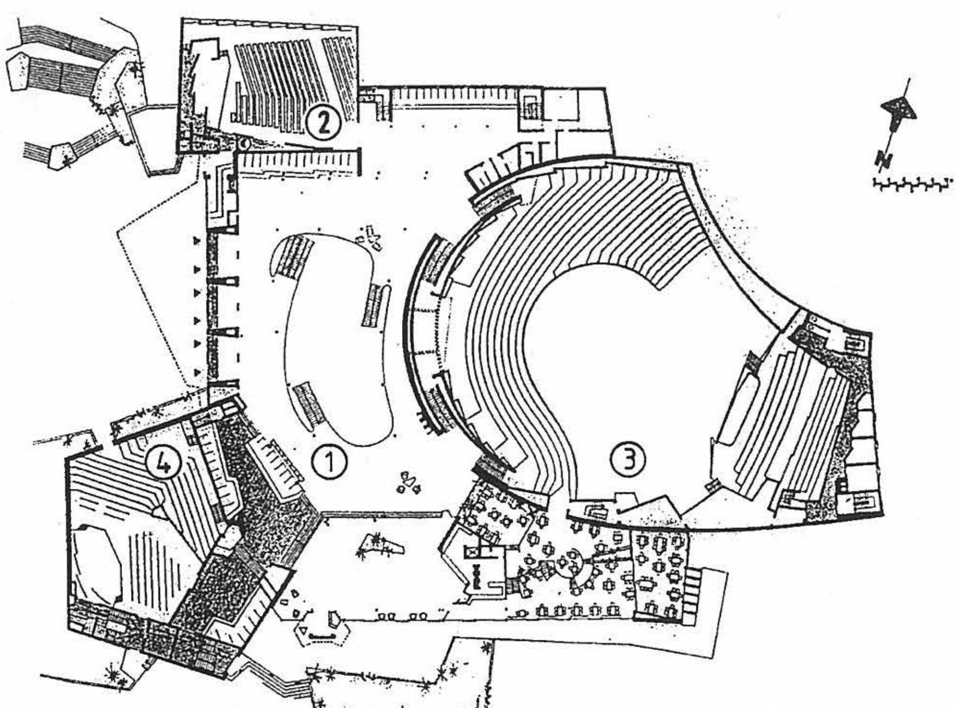


Main entrance and west facade of the Liederhalle. In the background the Beethoven hall. All photos: R. Pörtner, except where stated otherwise.

look into the past. Observing the contours of the church tower today, the once sharp edges of the tower appear as wavy lines.
The full extent of this loss can only be appreciated when comparing the original concrete facade of the Goetheanum in Dörnach, Switzerland. This remarkable building was designed by Rudolf Steiner and built in 1928. There is an obvious reason for this comparison. Initially, the intention was to apply the same principle used to restore the Antonius church in Basel to the concrete facades of the Goetheanum in order to make them 'maintenance free' for the future. In comparing the images of both buildings, two questions come to mind: how will the additional thickness of concrete alter the delicate proportions and profiles? – and how will the landscape of the existing exterior contours with sharp 'ridges' and smooth 'valleys' look after the renovation?

Principle difference

Those who are concerned with older buildings will share the experience that the most appropriate approach for restoration is often determined by evaluating similar cases, the structural system, and the causes of damage. This also applies to many iron and reinforced concrete structures.
The Feierhalle in Jena/Göswitz dates from 1906 and is characterized by an early prefabricated structure. There are supports, concrete slabs, central beams, lintels, and construction members with a specific



Plan showing the common foyer (1), the Silcher (2), the Beethoven (3) and Mozart halls (4).

architectural form. No reinforcing system corresponding to our current building standards has been applied, but iron straps that serve as wall anchors are tailed in following the architectural shapes of the structural components. Here, the masons have applied the tradition of constructional stone to reinforced concrete.
Another hall, in Osthofen near Worms, features girders, supports and ceiling slabs of reinforced concrete. The building, which was probably built around 1900, shows great similarity with the Hennebique system. The dimensions of structural members are unmistakably influenced by the tradition of timber construction. The model of the arched girders with straps is typical for the way such reinforcements were translated to concrete construction.
Comparing the mass of the constructional members of the Erlweinspeicher in Dresden (1926), and that of the load bearing components and space enclosing elements in the cross sections of the wind tunnel in the German Aviation Research Institute in Berlin, built in the early 1930s, shows that there is no universal recipe for the renovation of concrete heritage. However, it seems to me that common procedures for performing preliminary investigations can definitely be applied to such structures as well. There is no principle difference between assessing buildings of either reinforced concrete or historic masonry or timber structures.

Carbonation

When taking into account the architectural and monumental considerations, as well as the static and constructive aspects, it is necessary to comprehend the circumstances under which reinforcement steel corrodes. If the particular case of salt contaminated concrete is put aside -for the sake of argument- this process can be summarized as follows.
During carbonation of concrete, carbon dioxide from

the air reacts with the calcium hydroxide in the pore water of the concrete to produce chalk and water ($CO_2 + Ca(OH)_2$ -> $CaCO_3 + H_2O$). During this process, the conversion of soluble calcium hydroxide into the chemically stable chalk has a positive effect. It results in an increase of volume, that helps to seal the capillary pores. A disadvantage, however, is the decrease of pH value in the concrete from 12.5 to 9. In fresh concrete, the high pH pore water forms a thin but impermeable layer around the steel, the so called passive layer. Once the carbonation front reaches the reinforcement this passive layer is broken down, 'depassivating' the steel. Depassivated steel is subject to corrosion as soon as water and oxygen are simultaneously available as well.

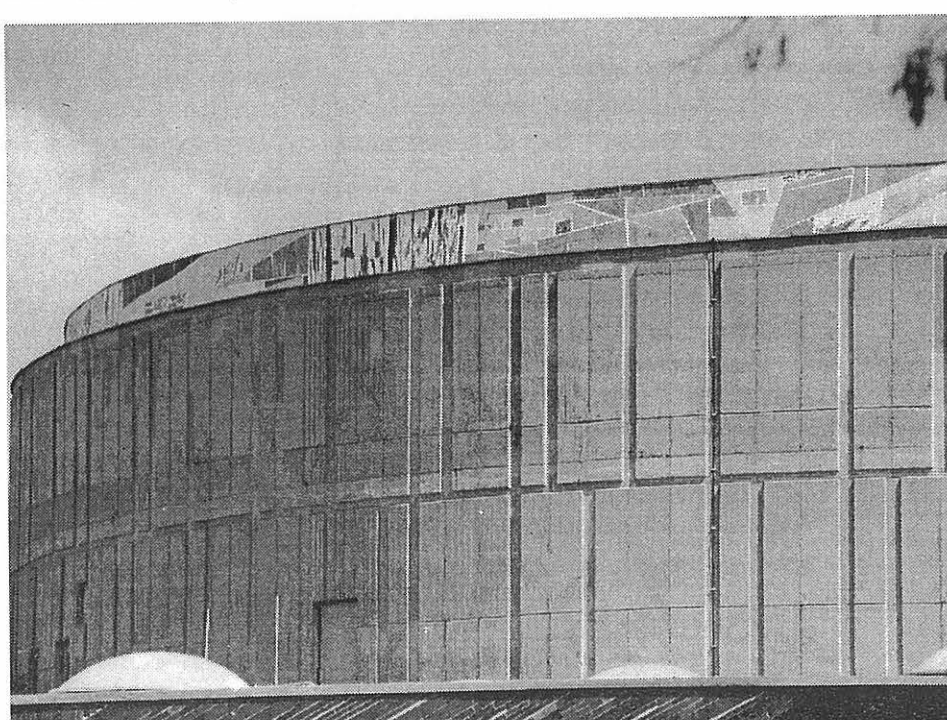
Three composers

The first Liederhalle, built in Italian renaissance style in 1863 after a design by the architect Friedrich Leins was bombed in 1943. Six years on, the City of Stuttgart announced a design competition to rebuild the concert hall. The plans by the Adolf Abel – Rolf Gutbrod team, and a design by Hans Scharoun were selected for elaboration, though, at the time, there were insufficient funds to realize neither of the projects. It was only in 1954 that Abel and Gutbrod were invited to make construction drawings, after which their project was eventually built between 1955-56.
In urban terms, the concert hall is characterized by the combination of a building and a park yet avoiding any axial interrelation. The architecture borrows its strength from the contrast between differentiation and combination. Facade openings contrast with the closed surface of full walls, and the interaction between man made concrete blocks and natural vegetation is equally attractive. A pattern of rectangles of various sizes is organized to create a decorative band over the concrete facades. Raised reliefs are located so as to be seen from a distance, while bas–reliefs lend a lively character to the facades at a closer range.
The building actually is composed of three halls, with a foyer and other common facilities that serve all three rooms. Developed as individual structures, the halls differ from one another in size, shape, and height. In addition, the choice of different materials results in a characteristic facade for each of the three halls. Split clinker slabs and bare concrete make up the cubic shape of the Silcher hall, which is the smallest of the three. Natural stone panels and mosaics decorate the pentagonal Mozart hall, while exposed concrete characterizes the free form of the largest of the three rooms, named after Beethoven. Elements and materials that are predominant in one hall, reoccur sparsely in the form of decorations in the other.

The face of distress

Between 1991 and 1993, all facades in the Liederhalle except the concrete facade of the Silcher hall, were renovated. At the Beethoven hall –as with most concrete structures in Germany– the damage fell into three main categories:

- The occurrence of cracks caused by shrinkage and creep of the concrete; in some locations also caused by bending due to thermal movement or as a result of differences in pourings.
- Weathering by frost, wind, and rain, and the effects of aggressive environmental conditions.



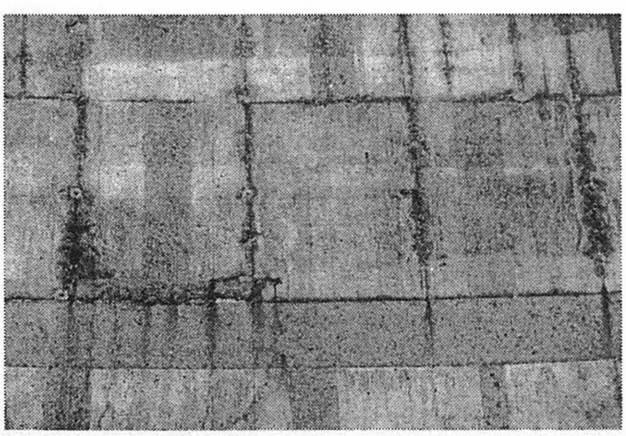
The curved concrete wall of the Beethoven hall with raised reliefs of rectangular patterns after reprofiling.

A relatively small but positive side effect of weathering is the concrete showing the natural colour of the aggregate when the cement is washed away.

- The main cause of damage, though, was chipping and spalling of the concrete covering. The reinforcement steel consequently started corroding causing even larger cracks in the concrete, after which the combined efforts of rust and frost expansion accelerated the damage.

From a concrete–technological and constructional perspective, concrete structures are fully manageable today. However, the basis for future shortcomings may have been layed during pourings. The right moment for pouring may be missed; too much water may have been added; out of carelessness, the concrete cover may have been too thinly applied; the formwork might have been poorly constructed; it may have been insufficiently compacted, or inadequately treated, or made during unsuitable weather conditions; and so on. Also this aspect has two sides, since often such shortcomings lend a concrete face its articulate, particular appearance.
In cases where exposed concrete has been reconstructed according to common technical standards, nothing remains of this characteristic appearance. This is exactly what happened to the

Shortcomings of concrete lend the facade an articulate, particular appearance.



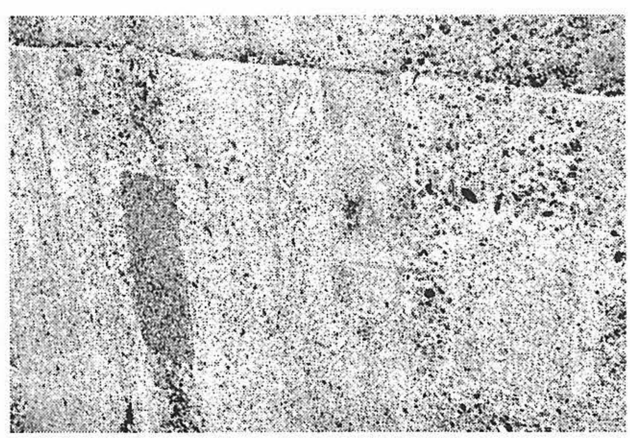
facades of the Silcher hall, when these were completely coated with a chemical agent in 1986. No natural aggregate colour is visible at the Silcher hall anymore. The surface now has the appearance of icing sugar and ageing comes with no aesthetic improvement either.

Subjective estimate

Considering the loss of original substance at the Silcher hall, and wanting to spare the Beethoven hall the same fate, the Baden–Württemberg Office for Architectural Preservation listed the building as a cultural monument. This was the situation when our office and the Institute for Solid Construction and Building Materials Technology of Karlsruhe University

An area subject to concrete spalling parallel to reinforcement steel, due to carbonation of the concrete.

Tests for matching texture and colour of repair mortars. *See also colour section.*



were called in to help.
Firstly, we reported on the condition of the building and the damage, which we considered to be an absolute prerequisite as a basis for any physical renovation measure. In the first survey of damages all concrete work was inspected, including architectural components, cracks and their widths, structural beams, areas that suffered from concrete spalling and chipping at the surface, zones where efflorescence or dripping occurred, surfaces with particular finishes such as at some of the stippled or moulded facades for example, the trumpet shaped ceramic decorations, and, off course, the reinforcement of the exposed concrete.
At the convex wall on the southwest side, damage

mostly occurred in the grooves left by the formwork, as well as in the section of the 'attica'. The extent to which the damage had progressed in this area was approximately 8% of the surface concerned, though higher in some locations. Yet in the centre of the same facade the damage covered less than 1% of the surface, which was obviously a positive side effect of the wild vines that covered this part and that apparently had protected the concrete effectively.
In the first phase of the investigation, the average extent of the damage was estimated at a mere 3% of the surface. This result sharply contrasted with the impression we had after an initial visual inspection beforehand, that apparently had been a too subjective estimate.
It is very well possible that the occasional concentrations of extensive damage had made such a strong impression that the overall situation was assessed too negatively at first.

Restrained approach

Further to the general survey, zones were determined that required a more extensive investigation of distress. A grid of metal wire on wooden battens was put over these areas in order to define smaller sections for a more precise assessment. For every section the concrete was then diagnosed referring to either of the following four categories, taking the worst conditions found in a section as a reference:

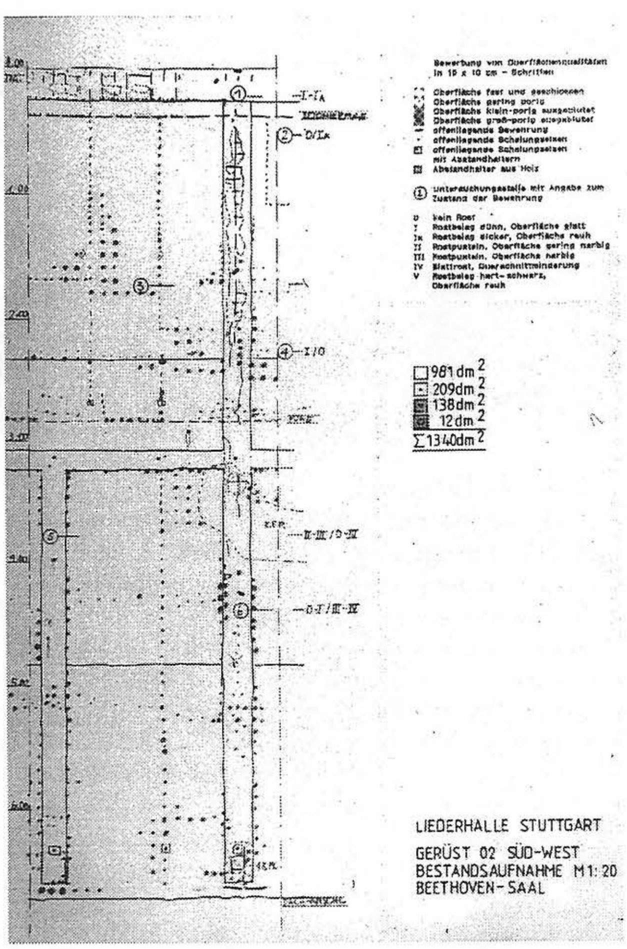
- Firm and closed, which applied to approx. 76% of the area shown.
- Slightly porous over approx. 10% of the area.
- Small pores with efflorescence over approx. 14% of the area.
- Llarge pores with efflorescence over less than 1% of the area.

In addition to the conditions of the surface, also the carbonation depth, the concrete covering, and the degree of corrosion of the reinforcement steel were assessed. Five levels of corrosion progress were defined to map damage to reinforcement steel:

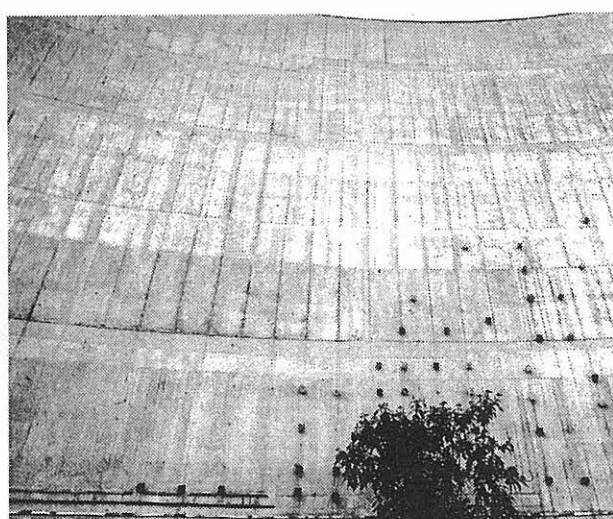
- Thin coat of rust, steel surface smooth.
- Thick coat of rust, steel surface rough.
- Rust 'pustules', steel surface slightly pitted.
- Rust 'pustules', steel surface completely pitted.
- Extensive corrosion resulting in a reduction in the cross section of steel.

Remarkably, it proved to be not the steel under the firm and closed surface that was best protected, but rather the steel under the slightly porous one.
Future progress of steel corrosion can only be roughly estimated unless extensive inspection and testing of the basic environment of the concrete is performed.
At the time of the investigation, the carbonation front had reached the reinforcement in over 50 % of the surface. Some steel, that had been exposed ever since completion of the building due to shortcomings in construction work, on the other hand showed virtually no corrosion. Another consideration that prevents a reliable estimate of future rebar corrosion is that in the coming 20 to 30 years, the carbonation front will only proceed extremely slowly. Damage progress will also depend on the relative humidity in the concrete, the covering, the density of the material, and the diameter of the rebars. It can be assumed

At selected zones, extensive investigations were performed to assess the condition of the concrete section by section.



The convex wall of the Beethoven hall showing formwork joints. The dots are ceramic decorations, that were repaired.



that, in the coming years, there will be only isolated occurrences of damage. Instead of proposing an extensive remedial programme right away, we decided to inform the owners of the building about the limited risk and they eventually accepted the responsibility to abstain from overall preventive measures.

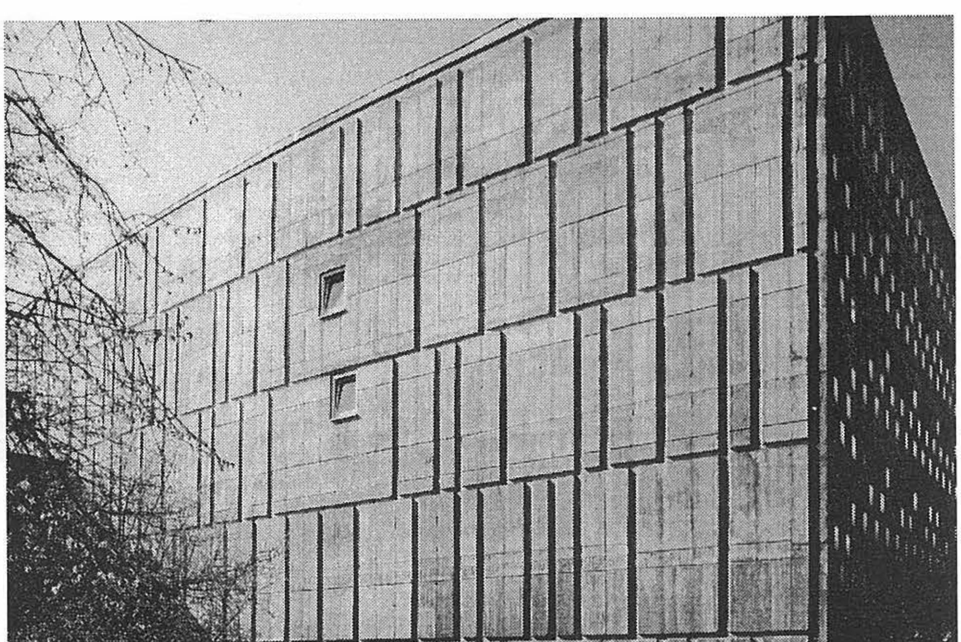
Craftsmen

The first estimates for restoring the facades of the Liederhalle were already submitted as early as 1990. The following years, until recently, were used to perform laboratory researches as well as series of tests on site. The concrete recipes were further developed in the laboratory, and then tested regarding their suitability for concrete repair work in accordance with the technical standards. This meant tests were performed to assess concrete density and firmness, vapour diffusion, frost resistance, and working properties. In addition, colour matching was performed by testing different aggregates. It proved essential to use the same coarse aggregate as originally, but the pit from which the material was taken in 1955 had been closed in the meantime. Fortunately, the coarse aggregate from a neighbouring pit appeared sufficiently similar to match repairs with existing work.
Two companies were selected to compete for the job. One company was a certified firm of masonry craftsmen, which, at that time, had done no work on concrete. Two employees of this company, however, were very experienced with restoration work. The other company was an industrial firm with a special knowledge of reinforced concrete construction, that was experienced in repair of larger, older buildings. The contract went to the masonry firm, and we have never regretted this decision.
The restoration works were then executed according to the principle to only repair affected areas by reprofiling locally, as a premise for our intentions. Visible damages were to be repaired, but no general preventative measures were to be taken. Mere blemishes and unobtrusive stains were to be neglected. The results achieved through such repair work mainly depend on the amount of care given to the job, the level of understanding, and the level of craftsmanship of the men and women carrying out the repairs.
Another contributing factor is careful supervision of the execution, quality control both in the laboratory and on site, and strong directions regarding static and constructive aspects as well as in architectonic and artistic terms.

Matching mortars

The works encompassed the following steps:

- The areas for repair were selected and marked.
- Loose concrete was removed with careful cuts.
- To avoid concrete to detach from the substrate, mortise chisels were not used to outline the repairs but concrete at the edges of the areas to be reprofiled was removed with small chisels, while larger chisels were used in the centre.
- Superfluous reinforcing steel was removed; after cleaning the remaining exposed rebar through abrasive blasting an anti–corrosive primer was applied, blinded with quartz sand to provide an appropriate substrate.
- A cement–water mixture was then brush applied as a bonding agent.
- Layer by layer, a fully mineral (non–modified) repair mortar was applied.
- After removing excess mortar while still wet, essential formwork marks were remodeled onto the surface.
- After curing, the concrete surface was dressed



The stout elevations of the Liederhalle after restoration.

with droves, punches and bushhammers; the loss of material at the surface through dressing was compensated by leaving excess repair mortar when reprofiling.

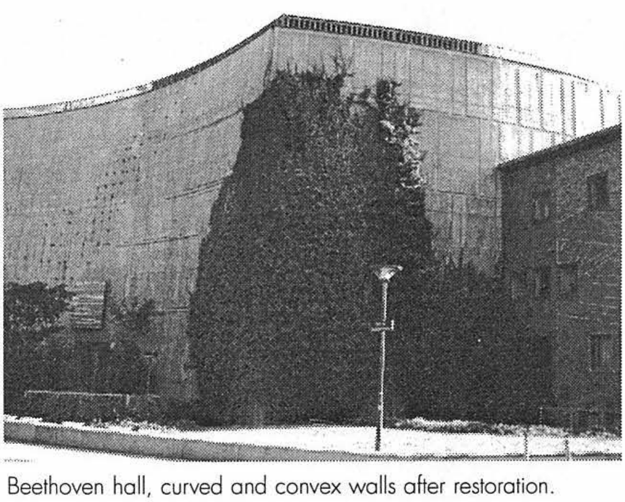
The difficulty in obtaining an acceptable appearance through reprofiling can be compared to inserting a patch into an old plain coloured carpet, without being able to match the insert for colour beforehand. The first reprofiling on the west side required the colour tone to be matched by adding a mineral pigment for some parts. On a fresh cement surface, the tone is firstly determined by the grey colour of the cement, but when the cement coat has weathered away the colour of the aggregate must be taken into account as well. Furthermore, light and humidity conditions will affect the colour as long as a rich cement coat remains over the surface.

After the inspection reports were evaluated, only 4% of the facade's surface actually needed repair. In the course of the works, the colour matching of mortars became more and more reliable. This applies to the appearance in detail, as well as the overall impression of the facades.

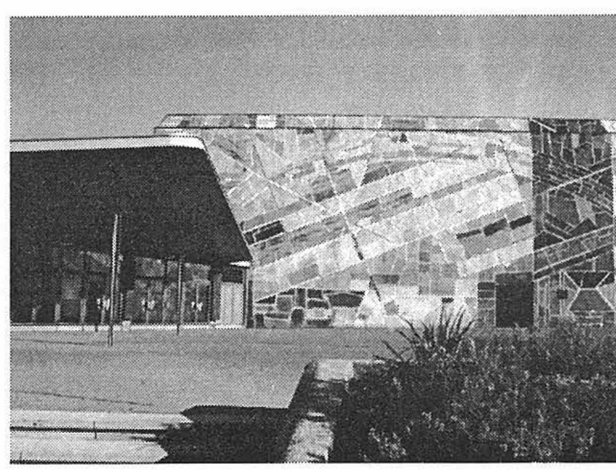
Trumpets

On the north side, the partly deteriorated and partly missing ceramic decorations by the artists Barbara Jäger and Omi Risterer from Karlsruhe, were carefully repaired and replaced where necessary.

In order to do this, it was necessary to rediscover the composition of the coloured glazings of these trumpet–shaped elements. Furthermore, the transparency of the glazings had to be redeveloped



Beethoven hall, curved and convex walls after restoration. Photo: B. van Swinderen.



The Mozart hall with its decorative stone cladding after restoration. Photo: B. van Swinderen.

by series of baking tests to comply with current toxicological specifications.

If the costs of the restoration of the Beethoven hall is calculated per square meter of renovated surface, the cost is relatively high: around DM 8,000 to DM 10,000 per m^2. If these costs are taken over the entire area of the concrete facades, a price of DM 300 per square meter is calculated. Renovation of the entire concrete surface in accordance with current standards would not have been possible for this price.

In conclusion, the real value of the careful concrete repair at the Beethoven hall lies in the preservation of its appearance and the authenticity of this building as a cultural document. It has been decisive to restrict the works to patch repair by reprofiling only locally and with mineral materials, and to avoid overall preventive measures. This approach would not have been possible without the great deal of care given in performing the preliminary surveys. Also the close supervision on the site has been essential, as have been quality tracking and systematic control.

To my mind, the procedures that were used to perform the initial survey programme are appropriate to other cases, although the execution can never be considered to be a patent recipe. Important factors that triggered the decision to patch repair were the estimated cultural value of this landmark by the owners, the relatively small proportion of facade surfaces actually being damaged, and the employment of good, responsible craftsmen.

Rudolf Pörtner is a principle of Wenzel, Frese, Pörtner, Haller, Büro für Baukonstruktionen in Karlsruhe, Germany. Text revised by the editor.

A multiphased approach

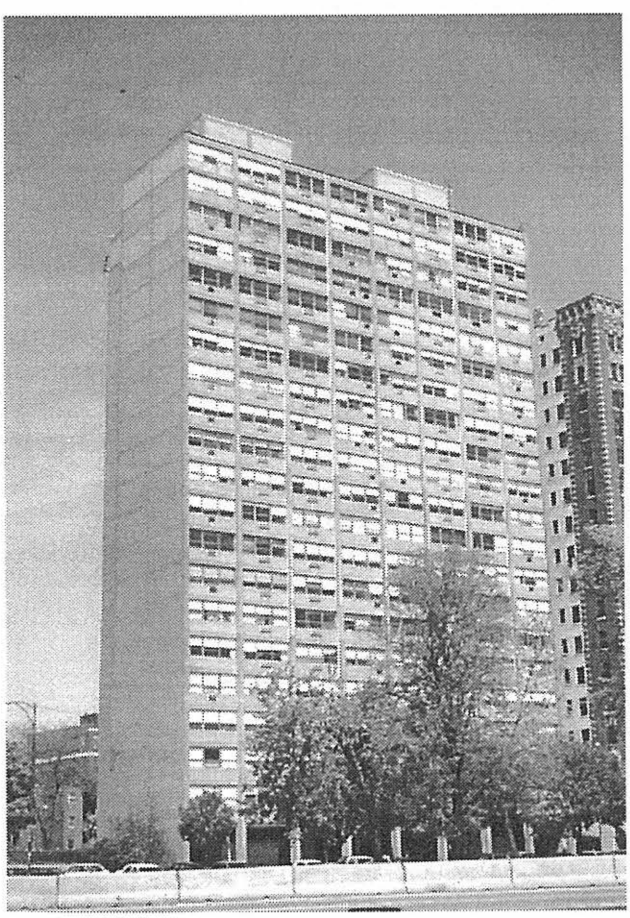
Promontory apartments, Chicago (Mies van der Rohe, 1949)

The Promontory apartment building was Mies' first constructed highrise building. The postwar steel shortage dictated the use of concrete instead of the steel-and-glass curtain wall of the original design. Distress was related to cracking and spalling of the concrete, deterioration of the mortar joints and sealant joints. The goal of the restoration project was to address deterioration of these exterior elements with materials and techniques that would be sympathetic to the existing facade and perform well. To slow down future deterioration, moisture infiltration was reduced by applying a silane-based sealer without a film-forming topcoat to avoid a negative impact on the texture, reflectance, and overall appearance of the surface.

by Paul E. Gaudette and Harry J. Hunderman

Reinforced concrete, a modern historic building material, is commonly used as the structural frame for many different types of buildings and structures. Like masonry and stone, concrete exposed to the elements is susceptible to deterioration from water penetration. The conservation and effective repair of concrete is dependent on a thorough understanding of the nature of the material, the pathology of deterioration, and the available repair technology and craftsmen.

Front and side elevations of the Promontory apartment building. All illustrations by P. Gaudette, except where stated otherwise.



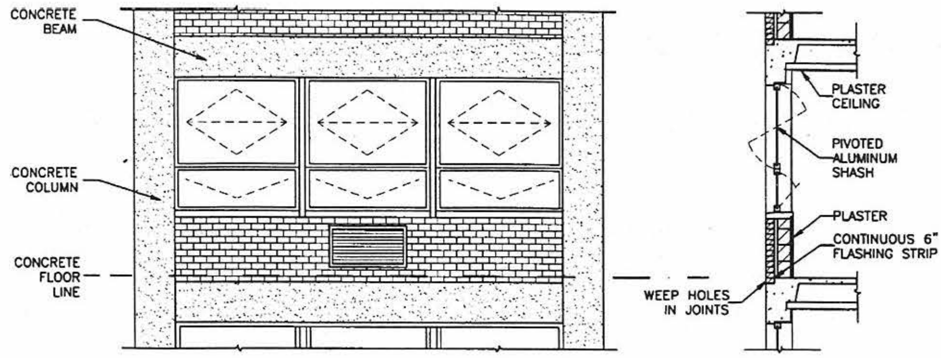
The 21-story Promontory apartment building[1] (1949) is typical of the postwar trend toward straightforward design with an emphasis on efficiency, low cost, and expression of structure. The exposed reinforced concrete frame of the building is infilled with light-colored brick panels. The concrete frame is emphasized by the projection of the columns beyond the exposed floor slabs. The windows are aluminum-framed; this is an early architectural use of aluminum following the popularization of this material for wartime aircraft construction.

The current exterior restoration project was prompted by water leakage and the deterioration of elements of the facade including the exposed concrete, masonry walls, and joint sealants. The challenge of this project was to execute repair work that would perform well and match the appearance of the original existing materials. This paper summarizes the phases of the restoration project, focusing on issues related to concrete, including the investigation, laboratory analysis of building materials, development of the concrete repair mix, trial repairs, and the repair program.

History

The Promontory apartment building, located at 5530 South Shore Drive in Chicago's Hyde Park neighborhood, was Mies van der Rohe's first large-scale commission outside of the Illinois Institute of Technology campus and his first constructed highrise building. The building was also Mies' first collaboration with the developer Herbert S.

A typical bay. Brick masonry was used as infill between the concrete frame elements. Aluminum pivot and hopper windows extend above the masonry to the concrete spandrel beam of the next floor.



Greenwald (1915-1959), who became one of his most important clients. Greenwald initially invited Walter Gropius, Eero Saarinen and Frank Lloyd Wright to submit proposals for the project. While they all declined, Gropius suggested that Greenwald contact Mies.[2] Ludwig Mies van der Rohe (1886-1969) began his career as an architectural apprentice in 1901 in Aachen, Germany, and moved to Berlin in 1905. In 1907 he received his first commission to design a house but it was never constructed. Mies served as director of the Bauhaus, founded by Gropius in 1919, until it was closed by the Nazis in 1933. In 1938 Mies came to the United States upon his appointment as the director of architecture at Chicago's Armour Institute, which merged with the Lewis Institute to become the Illinois Institute of Technology. The Promontory apartment building was also Herbert Greenwald's first solo project.[3] Greenwald had started out in teaching and social work. While attending the University of Chicago he worked as a real-estate agent and developer. With backing from others, he established the Herbert Construction Company in 1945, acquired the property at 5530 South Shore Drive with a partner in 1946, and began construction in 1948. In the postwar construction climate, Greenwald could not find mortgage lenders. His solution was to offer the apartments on the mutual-ownership plan, a cooperative investment concept with which he had become familiar during his university years. At first the design was considered too innovative and too 'ultra-modern' to suit the public taste. To the surprise of the real estate community, however, Greenwald sold more than half of the apartments from the plans. The other half were sold before the concrete frame was completed. The construction proved very economical, well below even that of most of Chicago's low-income housing projects.[4]
The original design for the Promontory apartment building included a curtain wall of steel and glass that was the forerunner of Mies' later buildings at 860 and 880 North Lake Shore Drive. The postwar steel shortage, however, dictated the use of concrete.

Description

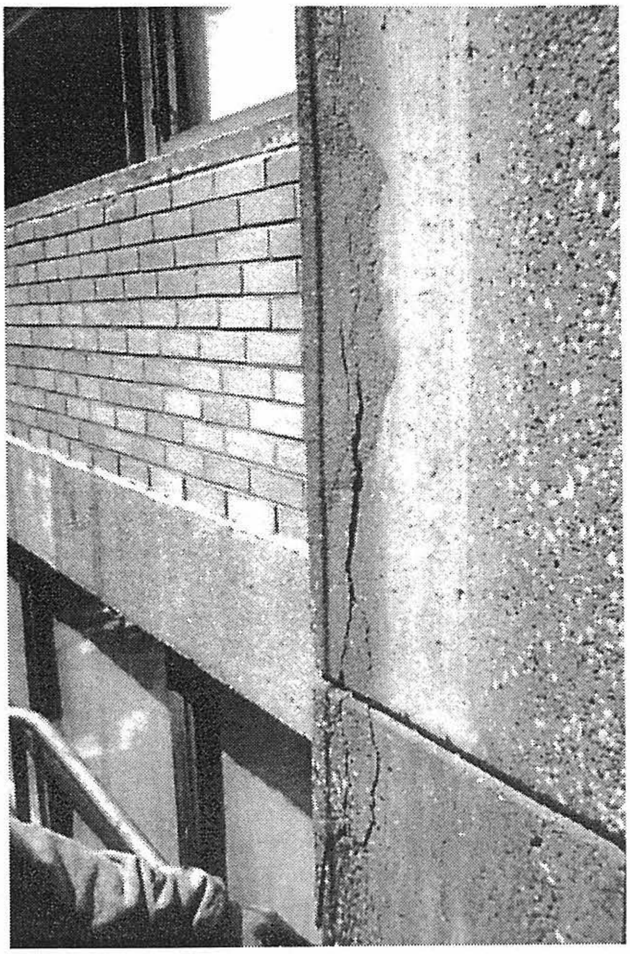
The structural system for the Promontory apartment building consists of a frame of concrete beams and columns. The interior floor slabs are supported by a one-way floor joist system that spans into the floor beams. The perimeter components of this structural concrete frame also act as part of the exterior facade. The columns are buttressed and step back, or reduce in cross-sectional area, at the sixth, eleventh, and sixteenth stories of the building. In plan, the perimeter columns extend past the slab edges.
Brick masonry was used as infill between the structural concrete elements of the exterior facade. The infill extends from a recessed curb along the top of the concrete slab edge to the bottom of the window sill. The head joints located along the bottom course of brick were left open to act as weeps for the masonry walls. Copper flashing was installed at the base of the masonry wall to assist in directing water out of the wall through the weeps. Air conditioners were later installed in the brick masonry spandrels, based on details provided by Mies in 1966.
The aluminum-framed windows have a 'fixed' upper sash that can be unlocked and pivoted for indoor washing, with an inward-opening hopper below. Fresh air is provided through the hopper windows. Steel, aluminum, and stainless steel were considered for the window frames.[5] Aluminum, not yet widely exploited in curtain walls but readily available following expansions in the industry during World War II, was finally chosen.

Investigation

Although there have been a number of repair programs at the Promontory apartment building since it was constructed, deterioration of the concrete, brick spandrels, sealant, and windows led to the comprehensive investigation of the facades. The primary types of distress were related to cracking and spalling of the concrete, deterioration of the mortar joints and sealant joints. The purpose of the investigation was to determine the causes of the deterioration and to develop a plan for the restoration of the facades. The investigation consisted of:

- Review of available documentation.
- Initial visual inspection.
- Hands-on, close-up examination.
- Laboratory analysis of the building materials.

The investigation of the facades was designed to



Previous repair involved darker epoxy-based mortars. Since repair was installed only to the level of the reinforcing steel delamination occurred in these areas. *See also color section.*

evaluate existing conditions and distress. Original drawings and field notes were available, but not the original specifications. After visual examination of the facades from at grade, from interior spaces, and from the roof, areas of the building were selected for detailed examination. The detailed inspection was made from a suspended scaffold at four representative bays. During the detailed inspection, areas of delaminated concrete were removed because of safety concerns. Selected areas of brickwork were opened to determine existing conditions, causes of deterioration, and as-built conditions. Samples of the concrete, mortar, and sealant were also removed for laboratory analysis.
Previous repairs had been performed at the building, but were not documented in the building records. These repairs appeared to have been implemented at several times over the life of the building. During the detailed examination, openings were made to assess the condition of these repairs and to determine the repair techniques used.
From this examination, it was determined that crack repairs had consisted of an application of a slurry of epoxy and sand installed over cracks in the spandrel beams. The previous repair materials appeared brown in color and did not match the original concrete in color or texture. These repairs were very noticeable from the street level, cracked over the original crack, and had a negative impact on the overall appearance of the building.
The previous repairs were found to be cracked, delaminated, and debonded from the original concrete. It was obvious that patch material was applied without removing the original concrete around the reinforcing steel. Typically, the repairs consisted of the installation of a trowel-applied mortar over corroded reinforcing bars. These repairs were also very noticeable from the street level.
New sealants had been applied over existing sealants with little, if any, surface preparation. Masonry panels had been repointed by removing loose mortar and applying new mortar over the top surface, filling some of the weeps at the bottom of masonry panels with sealant and mortar, and installing sealant in the bottom joint of the masonry panels.

Laboratory analysis

After the field investigation, materials were analyzed to determine material components, composition, and causes of deterioration. Laboratory studies of the concrete included petrographic evaluation following ASTM C856 [6] and tests to determine air content, water-to-cement ratio, cement content, general aggregate identification, carbonation depth and chloride content.
Petrographic evaluation was performed to provide a general identification of components and aggregates of original concrete. This information was needed to develop a mix design for the repair concrete. The petrographic studies revealed that the original concrete was made with natural gravel coarse aggregate that is petrographically similar to the 'Elgin Gravel' that has been used in the Chicago area for many years. The fine aggregate is composed of siliceous sand.
Concrete deterioration in building facades is generally related to two principal causes: corrosion of embedded steel and deterioration of the concrete itself. Corrosion of steel occurs where embedded reinforcing steel is not protected by the concrete's normal alkaline environment (which may be due to the presence of sufficient chloride ion), and the steel is exposed to water or high humidity levels. Protection of the reinforcing steel is directly related to depth of concrete cover. At the Promontory apartment building, deterioration was caused primarily by corrosion of embedded steel, which was inadequately protected.
Corrosion of the embedded reinforcing steel can also be related to carbonation of the concrete, which results from the reaction of carbondioxide with calciumhydroxide and moisture in the concrete, causing a reduction in alkalinity (pH). When carbonation extends to the level of the reinforcing steel, the concrete no longer provides an alkaline environment and therefore no longer protects the steel

from corrosion. In the samples evaluated, carbonation was found to be typical for a building of this age and exposure and was not considered to be a major factor in deterioration.

Laboratory analysis of the concrete samples also indicated a relatively low cement content (4 to 4.5 bags of cement per cubic yard of concrete) and a variable, moderate to moderately high, original water-to-cement ratio. In addition, microscopic examination revealed that the variation in the amount of exposure of the aggregate particles on the surface is due to differential dissolution of exposed cement paste. The more that water 'scrubs' the surface of concrete, the more the cement paste is dissolved and washed away, exposing the aggregate. This weathering is typical of concrete surfaces.

In the samples examined the body of the concrete was found to be sound and intact, with disruption confined to surface erosion and spalling. The observed spalling is associated with the expansive forces created by corrosion of embedded steel reinforcement. Chloride levels in the samples were found to be at or slightly above the threshold at which the corrosion of embedded steel is promoted.

The concrete was found to be air entrained with an air content of approximately 3%. This is considered in the low range. The use of air entrained concrete in a structure of this period is not typical (air entrainment, which has been found to improve the freeze/thaw durability of concrete, did not gain popularity in construction of highrise buildings until much later). Concrete used in the structural frame of the Promontory apartment building was specified to be air entrained to facilitate its placement. This was probably due to the concern for a consistent appearance of the concrete portion of the exterior facade.[7]

Restoration strategy

The goal of the restoration project was to repair the exterior concrete, address deterioration of other exterior elements of the facade, and reduce the rate of future deterioration of exterior building materials by reducing the rate of moisture infiltration into the facade. The primary objective of the repairs was to use materials and techniques that would be sympathetic to the existing facade and perform well. Finally, repair design needed to meet the installation tolerances used in the original construction. The concrete and brick were meticulously installed in extremely straight lines and with the very low tolerances typical of Mies-designed structures.

In order to achieve these goals, the project was organized in three phases:

- Development of trial repair materials and procedures.
- Performance of repair work at one trial drop of the building.
- Performance of repair work on the rest of the building facade.

Trial mixes and repair techniques were evaluated to determine how to best match the original appearance while providing a durable repair. The implementation of repairs at one trial drop permitted technical and aesthetic evaluation of the completed repairs and an assessment of the scope of work and the contractor's procedures. Information gathered in the first two phases was utilized in refining requirements for the project.

The work completed under each phase consisted of the following steps:

Phase 1, developing of trial repair materials and procedures, involved:

- Determining repair materials.
- Developing and testing trial mixes.
- Developing repair procedures and repair techniques.
- Performing finishing samples, using various techniques.
- Selecting repair materials and finishing techniques to match existing concrete.
- Selecting system to reduce the amount of moisture penetration into concrete.

Phase 2, performing repair work at one trial drop of the building, included:

- Using trial repair materials and techniques.
- Valuating the work, modifying procedures, and repeating trial repair work as needed.
- Performing repair work on the trial drop.
- Modifying repair materials and techniques to adapt to actual as-built conditions.

Phase 3, performing repair work at remaining portions of the facade, included:

- Incorporating lessons learned in Phase 2.
- Performing repair work at trial repair area.
- Performing work on remaining areas of the building.

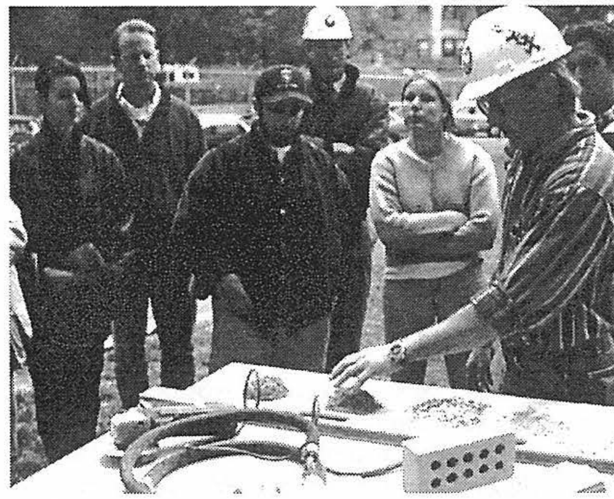
The actual repair program is explained step by step in the following paragraphs.

Mix design

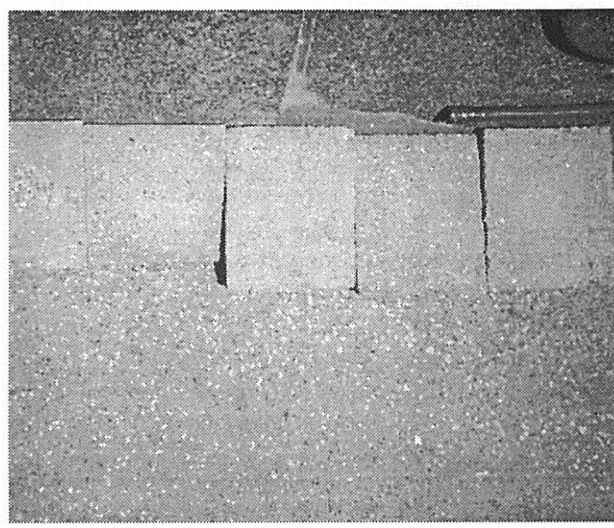
Phase 1 focused on developing a mix design for a repair concrete to match the original. The first problem was to identify aggregates, sand, and cement in the original concrete. Laboratory analysis revealed that the aggregate was a natural gravel composed primarily of dolomitic limestone. The natural sand was composed primarily of quartz and chert, with smaller amounts of limestone and minor amounts of shale. The cement was buff/white in color. Fortunately, the majority of these materials are readily available locally. The buff-colored cement, not commonly used or produced today, was more difficult to obtain.

Testing during the project helped in maintaining consistency in the repair materials. The testing parameters are developed during the trial repair phase so that they can be evaluated and adjusted prior to implementation of full-scale repairs. Initial parameters developed for laboratory or field testing, included slump, air content, and compressive strength. Slump (measured by ASTM C143) is a measure of the concrete's workability and consistency, which determines its ability to be consolidated properly within the forms and repair areas. A slump test is performed by placing fresh concrete into a cone, removing the cone and measuring the vertical distance the concrete settles. Air content is measured by a pressure meter (measured by ASTM C231) and indicates the level of entrained air (the incorporation of microscopic air bubbles), which provides protection for the concrete against damage due to cyclic freezing action. The concrete is air entrained by the addition of an admixture during the mixing process. Compressive-strength testing (by ASTM C39) confirms that the concrete meets the required strength for the installation.

In order to match the existing finish, texture, and color of the original concrete, a conventional concrete was selected instead of a polymer-modified repair concrete, which is now typically used for facade repair but tends to result in patches that are darker than the original concrete. Polymer-modified patches are generally acceptable where a coating is to be used to cover the entire repaired surface. However, no coating was previously used or was intended to be used on the facade of the Promontory apartment building. Polymer-modified concrete also has a higher bond strength and is more resistant to moisture penetration than conventional concrete. However, the repair concrete developed for the Promontory apartment building was designed to be attached to the original structure mechanically and was air entrained to provide better durability in a freeze/thaw environment.



Composing a matching concrete mix on site, employing local sand, aggregates and a buff-colored cement which was hard to obtain. Photo: W. de Jonge.



Trial repair mix samples adjacent to the original concrete facade. *See also color section.*

Application

All concrete repair materials were placed into formwork with a minimum depth of approximately 2 inches. Trowel-applied thin patches, using repair materials without forms, were not used. Formed patches with greater depth provide more room for proper placement of the repair concrete and result in a more consistent, durable repair. In addition, all patches were anchored with the original reinforcing steel by excavation of existing unsound and sound concrete to a minimum of 3/4 inch beyond the depth of the exposed steel within the patch to provide more substantial mechanical attachment to the structure. In the case of misplaced original steel, additional reinforcing steel was added to provide even greater attachment. The placement of the concrete was also improved by using both internal and external vibration techniques. These techniques can be used with formed patches but not with trowel-applied patches.

Finishing samples

Approximately twenty, 1 foot square samples were prepared in forms, separate from the building. The samples used a variety of mixes, with different proportions of buff-colored cement and aggregate components, and different finishing techniques. It was difficult to match the appearance of the existing concrete because of the varying degrees of paste erosion and resultant aggregate exposure. Finishing techniques and procedures were developed to allow the contractor to vary the exposure of aggregate in the concrete to match the appearance of the original facade. Some of the surface finishing techniques evaluated included the application of a surface retarder, sand blasting, water blasting, low pressure water blasting, and hand brushing. Samples that utilized a surface retarder were rejected because the resulting appearance was too even and exposed too much aggregate in comparison with original concrete.

The most effective finishing techniques involved a combination of very light water blasting and hand finishing. Once the finishing techniques were refined, the proportions of aggregates and of the buff/white cement mixture were adjusted.

Penetrating sealers

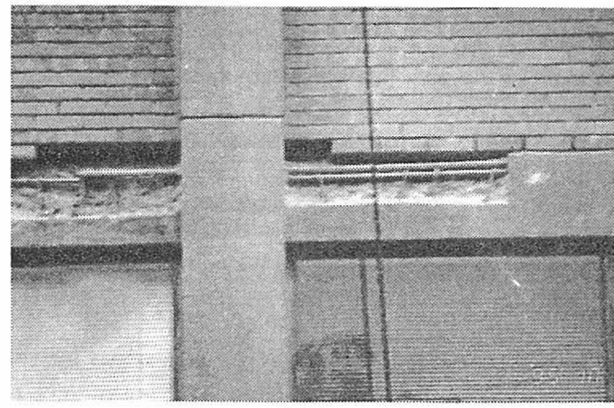
Previous crack repairs using an epoxy material were unsuccessful in bridging cracks and in preventing moisture from entering the concrete. As a result, embedded reinforcing steel in the area of the crack continued to corrode, and deterioration continued in areas of previously repaired cracks. To correct this situation, the cracks were routed to 3/8 inch thickness and filled with a sealant. The sealant color was selected to match the adjacent concrete as closely as possible. To further reduce moisture penetration and deterioration, a penetrating sealer was applied to the concrete facade. During the past several years, new penetrating sealers have become available that make fine cracks and pores in the concrete resistant to water while allowing water vapor that does enter the concrete to escape. These new penetrating sealers include silanes and siloxanes. A silane is a very small molecule, called a monomer, whose size approaches the size of the pores in many stone and concrete substrates; consequently, the silane is able to penetrate deeply into the pores. The silane chemically reacts with the surfaces of the pores and makes them water-repellant or hydrophobic. A siloxane is a pre-polymer made up of a number of monomer units; its size is therefore larger than a silane. The siloxane is also chemically reactive and bonds to the surfaces of the substrate pores. Neither silanes nor siloxanes are film-forming, and they do not alter the appearance of the facade. Some silanes or siloxanes are used in combination with a film-forming acrylic topcoat. In addition, some formulated products combine a silane or siloxane with a film-forming polymer. Film-forming products may alter the vapor permeability of the substrate and may also affect the texture, reflectance, and overall appearance of the surface. The penetrating sealer selected for use on the Promontory apartment building is a silane-based product without a film-forming topcoat.

Mock-up

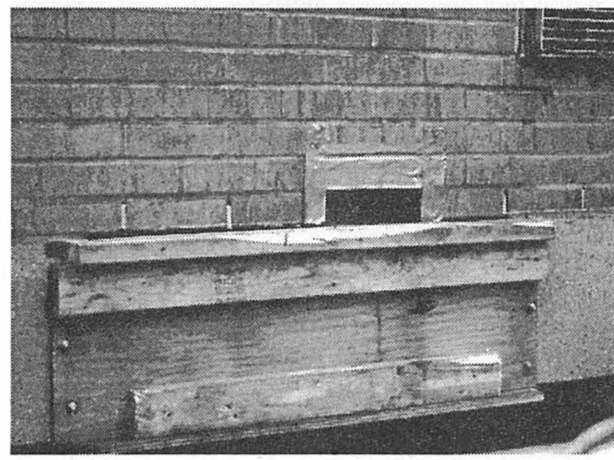
After finalizing the repair mixes and finishing procedures, repairs were performed in a mock-up on the building. The location of the mock-up was selected to be accessible and unobtrusive. The mock-up was executed on an area of concrete at one floor level across one bay. Refinements to the mix and placement procedure were made during the mock-up. For example, placement of the mix design selected during the sample preparation was difficult because the concrete did not flow readily, resulting in inadequate consolidation of the concrete within the patch. A small amount of water was added to the mix to facilitate better placement of concrete in the formwork and other adjustments were made as the mock-up proceeded.

Surface preparation

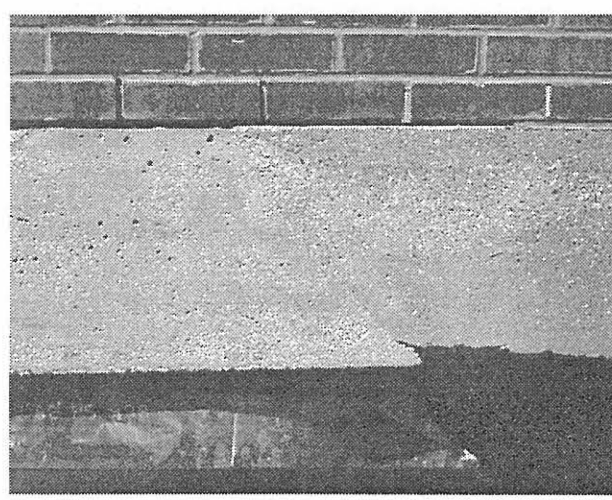
Surface preparation is one of the most important components of any concrete repair. The steps



Completion of the preparation work in a repair area prior to installation of formwork.



Installation of formwork to a spandrel beam before concrete placement.

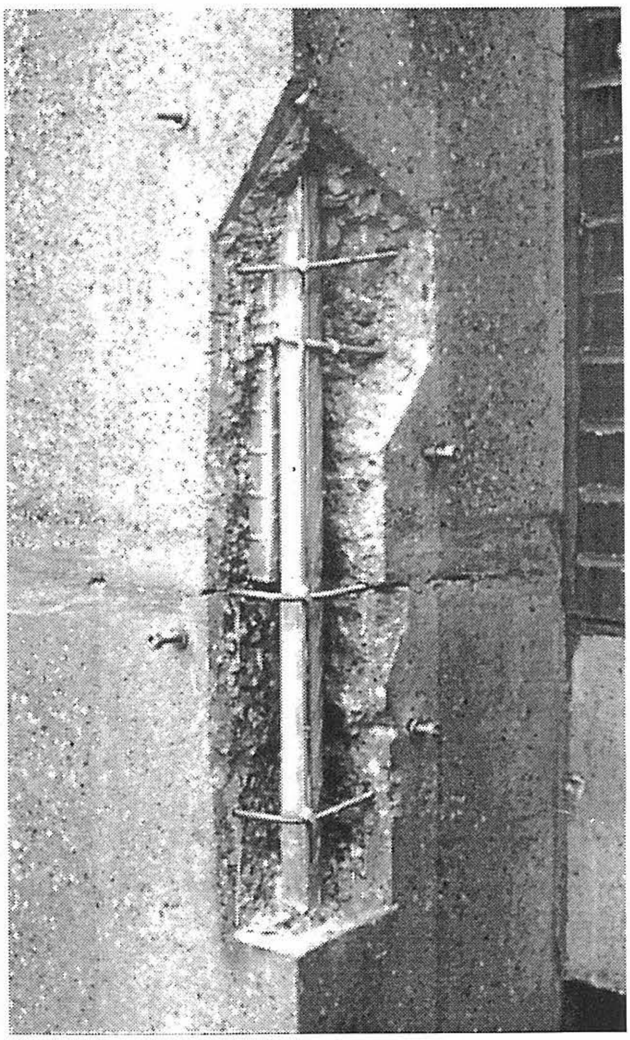


The complete installation of repair and finishing at the Promontory apartment building. *See also colour section.*

followed at the Promontory apartment building are fairly typical of concrete repair work but were slightly more aggressive in removal of concrete within the patch area, to provide better encasement of the reinforcing steel within the repair material and to improve the performance of the patch. The procedure for surface preparation was as follows:

- Remove loose and unsound concrete from the exposed portions of the columns and spandrel beams.

- Bevel sawcut the perimeter edges of the repair area to a depth of 1 inch and approximately 1 inch beyond visible corrosion of the reinforcing steel.
- Chip concrete within patch area to a minimum of 3/4 inch deeper than the reinforcing steel.
- Sand blast and air blast the patch area to clean away laitance, dirt, and other debris from the exposed concrete.
- Sand blast and air blast exposed reinforcing steel to remove rust, dirt, and other debris.
- Inspect the exposed reinforcing steel for loss of cross-sectional area due to corrosion and replace as required.
- Install supplemental steel, as required.
- Apply a corrosion-inhibiting coating to the exposed reinforcing steel within the patch.



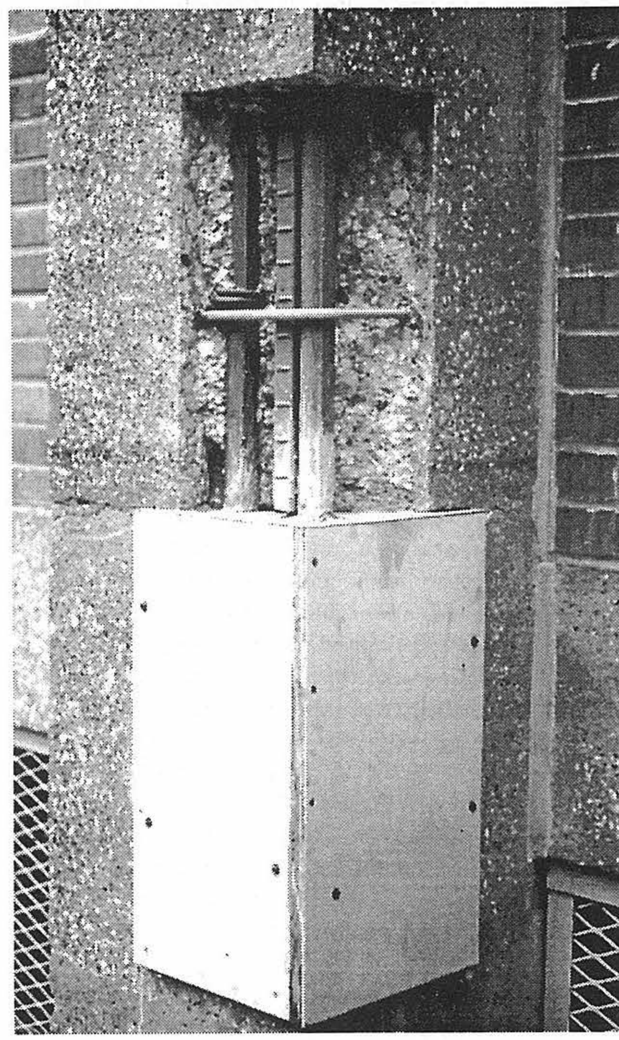
A patch at a column prior to installation of formwork. The reinforcing steel is treated with a corrosion-inhibiting coating.

Installation

It was extremely important to match the surface profile and finish of the adjacent concrete. Heavy grinding of the patch surface would have prevented matching the finish and texture of the adjacent concrete.

The procedure for placement and finishing was as follows:

- Install formwork at all repair areas to match existing profile of adjacent concrete.
- Test concrete for conformance to specifications.
- Place concrete into forms using internal and external vibration techniques.
- After approximately 24 hours of curing, remove the forms.
- Expose aggregate at the exterior surface of the new concrete with a combination of low-pressure water blast and hand brushing to expose the aggregate to a depth that resembles the original concrete adjacent to the repair area.
- Cure the repair concrete by installing plastic over the repair area for a minimum of seven days.
- Test concrete for conformance to specifications.
- Apply penetrating sealer to both the original



Formwork was to match the existing profile of adjacent concrete work. Photo: W. de Jonge.

and repair concrete to reduce the amount of water penetration.

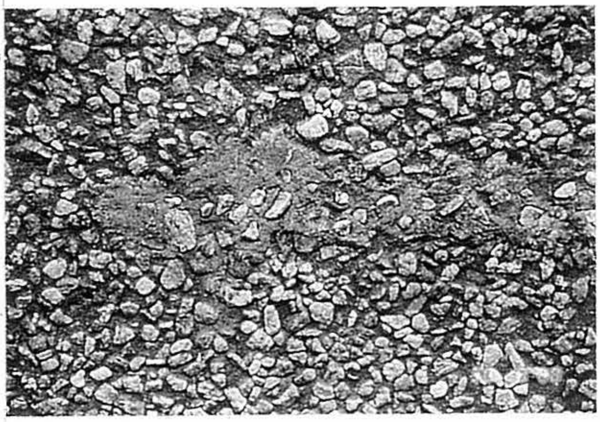
Conclusion

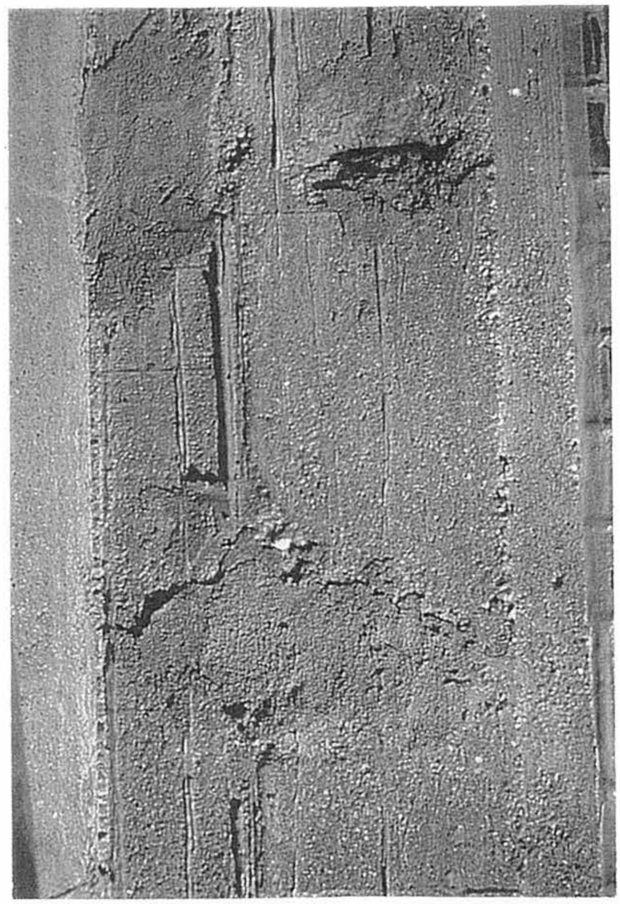
During the sample repairs executed on one bay of the facade, procedures and materials were adjusted to achieve a concrete repair that matched the adjacent original concrete in appearance and met the established criteria for good concrete repair practice. The multiphased process of investigation, laboratory analysis, trial samples, mock-ups, and full-scale repairs allowed refinement of the repair design, maintaining of installation procedures, and implementation of quality control measures as the project progressed. A preservation approach was used to guide technical and engineering decisions, resulting in repairs that perform to modern practice standards and are aesthetically successful.

Paul E. Gaudette is a senior engineer with Wiss, Janney, Elstner Associates, Inc. (WJE) in Chicago, has focused on the investigation, testing, repair, and restoration of concrete in historic and contemporary structures. Harry J. Hunderman, FAIA, a preservation architect, is a senior consultant and the architecture group manager with WJE in Northbrook, Illinois, and president of APT. This article is reprinted courtesy of the Association for Preservation Technology International and the authors.

Notes:

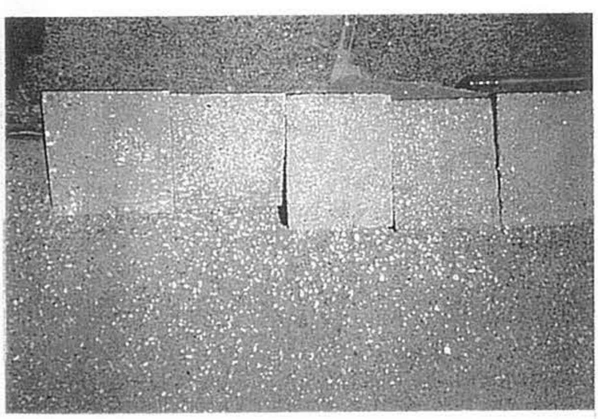
1. The Promontory apartment building may have been named for Promontory Point Park, a point of land that extends into Lake Michigan landscaped in the 1930s by Alfred Caldwell, a prominent follower of the Prairie School landscape tradition of Jens Jensen.
2. 'Chicago Apartment Developments - Mies van der Rohe's Promontory and Lake Shore Projects: Glass and Brick in a Concrete Frame', *Architectural Forum*, January 1950, pp. 69-77. Mies van der Rohe is identified as the architect for the Promontory apartment building, with Pace Associates, associate architects; Holsman, Holsman, Klekamp & Taylor, consulting architects; Frank J. Kornacker, structural engineer. The general contractor was Peter Hamlin Construction Company.
3. Greenwald's real estate ventures are described in Miles L. Berger, *They Built Chicago: Entrepreneurs Who Shaped a Great City's Architecture*, Chicago 1992.
4. Construction of the Promontory apartment building cost $8.55 per square foot, 'less than most slum clearance projects', *Chicago Apartment Developments*, p. 70.
5. The review of window frame materials is documented in field notes that are part of the original construction documents.
6. ASTM is the American Society for Testing and Materials.
7. *Architectural Forum*, p. 70. This article, written soon after the building was completed, notes that 'use of air entrained concrete made a dense surface capable of self-finish'.

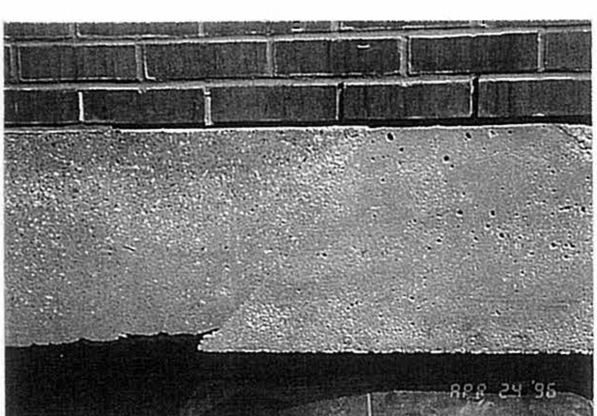


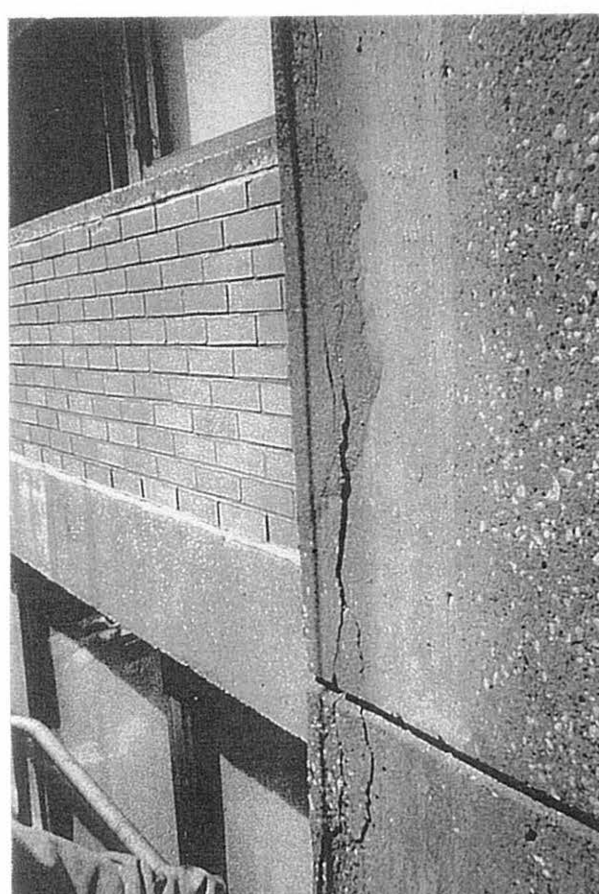


Previous examples of indiscreet patch repair at the Bank of Norway (top, left) and the Notre Dame in Royan (top, right). Later restoration involved repair with mortars that are more sympathetic to the original materials in terms of texture and colour. Photos: HTC and P. Oudin.

Previous repair of exposed concrete at the Promontory apartment building involved a darker epoxy-based mortar; major delamination was found at such locations (bottom, right). Trial repair mix samples adjacent to the original facade show slight variations in colour and texture to match the original material (left). The complete installation of repair and finishing at a spandrel beam shows the careful match between repairs and original material (bottom, left). Photos: P. Gaudette.







A tailored remediation strategy

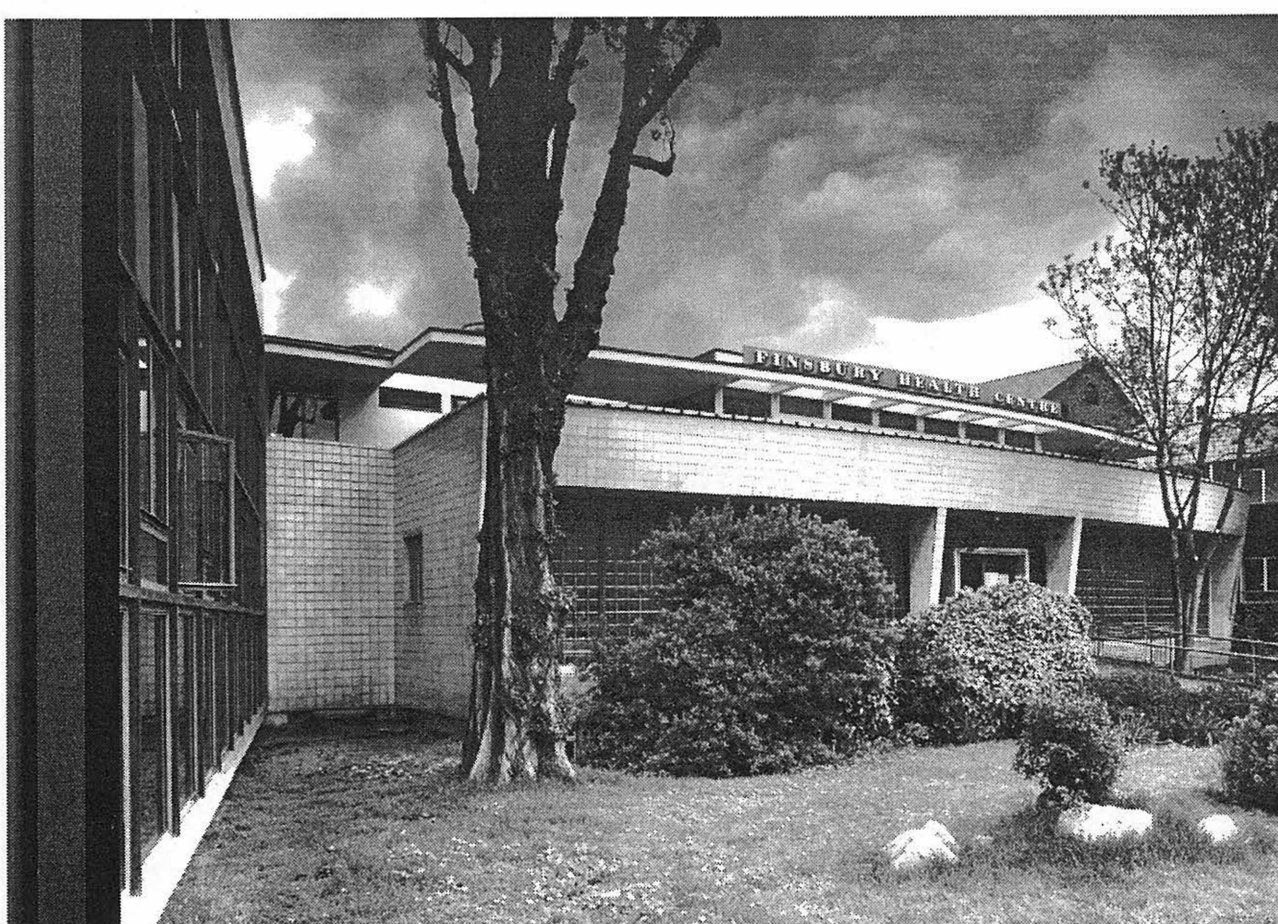
Finsbury Health Centre (Lubetkin & Tecton, 1938)

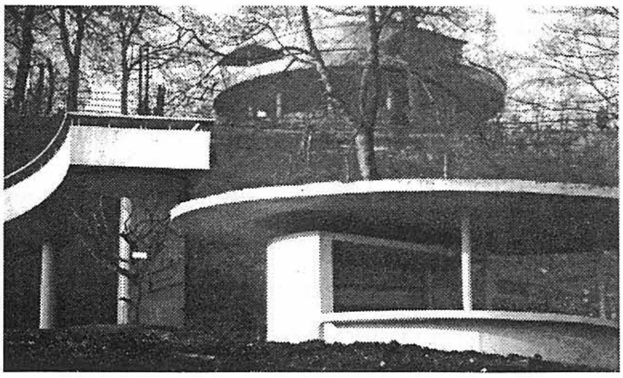
Avanti Architects recently carried out a conservation project at Finsbury Health Centre, one of Lubetkin's most celebrated works of the late 1930s in London, and now a Grade I listed building. The particular emphasis of this post conference book is the repair and conservation of exposed concrete, but there is relatively little of this at Finsbury. It is therefore helpful to realize how, even by as early as 1935 when Lubetkin and Tecton began work on Finsbury, they were starting to move away from the extensive use of concrete as a facing material.

by John Allan

To understand Lubetkin's development as an architect the constant evolution of structural themes in his work must be understood. Lubetkin is pre-eminent in the English Modern Movement for his exploitation of reinforced concrete as a virtuoso medium. The early commissions he received for zoological pavilions provided an ideal vehicle for this expressive use of the material. They were quick, they were cheap, they were small and the functional programme was susceptible to a high level of sculptural invention. Indeed, and somewhat ironically for an architect of such fervent socialist conviction, it is by these seemingly frivolous divertissements for what we would today call the 'leisure or entertainment industry' that Lubetkin originally made his name in England.
But these buildings also offered an ideal opportunity to experiment with the structural potential of reinforced concrete. And initially they almost all exploited concrete in the then progressive mode of the

Finsbury Health Centre after the latest restoration work. Photo: Courtesy Makers Ltd.





Quick, cheap, small and sculptural. Lubetkin's early use of reinforced concrete in the zoo. All photos: J. Allan, except where stated otherwise.

early 1930s -that is thin-wall fairface monolithic design, or what Ove Arup was later to call 'muddy structure' on account of the fact that, as he put it, 'although you can ensure that it is perfectly safe, one doesn't know exactly how the stresses are distributed'.

Articulation

Lubetkin's first major social building, the large block of flats in Highgate, North London known as Highpoint (1935) was his earliest attempt in England to apply fairface reinforced concrete on a large scale.

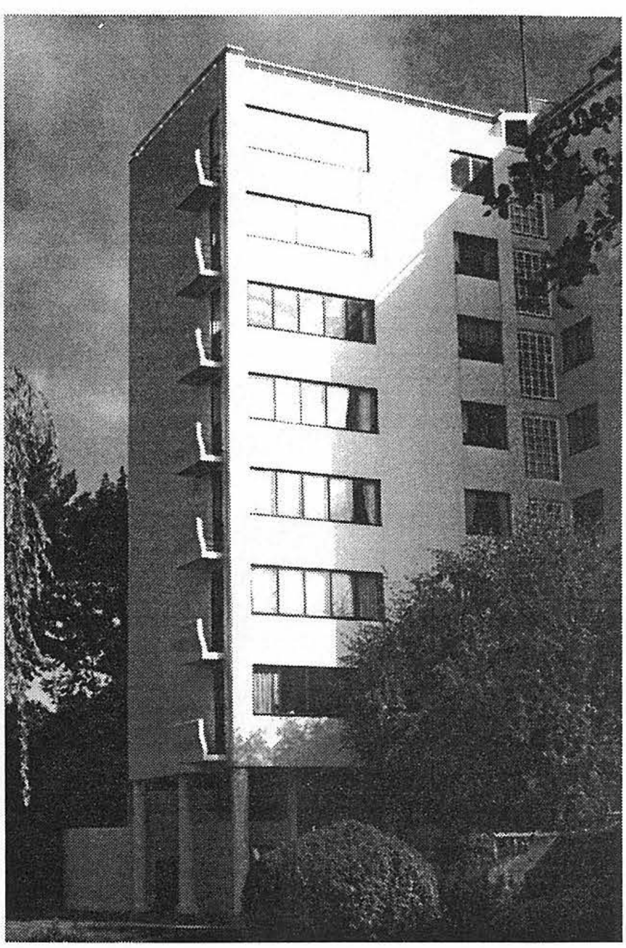
Like the zoo buildings, Highpoint was highly engineered in structural terms, benefiting as they had, from the assistance of Ove Arup whose use of a sliding shuttering construction system for the monolithic reinforced concrete carcass meant that the external expression and the structural realization of the building effectively became one and the same thing.

This was the first and last time Lubetkin and Arup used external load bearing walls (or 'eggshell structure') as the overall structural solution in a large housing scheme. As their work develops so the distinction between structure and expression is made increasingly clear. At Highpoint Two (1938) for example, the structure is a hybrid of frame and load bearing external wall which produces an architectural response of infill and cladding respectively.

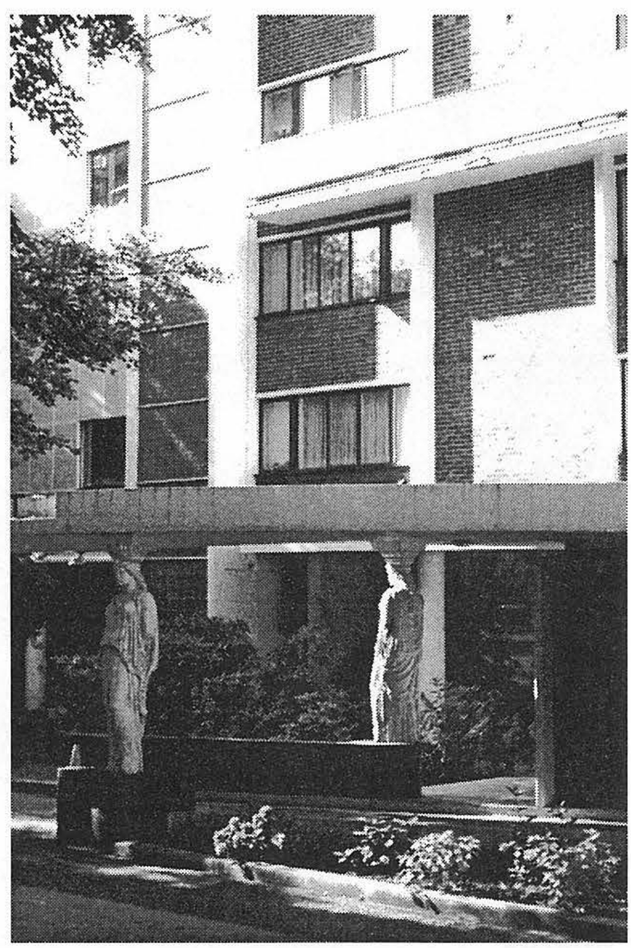
Even in the later zoo buildings Lubetkin was using materials such as brickwork or terrazzo panels as a means of wall-facing that avoided large areas of exposed concrete.

This change from an aesthetic of jointlessness to one of articulation is of profound significance in the development of modern architecture out of its International Style phase, and seems to me to have a direct bearing on the subject of this publication. Modern architectural composition was moving from

Highpoint One, 1935, where fairface concrete structure is fused with architectural expression to produce a 'jointless aesthetic'.



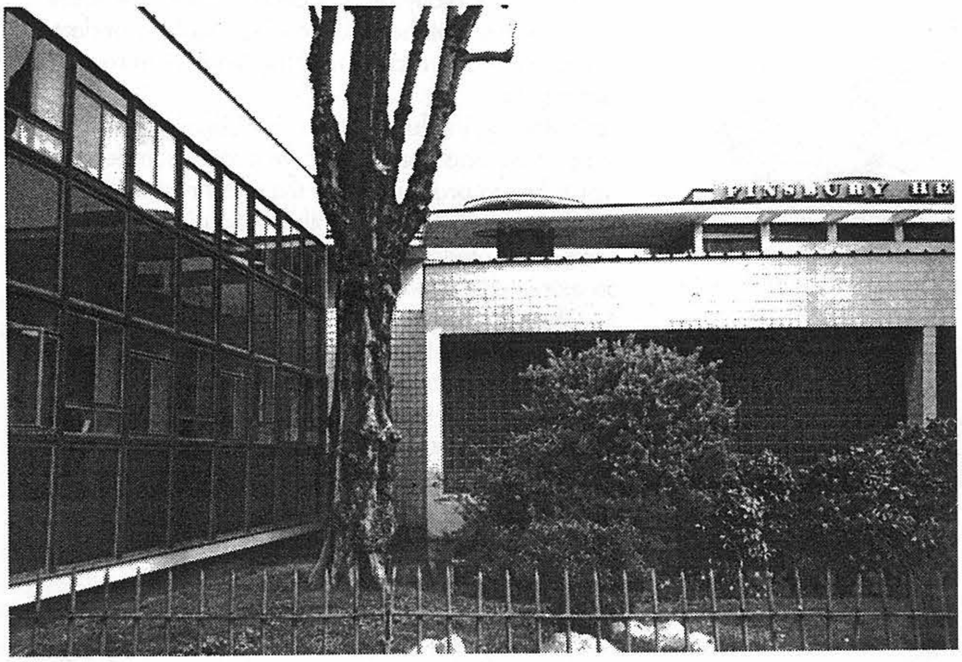
Highpoint Two, 1938, where frame and load-bearing structure results in infill and cladding - an aesthetic of articulation.



an artistic concept of sculpture to a constructive process of assembly. In England this progression was led by Tecton, though quickly taken up by others.

Hybrid structure

There are various reasons for this. Firstly, although it would be incorrect to credit Lubetkin and Arup with all the wisdom of hindsight available today in regard to the long term performance of reinforced concrete, it is certainly clear that they were becoming concerned at the poor weathering of some of the earlier work. Lubetkin himself told me that his original aim for Highpoint I was to clad the whole block in faience panels, but that this had to be abandoned as too expensive.



Finsbury Health Centre, 1938. Hybrid structure to suit a complex brief, with tile cladding, glass block infill, curtain walling and coated concrete.

It must be remembered that we are talking about London before the clean air legislation and introduction of gas central heating of postwar years. This was still the Victorian smog-ridden London where millions of homes were heated by open coal fires releasing thousands of tons of damp soot-laden deposits over the whole city. Prewar London was essentially matt black, slate grey and very dark brown, which is one reason why the Modern Movement made such a deliberately conspicuous intervention initially. As Lubetkin himself used to say, 'we wanted to give a face to our age'.

Secondly, Lubetkin -as well as some other modern architects- were becoming dissatisfied with the restrictive architectural vocabulary of fairface concrete used as an all-over material regardless of position, role, status and hierarchy - increasingly impatient with its range of expression in what one British historian Reyner Banham later called the 'teenage uniform' period of modern architecture in reference to this declamatory use of reinforced concrete. Lubetkin had so much more that he wanted to say. But third, and most important of all, is that programmatic requirements of the later buildings usually suggested structural responses that made the simple exposed load bearing external wall solutions of earlier schemes unsuitable. Highpoint Two for example had a quite different social brief from its predecessor, which produced widely differing apartment types, and in turn, a different structural response.

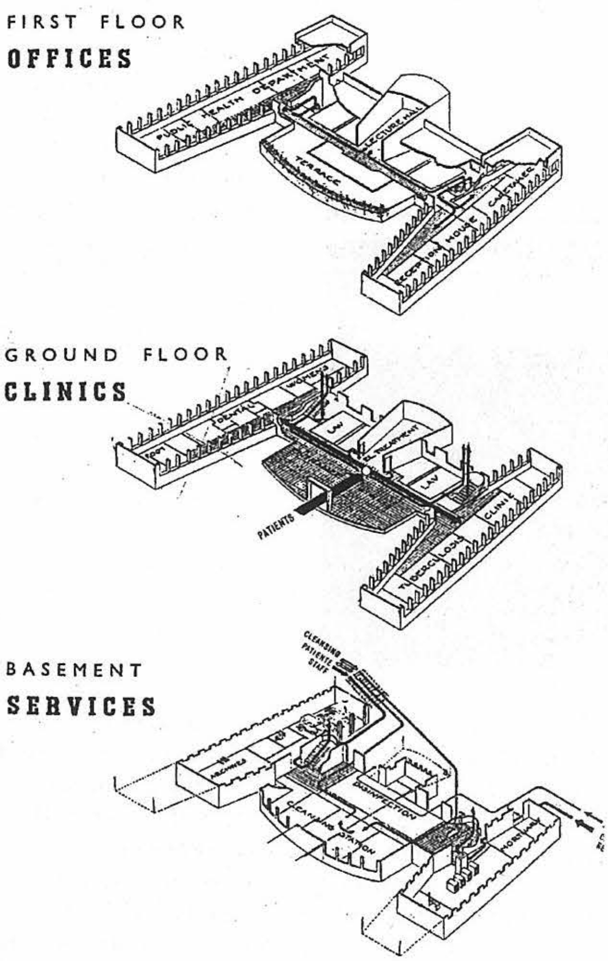
All these considerations apply to Finsbury Health Centre where again in response to a novel and complex operational programme a hybrid structure is used in combination with several different facing materials -including coated reinforced concrete. This diversity of systems and materials and their interaction very much informed the conservation project Avanti Architects undertook in 1993-94.

As well as concrete conservation and repair the work involved renewal of flat and vaulted roofing, renewal and repair of steel windows, replacement of steel flashings, replacement of spandrels, renewal of tiling, rationalization of services, removal of asbestos, refurbishment of hardwood framing, and replication of signage. So although I will focus on the concrete repair aspect, it should be understood as but one element in a composite conservation strategy.

Finsbury Health Centre

The accommodation of Finsbury Health Centre is arranged on two main floors and a slightly smaller basement. The main entrance, reception, waiting and circulation areas are in a central link block and the services, clinics and offices in two wings. A lecture theatre is placed in the centre to anchor the composition.

The hybrid structure to which I referred uses reinforced concrete in a column and slab system in the central link block, and in an external load bearing wall beam and mullion solution for the wings. The centre block is partly infilled with glass blocks, partly tile clad and partly rendered and painted. The wings are partly tile clad but mainly sheathed in a curtain walling system -one of the earliest examples of this solution in England. The logic of this also derived from the clinical programme which placed a high priority on ease of service alteration and interior flexibility. There are thus no



Finsbury Health Centre, diagram showing the geography of the building.

interior load bearing partitions in the wings.
In clinical terms the building has worked well over its 60 years of continuous use, and it is very much liked by its patients and staff. But the building fabric has worn and altered considerably, owing to a mixture of no maintenance or the wrong maintenance, as can be seen by comparing the 1938 views with survey pictures taken at the beginning of the contract.

Concrete repair

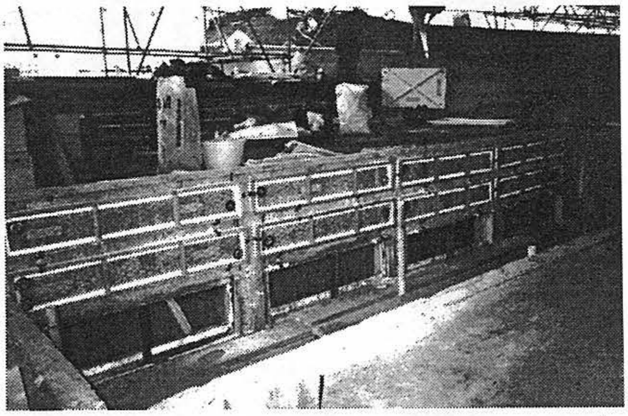
Extensive concrete repairs were required but the different geographical situations and uses of concrete called for different types of response. In areas where it was exposed fairface, the problems included carbonation, spalling, cracking and loss of coatings. In areas where concrete was rendered, the render suffered from cracking, debonding and loss of coatings. In areas where concrete was a substrate for asphalt or tile cladding (for example parapet upstands) it was generally sound but carbonated and with only some local damage. And where it was fully protected, for instance behind the curtain walling, it was as good as the day it was cast.
Because virtually all the concrete was clad or coated, and because in the latter case the current coating was not original, the problem of conserving authentic fairface work really did not arise. It might therefore be supposed that the solution was simply to undertake remediation and recoating using traditional repair techniques.
But following the further tests that became possible as soon as we had comprehensive access, the decision was taken to proceed using the more recently developed technique of realkalisation ('re-alk'). A number of interlocking factors combined to make this an extremely attractive option.

- The high ratio of latent damage to patent in other words the preponderance of concrete where only carbonation and not active spalling or excessive chloride was the problem.
- The regular and repetitive profile of most of the relevant areas - allowing use of standard re-alk pans.
- The continuity of reinforcement which is necessary to achieve viable circuitry for electro-chemical processes.
- The reduced disruption both to building users (most of whom were to remain in occupation during the repair contract), and to adjacent building fabric, in particular the faience parapet copings which were authentic and sound.
- The achievement of cost certainty as well as actual reduced cost, as we were able to obtain a fixed price quotation from the concrete repair contractor.

In terms of savings, the comparison showed for example on the wing parapets: re-alk £9,990 and conventional repair £13,870, a saving of 28%. For the building as a whole: £56,000 v/v £65,000, a saving of nearly 15%. These cost considerations were significant in the context of a limited client budget.

Economic response

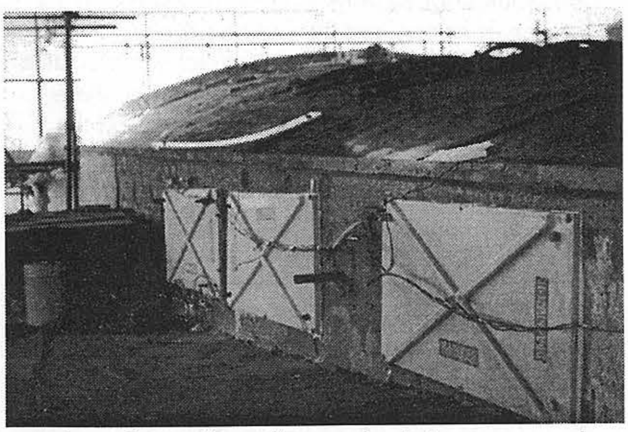
Having said this it is important to emphasize that these measures should not be regarded as simple alternatives. They have different pro's and con's and need to be seen and evaluated as complementary processes, along with the increasing range of other remediation techniques that are now available, and about which more is said in my conclusion. Also, some costs will be equivalent whichever approach is used -for example access costs, survey costs and recoating costs if applicable.
But for the purposes of the present publication I obtained from Makers, the contractors we used at Finsbury, a theoretical cost comparison between



Realkalisation being applied to planar areas allowing re-use of standard pans.

traditional repair and realkalisation for a 12 storey tower block with 2000 m² of plain concrete surfaces. It was assumed that there were 500 small areas of visible concrete damage, and 400 m² of concrete where reinforcement was suffering from carbonation

Realkalisation being applied to the lateral walls at the barrel roof.



attack. In the traditional repair both the patent and the latent damage must be replaced with polymer modified mortar, producing unit costs of £10/small area and £110/m² respectively. With realkalisation

Traditional concrete repair techniques used locally for difficult profiles.

the patch repair procedure can be less invasive as the re-alk process will itself re-passivate the reinforcement, while the latent damage requires no concrete replacement. The equivalent unit costs were £6/area and £70/m², producing an overall saving of nearly 37%.

Anyway at Finsbury we used both, albeit with the bulk of the repair being through realkalisation. The following illustrations show how the realkalisation technique was tailored to the specific architectural features of the building. Some traditional repair was still required, generally where small areas with unusual profiles made realkalisation uneconomic, like the distinctive ventilation funnels at roof level.

This is also the point to talk about colour. All render and concrete surfaces above basement level had been overpainted white during subsequent maintenance. By studying contemporary black and white photographs and removing later applications of paint and render it was possible to retrieve the original surface colouration. A typical Tecton palette of colours was discovered: intense red-brown applied to selected surfaces on the terrace; pale blue to the reveals of the glass block entrance screen, terrace canopy soffit and lecture theatre block, a dark 'French navy-grey' to basement and undercroft areas, and a cream colour elsewhere. On completion of concrete and render repairs, surfaces were re-coated with closely matching colours from the Sika and SBD concrete repair systems.

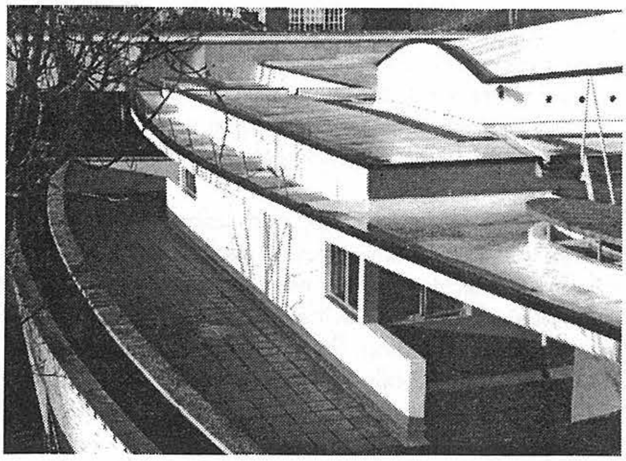
'Impure' conservation

Finsbury was a composite work involving a range of materials and techniques. It will also have become apparent that as much of the original character and fabric of the building had been obscured or lost through inappropriate replacement, our task was as much one of restoration as of repair. Moreover, in the context of our client's concern for reduced future maintenance cost, it also involved a measure of judicious improvement.

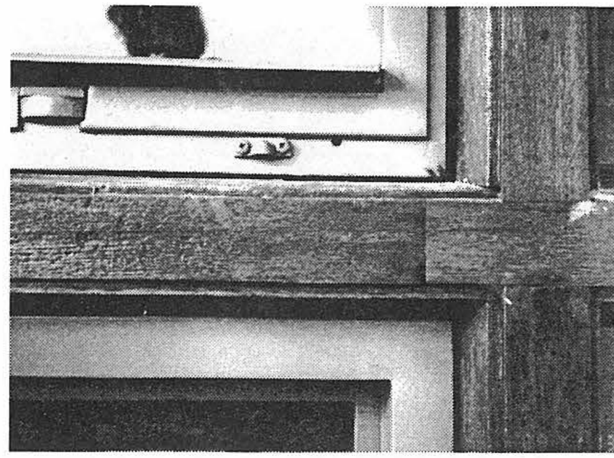
Now I am aware that these notions are disapproved of by academic conservationists, but as I have said at many previous occasions, I believe that the reality of 'impure conservation' is something that DOCOMOMO must recognize and address positively. Certainly at Finsbury we did not lose the opportunity to increase drainage falls, enhance weathering, improve seals, and so on, wherever it was possible to do this discreetly. I therefore want to describe briefly some of the other work we did there.

Re-roofing works

The original roof finish was rock asphalt generally laid over screed on 25 mm cork slab insulation. On the curved barrel roof the build-up was 25 mm rock asphalt on e.m.l. on 25 mm rock asphalt on 25 mm cork slab on concrete. In the central area of the building the rock asphalt, a naturally occurring



Re-roofing work showing seamless quality of polymer modified asphalt.



Detail of curtain walling showing rehabilitation of teak framing and replacement steel windows to original pattern.

material no longer available, was dressed over verges and projecting copes and was therefore an integral feature of the building's appearance. Research into alternative roofing systems, particularly single ply membranes found no material that could achieve the seamless monolithic quality of the original asphalt. It was therefore decided to use a polymer modified asphalt, which unlike the traditional product maintains its performance when subject to naturally occurring temperature extremes, together with 50 or 70 mm cork slab insulation in a warm roof system. Around the perimeter of the wing roofs a purpose made aluminium flashing was applied to the existing 100 mm thick reinforced concrete parapet walls, this avoided the need to cut an asphalt chase at the new kerb head position which might have disturbed the faience coping, to which I referred earlier. The barrel roof insulation was lined with three layers of 6 mm ply, felt and e.m.l. to reduce the surface temperature variation within the asphalt on the inclined surface. In order to regain the original appearance of the asphalt edges, the solar reflective paint was overcoated with a black finish.

Curtain walling

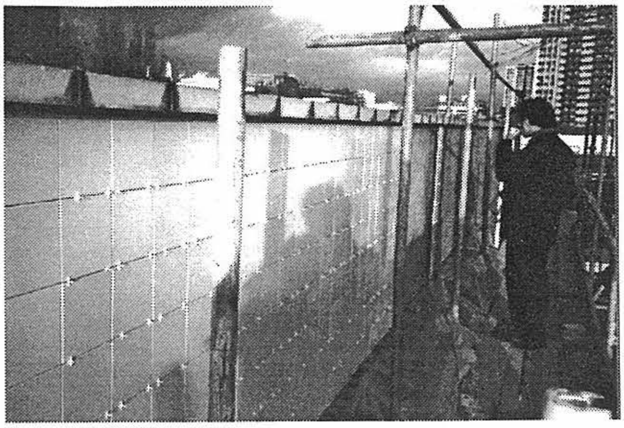
The curtain walling on the face of the wings, in a severe state of disrepair and marred by subsequent modifications, has been restored to its original appearance. The teak frame has been renovated and mild steel fixings replaced in stainless steel. Although it was possible to retain some of the original windows in the more protected areas, the condition of the majority led to the decision to replace those within the curtain wall system, and to introduce double glazing. The original vertical pivot action, the frame drainage grommets and friction turnkey details have all been replicated. Paint scrapes revealed that the windows were originally painted an olive grey colour. New steelwork is galvanized with a polyester powder coated finish. The original silver bronze lever handles and distinctive friction pivot levers have been salvaged and re-used on the replacement windows. One of the biggest challenges of the restoration has been the spandrel panels. These were access panels for the external service ducts running along the face of the building -and originally comprised 'Thermolux' panels- two sheets of clear glass with a coloured spun glass-silk interlayer. Although we discovered that Thermolux was still made in Germany, it is now only available in white.

None of the original panels survived to give an indication of colour, and the postwar replacements departed wildly from the original effect -which was at once dark but lustrous. The only evidence on these consisted of black and white photographs and the recollections of Lubetkin, Francis Skinner, now sole surviving partner of Tecton, David Medd, who visited the building as a student during construction. Miraculously, fragments of the original panels were discovered at the base of the ducts, these were sent to a materials laboratory for forensic analysis and colour matching. The final solution to replicate both the colouration and reflective properties of the original curtain walling was to place a laminated bronze tinted glass panel in front of the plain white Thermolux. This solution will have the additional benefits of protecting the Thermolux, improving insulation values and providing a more durable outer skin by virtue of the Class A lamination standard. Finally, in relation to the curtain walling, all the original steel flashings framing the curtain wall areas had corroded or deteriorated beyond repair, and were therefore replaced with matching galvanised powder coated equivalents.

Tile and faience

The tile cladding of concrete has been noted as Lubetkin's solution to achieving a better quality finish than simple fairface. The original cream coloured ceramic tiles were manufactured using a dust-pressed process. This allowed greater dimensional accuracy and resulted in the narrow joints (0-2 mm) characteristic of the building.

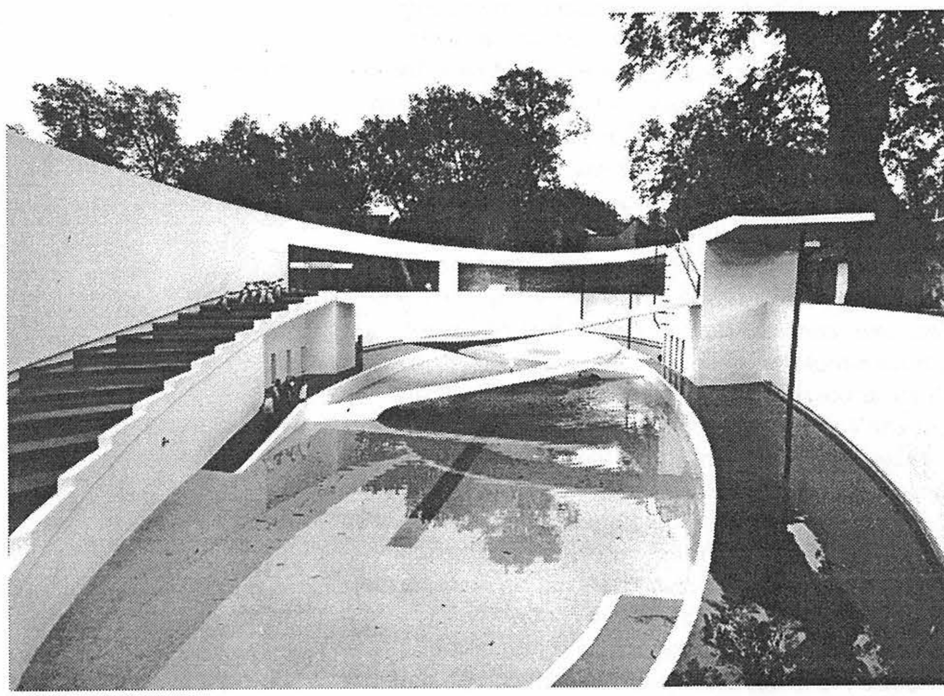
Unfortunately, the original tiles were not fully vitrified and therefore not reliably frost-resistant. In addition there was no effective provision of movement joints.



Retiling of wing surround, showing retention of original copings used as setting out module.

Wynford House, London, one of Lubetkin's postwar housing projects using concrete in many forms, to be rehabilitated by Avanti Architects using a wide range of remediation techniques. Photo taken from: J. Allan, *Berthold Lubetkin, Architecture and the Tradition of Progress*, London 1992.

The defective areas were much more extensive than initial visual evidence might suggest, with the result that although the centre facade could be retained with local repairs, the wing surrounds needed to be fully retiled. No UK manufacturer was prepared to produce the close glaze match and range of specials



Penguin Pool, London Zoo, was designed by Lubetkin and Tecton in 1934 exploiting the full structural potential of reinforced concrete. It has been expertly restored by Avanti Architects in 1987.

required in a vitrified dust-pressed tile. The final technical solution was achieved with the help of a tile factor who procured biscuit from various sources to be glazed in a factory in Northern France.
A number of technical issues still had to be resolved. The original tile, not being vitrified, absorbed more of the glaze, giving an appearance of greater depth and translucence. The modern tiles have a more refined body and glazes are more consistent than the original -with the attendant risk that the final effect would be too mechanical. The biscuit therefore had to be coated with white slip prior to glazing to achieve the correct colour and sheen.
The tiles were bonded to the render with a 3-6 mm thin/thick bed adhesive, with movement joints generally in accordance with current British Standards. And here at last I can reveal the added benefit of realkalisation with its avoidance of disturbance to the original faience copings. These copings, which would have cost over £200 each to replace, were modular with the original tile grid -one cope per two tiles- and so gave us our setting out discipline when it came to replacing the new tiles.

Conclusion

There is much in what I have called the 'composite' character of Finsbury Health Centre that justifies its occasional description as 'the first postwar building' in England. It was certainly seen by some as pointing towards the progressive ideals of postwar reconstruction, anticipating as it did the establishment of our National Health Service by a clear decade. The Royal Festival Hall on London's South Bank was its next and most obvious successor.

But it also leads on to Lubetkin's own postwar career, and may therefore provide some useful lessons for the conservation of his own later works. The ongoing evolution of structural archetypes in Tecton's work opened up a whole new seam of architectural composition for Lubetkin, with direct implications for the manner and extent to which exposed concrete was used. The material still shows its 'fairface' but in increasingly specific and articulated positions.

At one of his major postwar 1950s housing estates, Wynford House, where visible concrete is used in large cladding panels, structural framing, string course slips, parapet copings, window cills and planter boxes, Avanti Architects and a consultants team have drawn up comprehensive proposals for rehabilitation that will involve almost the whole range of available remediation techniques, including traditional repair, realkalisation, chloride extraction, corrosion inhibition and anti-carbonation coating -in addition to local replacement of certain elements.

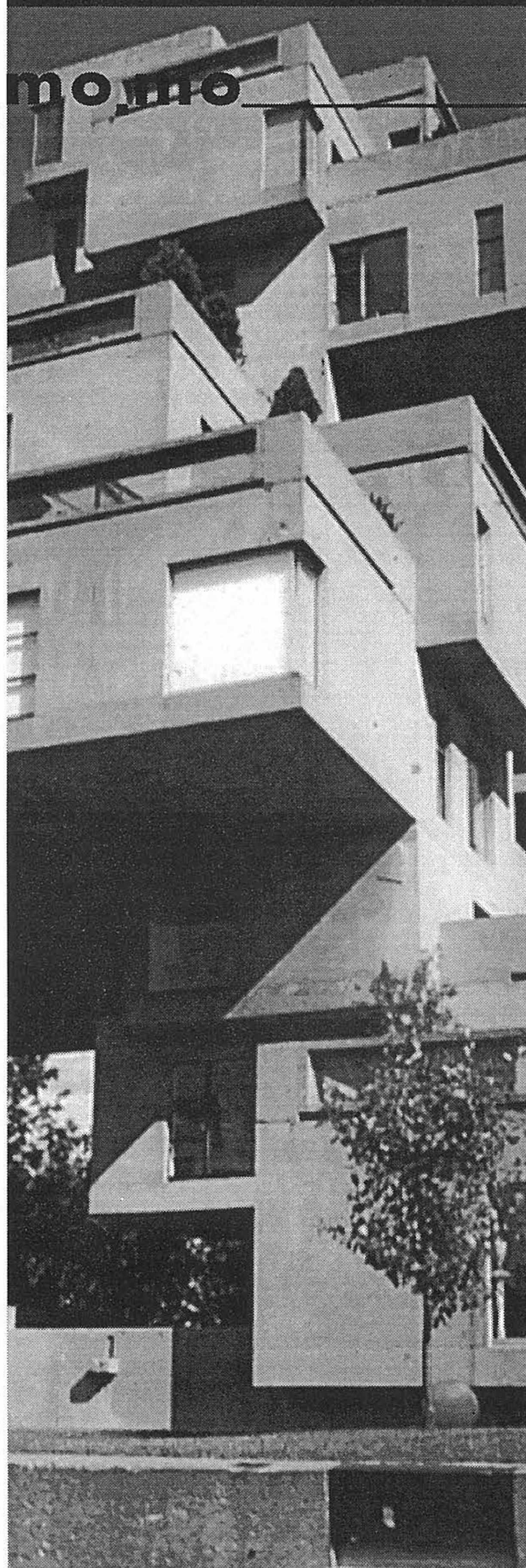
There is also the increasing awareness of new and less destructive preparatory and cleaning techniques to supplement the more familiar procedures of grit blasting, vacuum blasting and water jetting. I am thinking for instance of sponge blasting, of the Jos process and of the more recent Doff system. With a combination of sponge blasting and corrosion inhibitors one can now theoretically imagine a 'better than new' concrete repair that involves no loss of authentic material at all.

All these possibilities of course have their own pro's and con's, both technically and from a cost standpoint, but it seems to me that with the decade of consciousness raising achieved since DOCOMOMO's formation, we are, or should be, entering a new and more informed stage in the development of modern conservation. Building owners should not assume they are caught between two cultures -that of the conservationists and historians, and that of the products industries and specialist contractors- and are therefore obliged to make a choice. The two cultures should be merging; the conservationists becoming more technically discriminating, the technologists becoming more architecturally informed.

Specifically, in regard to reinforced concrete, one would hope that by exploiting selectively the increasing range of techniques available and by tailoring a remediation strategy to the particular circumstances of the individual project, it may be possible to achieve results that are both technically more appropriate and historically more authentic.

John Allan is a principle of Avanti Architects Ltd., London.

APPENDICES



Programme

08:45 **Reception**

09:15 **Opening**
Hubert–Jan Henket

09:30 **History of concrete**
Technology and architecture
Berthold Burkhardt

10:00 **Concrete is art**
Peter Thole

10:30 **Coffee**

11:00 **Concrete Atlantis**
Concrete in modern American architecture
Theodore Prudon

11:30 **Failure and repair of concrete**
Anthony van den Hondel

12:00 **Electro–chemical concrete repair**
Guri E. Nustad

12:30 **Luncheon**

13:30 **Notre Dame Cathedral, Royan (Gillet, 1958) France**
Phillipe Oudin

14:00 **Pumping station 'Parksluizen', Rotterdam (1968) The Netherlands**
Heide Hinterthür & Koos van der Zanden

14:30 **Finsbury Health Centre (Tecton & Lubetkin, 1938) United Kingdom**
John Allan

15:00 **Tea**

15:30 **Liederhalle Stuttgart (Abel & Gutbrod, 1956) Germany**
Rudolf Pörtner

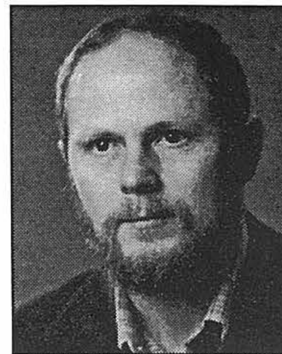
16:00 **Frederikstraat, The Hague (1978) The Netherlands**
Durability of electro–chemical repair
René G.J. Ackerstaff

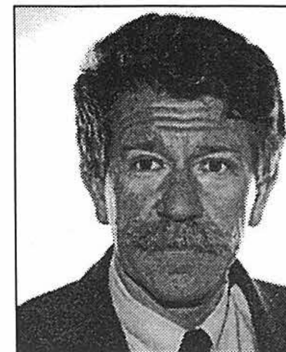
16:30 **Debate and questions**

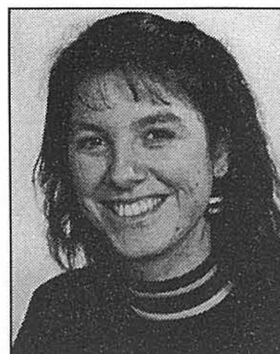
17:00 **Cocktail**

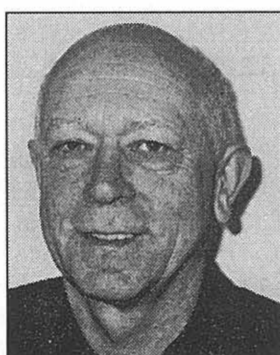
do.co.mo.mo_

Resumé of speakers









Hubert-Jan Henket
Theodore Prudon
Berthold Burkhardt

Rudolf Pörtner
Guri E. Nustad
Heide Hinterthür
Anthony van den Hondel

Philippe Oudin
Peter Thole
René G.J. Ackerstaff
Koos van der Zanden

Hubert–Jan Henket is an architect in Esch, the Netherlands. Among his most important buildings are the main office of the White Fathers in Dar es Salaam (Tanzania), the pavilion for the Museum Boymans–Van Beuningen in Rotterdam and the law court in Middelburg (The Netherlands). He is professor at the Faculty of Architecture of the Eindhoven University of Technology, and co–founder as well as chairman of DOCOMOMO International.

Berthold Burkhardt is an architect and structural engineer, as well as a professor at the University of Technology in Braunschweig, Germany. His expertise includes structures (concrete, steel, wood, lightweight), particularly of the Modern Movement.

Peter Thole is a principle of the Architect's Association Van Heumen & Thole in Zaltbommel, the Netherlands, with special interest in the architectural expression of concrete. For many years he lectured architectural design at the Eindhoven University of Technology, currently he teaches at the Academy of Architecture in Arnhem. He is the author of several publications on the subject.

Theodore Prudon is a partner with Swanke Hayden Connell Architects in New York City. Initially educated in architecture at the University of Delft in Holland, he holds a doctorate from Columbia University where he is also a professor of historic preservation. He has practiced, written and lectured extensively both nationally and internationally. At present he is very much involved in the preservation of the concrete bridges on the Merritt Parkway.

Anthony van den Hondel is a consultant with NEBEST bv, an engineering and consultancy firm in Groot Ammers, the Netherlands. He is an expert in building materials, particularly concrete.

Guri E. Nustad is a corrosion engineer, who has worked in the field of rebar corrosion and repair for the last 10 years. She is international project manager at FOSROC NCT in Oslo, Norway, and has been involved in the development of realkalisation and desalination since 1988.

Appointed since 1980 by the Minister of Culture, **Philippe Oudin** is chief architect for 'Monuments Historiques' in France. Among his main activities are restoration projects of Roman churches, abbeys, castles and manors, all which have been classified as historical monuments. He was in charge of the restoration of the Royan church, located in the department of Charente–Maritime.

Heide Hintherthür is a principle of Topaz Architects in Delft, and formerly with the Review Committee for architecture and historic buildings in Rotterdam. She has mainly been involved with material and colour consultancies for a number of buildings, and is the author of several publications on the subject.

Koos van der Zanden is with the Construction Department ('Nieuwe Werken') of the water authorities 'Hoogheemraadschap' of Delfland, the Netherlands. He has been involved with the preparation and execution of the concrete renovation of the pumping–engine 'Parksluizen' in Rotterdam.

As a principle of Avanti Architects Limited, London, **John Allan** has been involved with several restoration cases of buildings by Berthold Lubetkin. In 1988 he was commissioned to review the condition of Lubetkin's Finsbury Health Centre, which led to the restoration in cooperation with the original architect. He is the author of such noted publications as the chapter 'The conservation of modern buildings' in Building maintenance & preservation (1994) and the monograph Lubetkin, Architecture and the tradition of progress (1992).

Rudolf Pörtner is an architect in Karlsruhe, Germany, with civil engineers Wenzel, Frese, Pörtner, Haller, Büro für Baukonstruktionen. His main work concerns the restoration of buildings with historical importance. He has been decorated for several of his projects in Karlsruhe.

René G.J. Ackerstaff is a building engineer, Delft University of Technology, specialized in concrete maintenance. After working as a consultant he started the company HTC, high–tech–contracting. This company is licensee for the Norcure methods for realkalisation and desalination in the Netherlands and distributes a special group of CP–products such as conductive coatings, mortars and T/R units as well as testing equipment.

List of participants

R. Ackerstaff, HTC, betonrenovatie en onderhoud, Breda
J. Allan, Avanti Architects, London, United Kingdom
J. Andreasen, The National Forest and Nature Agency, Copenhagen, Denmark
J.M. Basyn, Project Monumentenzorg, Leuven, Belgium
S. Berndsen, Amsterdam
K.J. Bollenbeck, Bauabteilung des Generalvikariates, Cologne, Germany
P.J.A. Bongaerts, Gelders Genootschap, Arnhem
I.S.R. Borgman, University of Technology, Eindhoven
J. Borsholt, The National Forest and Nature Agency, Copenhagen, Denmark
J.H.M.E. van de Bosch, AM–Technobeton, Linne
B. Burkhardt, University of Technology, Braunschweig, Germany
E. Claessens, Catholic University of Leuven, Belgium
A. Doolaar, DOCOMOMO International, Eindhoven
C. Ernst, Hildesheim, Germany
V. Etienne, Nijmegen
H–J. Henket, University of Technology & DOCOMOMO International, Eindhoven
H. Hinterthür, Topaz Architecten, Delft
J.M. Hoenstok, Gemeente Den Haag, The Hague
A. van den Hondel, NEBEST bv, Groot Ammers
M. van Hunen, RdMz, Rijksdienst voor de Monumentenzorg, Zeist
W. de Jonge, LeodeJonge architecten, Rotterdam & DOCOMOMO International, Eindhoven
A. Kierdorf, Cologne, Germany
P.M.G. Koch, Eindhoven
M. Kuipers, RdMz, Rijksdienst voor de Monumentenzorg, Zeist
J.H. Köhne, ENCI nv, Den Bosch
N. Naert, Febelcem, Brussels, Belgium
G.E. Nustad, FOSROC NCT a.s., Oslo, Norway
G.E. Otomo, AA Graduate School, London, United Kingdom
P. Oudin, Monuments Historiques, Suresnes, France
W.R. van Pernis, Eindhoven
M.G. Polman, Van Doorn/Polman, Amsterdam
T. Prudon, Swanke, Hayden & Connell Architects, New York, USA
R. Pörtner, Büro für Baukonstruktion, Karlsruhe, Germany
D. Quiredo, Amsterdam
M. Rooden, RdMz, Rijksdienst voor Monumentenzorg, Zeist
H. Schmidt, TH Aachen, Karlsruhe, Germany
E. Schulte, University of Technology, Eindhoven
H.A.A.J. Seinen, Remmers Bouwchemie, Hoogeveen
D. Sharp, Dennis Sharp Architects, Hertford, United Kingdom
E. Slothouber, Gerrit Rietveld Academie, Amsterdam
B. van Swinderen, DOCOMOMO International, Eindhoven
P. Thole, Architecten Associatie Van Heumen & Thole, Zaltbommel
L. Verpoest, Catholic University of Leuven, Belgium
C.L. Vissering, Delft
K. Watanabe, AA Graduate School, London, United Kingdom
O. Wedebrunn, Royal Danish Academy, Copenhagen, Denmark
R. Wu, University of Technology, Eindhoven
Y. Yamana, AA Graduate School, London, United Kingdom
J.A. van der Zanden, Hoogheemraadschap van Delfland, Delft
P. Zwart, Hoofddorp

Selected bibliography

The following references give a selective guide to further reading in the main areas covered by this publication. Very few books yet exist on specific subjects involved in modern conservation - an indication of how recently this field has emerged. The general material available is more often in the form of articles in the professional press, exhibition catalogues, reports or collections of conference papers.
The list opens with some relevant charters, official publications, and general background literature. There are a number of valuable technical publications dealing with concrete repair on a purely scientific basis (that is, without regard to conservationist considerations). Trade literature from particular manufactures and specialist contractors is not included, though there is often useful technical information available in such publications.

Theory and methodology

- Allan, J., 'The Conservation of Modern Buildings', in E. Mills (ed.), *Building Maintenance and Preservation: A Guide to Design and Management*, Oxford 1994.
- *Architects Journal*, 'Restoring Buildings of the Modern Movement', special issue, nº 16, 1994.
- Banham, R., *The New Brutalism*, New York 1996.
- Burman, P., K. Garner and L. Schmidt (eds.), *The Conservation of the 20th Century Historic Buildings*, York 1996.
- Chandler, I., *The Repair and Refurbishment of Modern Buildings*, Batsford 1990.
- Collins, P., *Concrete. The Vision of a New Architecture*, New York/London 1959.
- DOCOMOMO, *International Conference Proceedings*, 1990, 1992, 1994 and 1996. This collection of papers taken together, are a comprehensive survey of the modern conservation initiative from an international perspective. Recommended as foundation reading for practitioners, academics and students embarking on the subject.
- DOCOMOMO, *International Newsletters*, issues 1-8 (published since the foundation of DOCOMOMO by its International Secretariat, Eindhoven, The Netherlands). From July 1993 (issue 9) re-titled *DOCOMOMO Journal*. The regular source of international news on modern conservation activities, with theoretical articles, technical studies and detailed project reviews. Recent Journals are dedicated to specific themes.
- DOCOMOMO, *The Eindhoven Statement*, Eindhoven University of Technology, The Netherlands 1990.
- Feilden, B., and J. Jokihleto, *Management Guidelines for World Cultural Heritage Sites*, ICCROM Rome 1993.
- ICOMOS, *Seminar on 20th Century Heritage*, Helsinki, June 18-19, 1995, working papers.
- Jester, T., and S. Bronson, 'Mending the Modern: A Selected Bibliography', *APT Bulletin*, Vol. 18, nº 4, 1997.
- Jokihleto, J., and H. Stovel, 'The Debate on Authenticity', *ICCROM Newsletter*, nº 21, July 1995.
- Jokilehto, J., 'Authenticity in Restoration Principles and Practices', *APT Bulletin*, Vol. 17, nº 3/4, 1985.
- Jurow, A., 'The Immaculate Conception - Ageing and the Modernist Building', Part I, *Archetype*, Vol. 2, nº 4, 1982. Part II, *Archetype*, Vol. 3, nº 2, 1983.
- Leatherbarrow, D., and J. Mostafari, *On Weathering: The Life of Buildings in Time*, Cambridge 1993.
- Macdonald, S. (ed.), *Modern Matters. Principles & Practice in Conserving Recent Architecture*, Shaftesbury 1996.
- Macdonald, S., 'Conserving Carbuncles, the Dilemmas of Conservation in Practice: an Overview of Current English Heritage Advice and Research for Twentieth-Century Buildings' in M. Stratton (ed.), *Structure and Style*, London 1997.
- Macdonald, S., 'Technical Responses to Typical Conservation Problems for Postwar Architecture in England: Current Research and Case Studies from English Heritage', *Conference Proceedings, Fourth International DOCOMOMO Conference*, Bratislava 1997.
- Monnier, G., 'A propos de la protection du patrimoine du XXe siècle', *Les cahiers de la recherche architecture*, Paris 1989.
- Slaton, D., and R.A. Shiffer (eds.), *Preserving the Recent Past Conference Proceedings*, Washington 1995.
- UNESCO, ICOMOS, *The International Charter for the Conservation and Restoration of Monuments and Sites (The Venice Charter)*, Venice 1964.
- UNESCO, ICCROM, ICOMOS, Knut Elnar Larsen (ed.), *Nara Conference on Authenticity Proceedings*, Proceedings of Nara Conference on Authenticity in Relation to the World Heritage Convention, 1995.
- Stratton, M. (ed), *Structure and Style, Conserving 20th Century Architecture*, London 1997.

Concrete

- Allen, R.T.L., S.C. Edwards and J.D.N. Shaw (eds.), *The Repair of Concrete Structures*, 1993.
- American Concrete Institute, 'Guide to Shotcrete', *ACI Manual of Concrete Practice*, part 5, Detroit 1985.
- American Concrete Institute, *ACI Manual of Concrete Practice*, Detroit 1994.
- Arup, H., 'The Mechanism of Protection of Steel by Concrete', in A.P. Crane (ed.), *Proceedings of the First International Symposium on Corrosion of*

Reinforcement in Concrete Construction, Chichester 1983.

- Arya, C. and P.R.W. Vassie, 'Influence of Cathode-to-Anode Area Ratio and Seperation Distance on Galvanic Corrosion Currents of Steel in Concrete Containing Chlorides', *Cement and Concrete Research*, 1995.
- Association for Preservation Technology (APT), *Historic Concrete Investigation and Repair*, Chicago 1989.
- Beaudet Cowden, A., *Historic Concrete: An Annotated Bibliography*, Washington 1993.
- British Cement Association, *The Diagnosis of Alkali-Silica Reaction*, London 1988.
- Broomfield, J., *Corrosion of Steel in Concrete: Understanding Investigation and Repair*, London 1997.
- Concrete Society, The, *Cathodic Protection of Reinforced Concrete*, Technical Report nº 36, 1989.
- Concrete Society, The, *Patch Repair of Reinforced Concrete*, Technical Report nº 38, 1991.
- *Coping with Concrete, Architect, Builder, Contractor and Developer*, 1990.
- Darby, M., D. Gooda and G. Jones, 'Re-alkalising Concrete', *Concrete Quarterly*, 1993.
- *Deutscher Ausschuß für Stahlbeton*, Festschrift 75 Jahre Deutscher Ausschuß für Stahlbeton 1907-1982, Heft 333, Berlin 1982.
- Emmons, P.H., *Concrete Repair and Maintenance Illustrated*, Kingston 1994.
- Glass, G.K., and J.R. Chadwick, 'An Investigation into the Mechanisms of Protection Afforded by a Cathodic Current and the Implications for Advances in the Field of Cathodic Protection', *Corrosion Science*, Vol. 36, nº 12, 1994.
- Glass, G.K., C.L. Page and N.R. Short, 'Factors Affecting the Corrosion Rate of Steel in Carbonated Mortars', *Corrosion Science*, 1991.
- Goven, F., 'Béton et Monuments historiques', *Monumental*, (16) March 1997.
- Hornain, H., 'Pathologies du matériau béton', *Monumental*, (16) March 1997.
- Hurd, M., 'The Evolution of Reinforced Concrete', *Building Renovation*, January/February, 1993.
- *International Journal of Construction, Maintenance and Repair*, special issue on concrete repair, July/August 1991.
- Jester, T. (ed.), *Twentieth Century Building Materials. History and Conservation*, New York 1995.
- Lawrence, C.D., 'Sulfate Attack on Concrete', *Magazine of Concrete Research*, 1990.
- Leek, D.S., 'The Passivity of Steel in Concrete', *Quarterly Journal of Engineering Geology*, 1991.
- Locke, C.E. and A. Siman, 'Electrochemistry of Reinforcing Steel in Salt Contaminated Concrete', in D.E. Tonini and J.M. Gaidis (eds.), *Corrosion of Reinforcing Steel in Concrete*, Philadelphia 1980.
- Marie-Victoire, E. (ed), *Les altérations visibles du béton. Définitions et aide au diagnostic*, Cahiers techniques du Cercle des Partenaires du Patrimoine, nº 1, 1996.
- McGuckin, S., 'Visual Concrete - Making Good', *Architects Journal*, December 1992.
- Morris, A.E.J., *Precast Concrete in Architecture*, London 1978.
- Mouton, B., 'Le béton armé dans le renforcement des structures', *Monumental*, (16) March 1997.
- Newlon Jr., H. (ed.), *A Selection of Historic American Papers on Concrete*, 1876-1926, American Concrete Institute, Detroit 1976.
- Pallot, E., 'L'utilisation du béton dans la restauration des Monuments historiques. Les origines de l'emploi du béton', *Monumental*, (16) March 1997.
- Pauser, A., *Eisenbeton 1850-1950,* Wien 1994.
- Picon, A. (ed.), *L'Art de l'Ingénieur*, Paris 1997.
- Prudon, T.H.M., 'Confronting Concrete Realities', *Progressive Architecture*, nº 62, November 1981.
- Pullar-Strecker, P., *Corrosion Damaged Concrete: Assessment and Repair*, London 1987.
- Ridout, G., 'Curing Carbonated Concrete', *DOCOMOMO Journal*, nº 9, 1993.
- Schollar, T., 'High Humidity Can Reduce Carbonation Risk', *DOCOMOMO Journal*, nº 9, 1993.
- Sergi, G., S.W. Yu and C.L. Page, 'Diffusion of Chloride and Hydroxyl Ions in Cementitious Materials Exposed to a Saline Environment', *Magazine of Concrete Research*, 1992
- Setzer, M.J., 'Draft Recommendations for Test Methods for the Freeze-Thaw Resistance of Concrete Slab Test and Cube Test', *Materials and Structures*, 1995.
- Shreir, L.L., *Electrochemical Principles of Corrosion - A Guide for Engineers*, National Corrosion Service, Teddington 1982.
- Stanley, C., *Highlights in the History of Concrete*, Cement & Concrete Association, 1979.
- Toulier, B., 'Histoire, techniques et architecture du béton armé en France', *Monumental*, (16) March 1997.

Case studies

- Allan, J., 'Restoration of the Penguin Pool at London Zoo', *DOCOMOMO Newsletter*, nº 3, 1990.
- Ball, M., 'Restoring Wright's Concrete Campus', *The Architects Journal*, 1993.
- Brierley, E.S., 'Park Hill, Sheffield (Lynn & Smith, 1953-60). The Social Impact of a Deck Housing Prototype', *DOCOMOMO Journal*, nº 16, 1997.
- *British Architectural Profile*, 'The Hoover Building Conservation', May 1993.
- Davies, C., 'Prescription for a Health Centre (Restoration Proposals for Finsbury Health Centre)', *The Architects Journal*, Renovation Supplement, March 1989.

- Devanthéry, P., and I. Lamunière, 'Bains de Bellerive-plage (Piccard, 1936-37)', *DOCOMOMO Journal*, nº 10, 1993.
- Direction régionale des affaires culturelles d'Ile-de-France, 'Restauration de l'église Notre-Dame du Raincy', *Patrimoine restauré Ile-de-France*, nº 2, 1996.
- Gatier, P.-A., 'Les Halles centrales du Boulingrin à Reims', *Monumental*, (16) March 1997.
- Jonge, W. de, 'Seaside Concrete and Steel Repaired', *DOCOMOMO Journal*, nº 9, 1993.
- Mailliet, J., 'Concrete Structure of Guggenheim Museum in New York Recently Improved', *DOCOMOMO Journal*, nº 9, 1993.
- Marie-Victoire, E. and B. Quénée, 'Eglise Saint-Joseph du Havre. Altérations et diagnostic', *Monumental*, (16) March 1997.
- Mouton, B., 'Restauration de l'église Notre-Dame du Raincy', *Monumental*, (16) March 1997.
- Saint, A., 'Notre Dame du Raincy', *The Architects Journal*, 1991.

Order form 'Curtain Wall Refurbishment'

Name:

....

Institution:

....

Address:

....

Postal code:

....

City:

....

Country:

....

- O Please mail .....copy(ies) with invoice. Preferred method of payment (no personal cheques accepted):
- O Mail order VISA, expiry date:............................

  Cardnumber:..

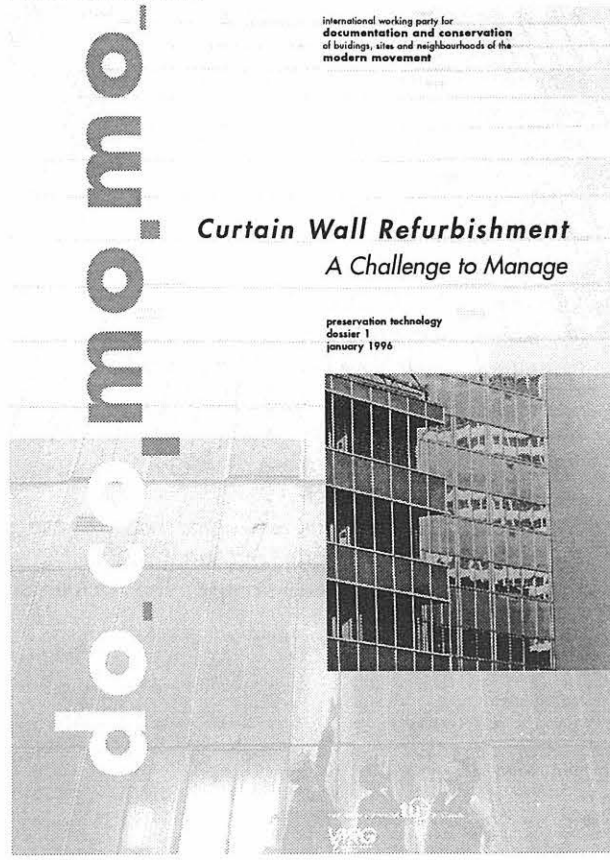
- O Mail order Mastercard, expiry date:...................

  Cardnumber:..

- O Transfer to bankaccount 52.78.75.961 of the ABN–AMRO Bank, Eindhoven, The Netherlands. Please add US $ 9.— to the total amount for transfer costs.

do_co_mo_mo_

Also available



Curtain Wall Refurbishment
A Challenge to Manage

Preservation Technology Dossier 1

A full report of the Curtain Wall Refurbishment seminar, with contributions by noted authors from Europe and the United States, is now available and includes:
- All lectures presented at the seminar
- Additional case studies and essays
- Over 90 pages in English
- Over 20 authors
- Fully illustrated, including black–&–white photographs, drawings and graphs
- The first comprehensive publication on the subject in Europe
- Ranging from architectural history to building physics and real estate impact

These proceedings can be ordered at cost price Dfl. 40.— plus forwarding and transfer costs.

Please send your order to:
DOCOMOMO International Secretariat
Eindhoven University of Technology
BPU Postvak 8
P.O. Box 513
5600 MB Eindhoven
The Netherlands

international secretariat docomomo
prof.ir. hubert-jan henket
ir. wessel de jonge

eindhoven university of technology
bpu postvak 8
p.o. box 513
5600 mb eindhoven
the netherlands

tel.: 31-40-247 24 33
fax: 31-40-245 97 41
e-mail: docomomo@bwk.tue.nl
internet: www.ooo.nl/docomomo

ISBN 90-6814-076-0