



Selection of suitable materials and techniques for the conservation of buildings in need of restoration

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Abstract

This report includes: (a) a review of suitable (compatible and durable) materials and techniques, including novel approaches not listed in current Codes, for the repair and strengthening of historic reinforced concrete (RC) structures, and (b) a summary of common conservation approaches in the four participating countries of the consortium. The report fulfills the obligations of Work Package 4, Task (ii) and is expected to contribute towards the formulation of conservation proposals for the case study buildings in need of restoration selected in the framework of Work Package 2.

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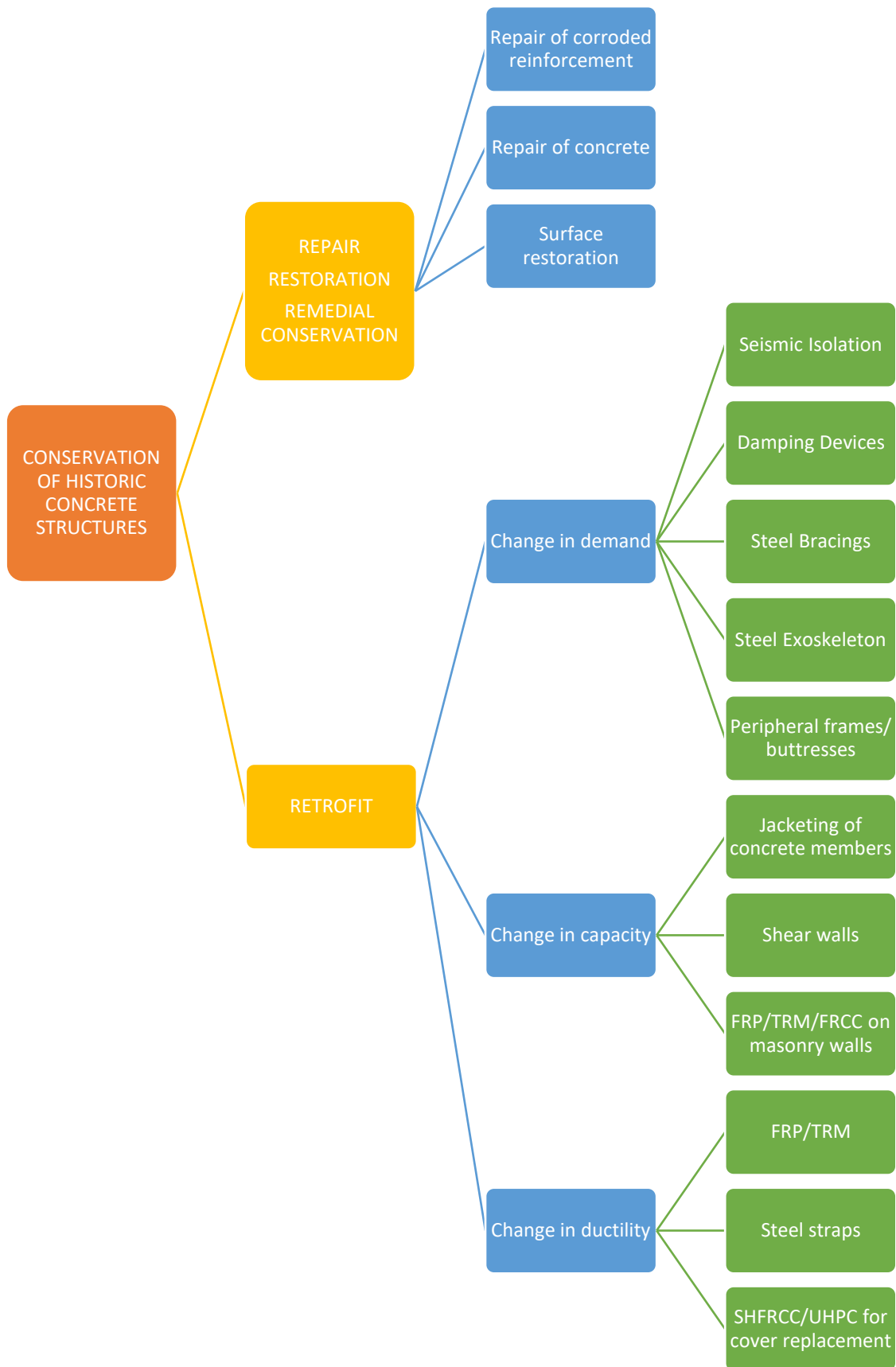
Part A: General overview of materials and techniques for the conservation of concrete buildings in need of restoration

This section includes an overview of existing common practices, described in the latest published literature, for the conservation of historic concrete structures. These are divided in categories, according to the effect they have on structural characteristics. The listed techniques may be applied in more than one of the categories used for historic structures, as these are shown below¹:

Restoration	This is a highly specialized operation. Its aim is to preserve and reveal the aesthetic and historic value of the monument and is based on the respect for the original material and authentic documents. It must stop at the point where conjecture begins; in this case, any extra work which is indispensable must be distinct from the architectural composition and must bear a contemporary stamp. Restoration in any case must be preceded and followed by an archaeological and historical study of the monument. <i>(In International Charter for the Conservation and Restoration of Monuments and Sites - The Venice Charter- 1964)</i>
Remedial conservation	All actions directly applied to an item or a group of items aimed at arresting current damaging processes or reinforcing a structure. These actions are only carried out when the structure is in such a fragile condition or deteriorating at such a rate, that it could be lost in a relatively short time. These actions sometimes modify the appearance of the structure. <i>(In ICOM-CC, 2008)</i>
Repair	The replacement or amendment of broken, damaged or faulty components or elements of a building, either inside or outside, or the minor alteration or renovation of a building in order to maintain its operating efficiency. <i>(Ontario Ministry of Municipal Affairs and Housing, Canada, 1982).</i> The restoration of a sound condition after damage or deterioration may involve restoration , such as returning dislodged parts to their original location, and/or reconstruction , where deteriorated or lost material is replaced with new material. <i>(In: Conservation Principles for Concrete of Cultural Significance - Getty Conservation Institute 2020).</i>
Retrofit	Aims at bringing the building to a higher standard, with respect particularly to energy efficiency, structural integrity, fire protection and modern amenities. <i>(James G. Ripley, Editorial in Canadian Building, April 1978)</i>
Rebuild/Reconstruct	To build again or to make extensive structural repairs on a building. <i>(Webster's II Dictionary, 1988).</i> To reproduce, by new construction, the exact form and details of all or part of an existing or vanished structure as these were at a specific period in time, either on the original site or at a new site. This term may sometimes be used in heritage context. It may also be used interchangeably with rebuild. The latter term, however, is more accurately applied to a building that has been partially or wholly destroyed or has deteriorated badly. <i>(Ontario Ministry of Municipal Affairs and Housing, Canada, 1982).</i>

- A. Repair/Restoration/Remedial conservation: this category includes actions that are related to the repair (i.e. bringing back to the original state) or the restoration (reinstatement of the original strength) or the support of (fragile) structural elements
- B. Strengthening/Retrofit: this category is related to the strengthening of a structure against seismic actions and inherent inadequacies. These techniques are used to bring the building to higher standards in relation to its seismic stability.

¹ http://ip51.icomos.org/~fleblanc/documents/terminology/doc_terminology_e.html



Classification of the intervention practices used for RC structures, based on the modification of frequency characteristics

A.1 Repair – Restoration - Remedial Conservation

The repair of historic structures is starting to take legislative form, with laws defining the rehabilitation procedures. For example, by using tax incentives, the U.S. Secretary of the Interior's Standards for Rehabilitation [1] provide guidelines for the overall strategies that may be applied, recommending **retaining and repairing, rather than replacing**, existing historic materials wherever possible. Additionally, aggressive treatments, such as **sandblasting**, are recommended to be avoided, since they can damage historic materials.

The new tendency proposed by researchers in the field of historic concrete is to replace the previously used term reversibility, which originated from art conservation, with the term retreatability [2], as the former was deemed unsuitable for building conservation. Retreatability is defined as:

“...the procedure signifying that the conservation treatment / repair material will not preclude or impede further treatment in the future” [2,3]

The use of preventive treatments is also crucial in order to slow the deterioration process that is taking place on structural elements. Types of such treatments may include the **application of film-forming or water-repellant materials** on the surface of the structure, or the use of electrochemical methods, such as **re-alkalization of concrete** or **cathodic protection of reinforcement** (Figure A.1-) [4].



Figure A.1-1 Concrete repair and electrical connections with reinforcement and activated titanium electrode on a column (left).
Application of the anodic system on column (right) [5]



Figure A.1-2 Deteriorated or redundant reinforcing bars are removed after evaluation by a structural engineer. An acetylene torch is being used to cut out the bars. Photo: NPS files [54]

When adding new reinforcement for the **replacement of corroded rebars** (Figure A.1-), tying of the old and new reinforcement together is more preferable, rather than tack welding, since the possible difference in carbon content between the old and new materials may result to corrosion [6]. The same principle is applied to the electrical continuity in the case of installing a cathodic protection system, where mechanical forms of bonding should be preferred to welded connections [6].

The procedure of **repairing cracks** in structural members is related to the width and length of those cracks (Figure A.1-1), whether these are still active, or whether they are related to reinforcement corrosion. Crack repair practices include **epoxy injections** or **epoxy repair cementitious mortars**.

The materials used for the application of repairs, as in the case of the **patch-repair method**, where the volume of deteriorated concrete that must be replaced is more extensive, must be carefully selected, since certain polymer-modified mortar coatings can reduce moisture penetration to minimum and may trap moisture within the original concrete [7]. The ideal material should have a low water absorption characteristic, in order to reduce ingress of chlorides and carbon dioxide to prevent corrosion, and a high water vapor transmission characteristic, in order to evaporate moisture and prevent damage and debonding from freeze-thaw cycles [8].

The repair material should be no stronger than the base material, as this can cause damage to the original concrete. In particular, repairs incorporating modern Portland cement should be carefully designed to match the lower strength of an older material [9]. Additionally, if the repair material will not carry loads, it should have a lower modulus of elasticity than the substrate, while if it will carry loads, the modulus of elasticity should be similar for the repair material and the parent concrete [10]. When the modulus of elasticity of the repair material is higher than that of the original concrete, there is the risk of damage to the latter [10]. Especially in historic concrete, where the aesthetic value is of significance, the patch repairs must be such so as to match the original fabric (Figure A.1-2).



Figure A.1-1 At the Virginia Heating Plant, Arlington, Virginia (1941), narrow cracks needed to be widened to receive concrete patches. Photo: NPS files [54]

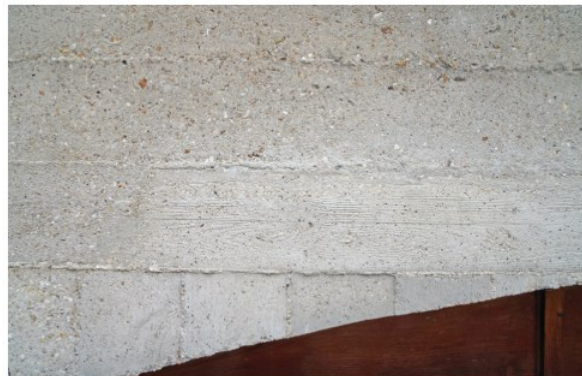


Figure A.1-2 (a) Example of poor aesthetic match; (b) Example of good aesthetic match. Photos: Ana Paula Arato Gonçalves, 2019, © J. Paul Getty Trust. [4]



Figure A.1-5 Unity Temple, Oak Park, Illinois (1906). Photo: NPS files [54]

The **surface restoration** process may include various procedures that take place after the repair work is completed. In Unity Temple (Figure A.1-), the entire building was **sprayed with a concrete mixture** consisting of pea-gravel and sand, which was then **hand-troweled**. Finally, the building was **grit-blasted** to remove the cement paste and reproduce the exposed aggregate finish.

The concrete members may be sounded with a hammer to detect all areas of deterioration, while, prior to the placement of the concrete, a **retarding agent** can be brush-applied to the inside face of the formwork to slow curing at the surface. Usually the sizes and types of aggregates used for surface restoration must be carefully selected to match the original concrete materials, while **mock-ups** of the repair concrete mix must be prepared and compared to the original concrete prior to its use. Other parameters that may influence the aesthetic result are the cement color, proportions of the mixing materials, aggregate exposure after the application and surface finish [11]. After the concrete is partially cured, the forms are removed and the surface of the **concrete is rubbed** to remove some of the paste and expose the aggregate (Figure A.1-3).



Figure A.1-3 Mock-ups of the concrete repair mix and craftsman finishing the repair with a nylon bristle brush to remove loose paste and expose the aggregate [11]

A more detailed description of the repair techniques is reported in “**State of the Art Report on new technologies to monitor, conserve and restore the materiality of modern buildings in a compatible, durable and sustainable way**” that can be accessed at:

https://consech20.eu/wp-content/uploads/2022/01/WP2_TUD-SoA_Report_New_Technologies_Restore.pdf

A.2 Retrofit against seismic actions

Three main characteristics of the structure must be taken into consideration when determining the necessary retrofit strategy:

- I. Strength, as the ability of the structure to sustain lateral loads without failure of the part or the whole.
- II. Stiffness, as a way to reduce lateral deflections and ensure secondary elements.
- III. Ductility, as a way to undergo large displacements and dissipate energy, without losing strength (but left with permanent structural damage).

A.2.1 Retrofit without changing strength and stiffness – Ductility enhancement

Wrapping of concrete members for confinement

The repair of structural members, especially those of historic character, may have to be less invasive than concrete jacketing, albeit necessary in a more general nature, in order to assist the structural members sustain vertical or lateral loads in a ductile manner. One of the most prominent techniques that may be used towards this goal is the **confinement of structural members with the use of steel (steel straps), fiber (Fiber Reinforced Polymers – FRPs, or Textile Reinforced Mortar - TRM) and/or cementitious composites (fiber reinforced cementitious composites)**. The confinement provided by these means, increases the compressive strength of concrete, as well as the shear capacity and bond between the longitudinal reinforcement and the surrounding concrete, especially in cases where lack of adequate stirrups may result in brittle failures. Most of these composites are solutions that do not alter the geometry of the members, while in most cases they are reversible interventions. Some techniques that are used for normal RC, though, such as steel encasement of RC columns, cannot be used in the case of historic concrete, due to aesthetic reasons.

Types of materials:

- Steel straps
- Fiber Reinforced Polymers (Figure A.2-1)
- Textile Reinforced Mortar
- Fiber Reinforced Cementitious Composites as cover replacement
- Ultra-High Strength Concrete as cover replacement



Figure A.2-1 Example of FRPs used to strengthen a glass brick door (Vocational school) [12]

A.2.2 Change in seismic demand

A.2.2.1 Base Isolation

This passive structural control technique is used to reduce the response of a building by partially isolating it from the ground excitation, and can be established by **base isolation units, such as lead-rubber bearings**. Base isolation is designed to allow movement or absorb energy and induce damping to the system. Base isolation cannot be used in tall high-rise buildings, or on buildings on very soft soil [13]. There are two types of base isolation systems, **elastomeric bearings and sliding systems**. A series of examples of base isolation on historic concrete structures are depicted in Figure A.2-2 a-c.

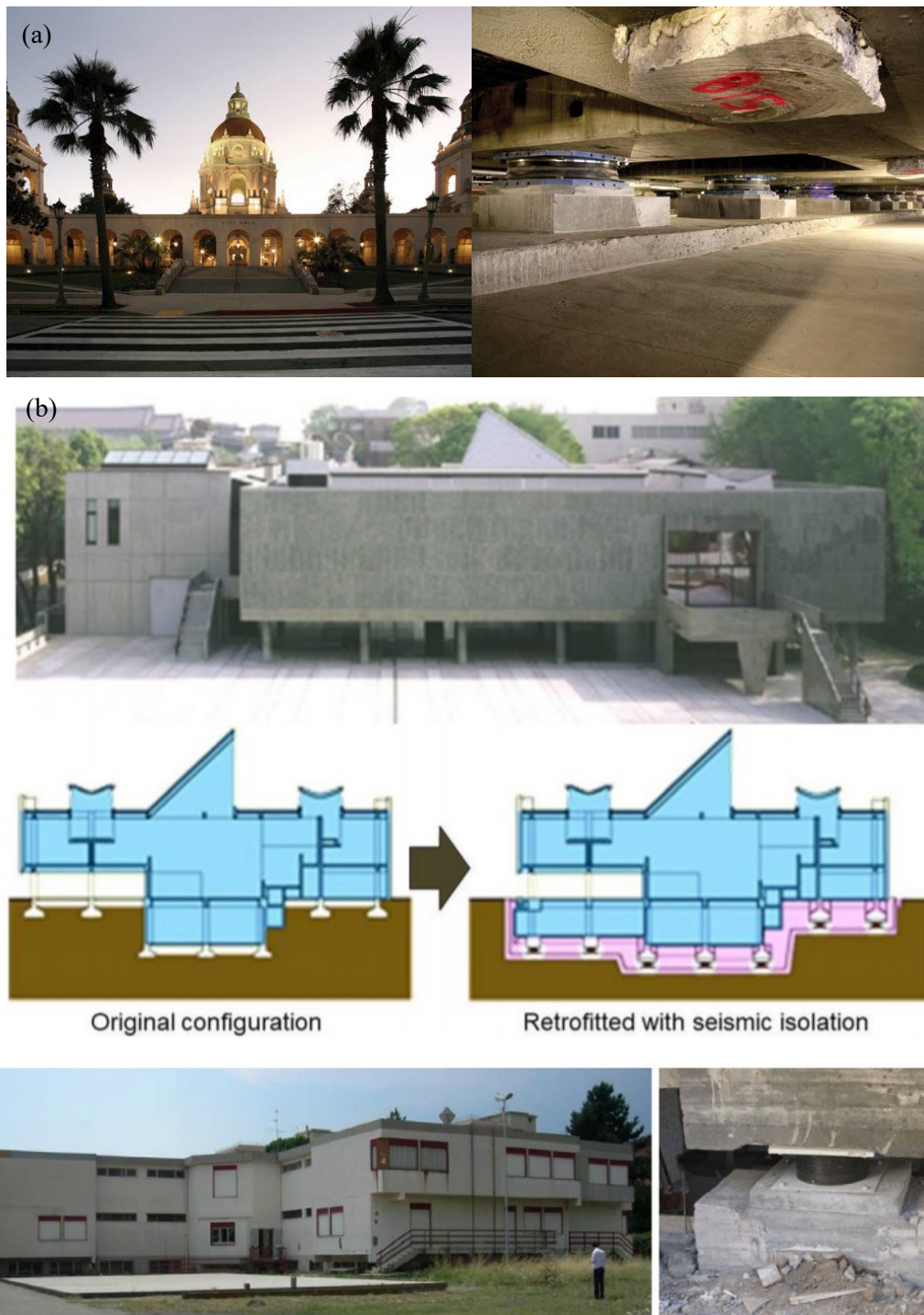


Figure A.2-2: (a) Pasadena Historic City Hall base isolation [14], (b) Seismic isolation retrofit of the National Museum of Western Art [15] and (c) The school of Riposto, Catania [16]

(a) Elastomeric bearings

Laminated natural rubber bearings or neoprene systems are used. The building is decoupled from the ground motion. Usually, a solid lead plug is placed in the middle to absorb energy and add damping.

(b) Sliding systems

The transfer of shear is limited due to this isolation interface system. One of the most common systems used is the “spherical sliding bearing” [13], with curved surface bearing pads with low friction. While the building slides freely during an earthquake, both horizontally and vertically, a limit is placed on the horizontal forces.

A.2.2.2 Supplemental Damping Devices

These systems may be placed anywhere along the height of a building to reduce seismic demand, usually in diagonal braces. They can be **viscous dampers, friction dampers or yielding dampers** and can be used effectively when base isolation is not possible or effective, i.e., tall buildings [13], by reducing the displacement needs. They are very convenient for the retrofit of existing buildings, since their application, especially if they are placed externally, does not affect occupancy.

(a) Fluid dampers

They are constructed from stainless steel pistons and filled with silicone oil or solid lead, with specially shaped passages, used to alter the flow and resistance characteristics of the damper (Figure A.2-3). They work as springs or dissipators (or as a combination of the two). The peak dissipator force occurs at peak velocity, which is happening at a different phase from peak force or displacement; therefore they do not increase the forces acting on the structure [13].



Figure A.2-3 The residential building on Spatafora Street in Messina, which is the tallest seismic isolated building (LRB) in Italy [16].

- Friction dampers (Figure A.2-1)

Metal or other surfaces in friction are used to absorb energy through the sliding of several steel plates, separated by shims of friction pad material.

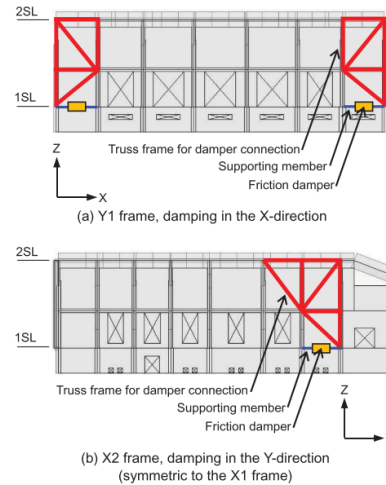


Figure A.2-4 Photograph of the front view of the main hall of Otaniwa Hakodate Betsuin (left). Placement of friction dampers in the controlled model (right) [17]

- Visco-elastic dampers (Figure A.2-1)

They consist of friction pads, visco-elastic polymer pads and steel plates. An elastomer is stretched in combination with metal parts, with energy absorbed by the controlled shearing of solids.



Figure A.2-5 Retrofit intervention by means of viscoelastic dampers in the school Gentile-Fermi in Fabriano (Ancona) [18]

(b) Hysteretic dampers

They are made of critical metal parts (usually steel) that yield in the process of absorbing energy. They can be designed to yield in bending, tension, or compression. They are made as U-shape or triangular bending plates and they are designed for the yielding to spread over a significant length.

- BRB frames: Buckling Restrained Braced frames (Figure A.2-1)

Energy dissipation is performed by a tension-compression brace, with yielding in both tension and compression. The buckling must be restrained when the member is in compression. Strains are kept to low values by increasing the yielding zone length [13].

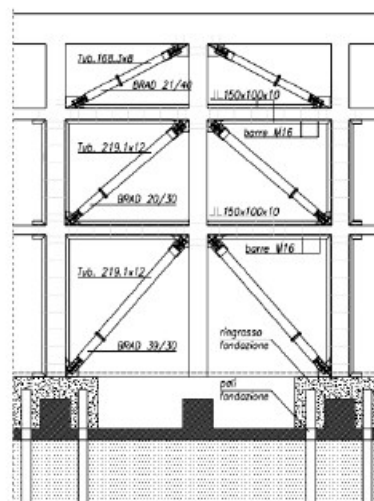


Figure A.2-3 Retrofit intervention by means of BRB frames in the school Cappuccini in Ramacca (Catania) [18]

- MRFs: Moment Resisting Frames (and MRFs with reduced beam sections or with friction connections)
- EBFs: Eccentrically Braced Frames (traditional and with replaceable links)
- CBFs: Concentrically Braced Frames
- Replaceable fuses – external plug & play dissipaters (Figure A.2-1)

Plug & play dissipaters consist of axial, tension-compression yielding, mild steel elements, inserted and grouted in a steel tube, externally applied on the sides of members, at the location of hinge formation.

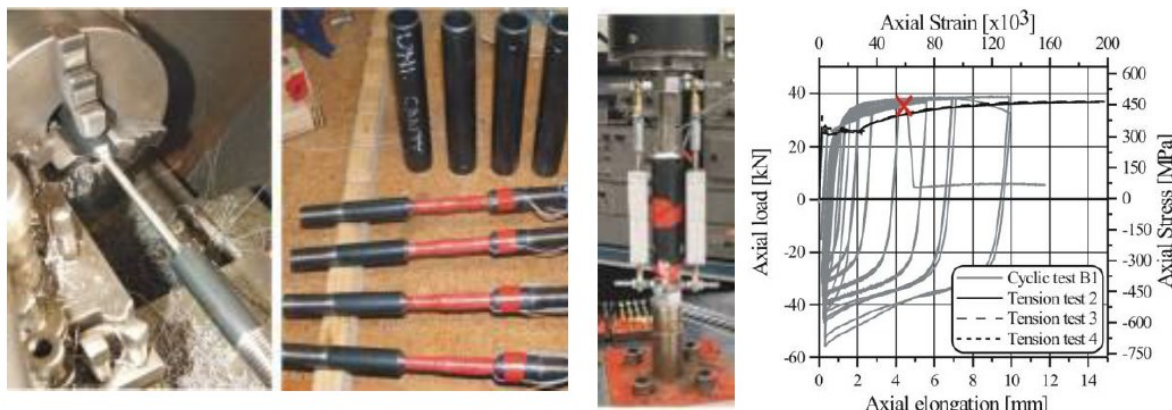


Figure A.2-7 Manufacturing process and testing of “Plug & Play” dissipaters [19]

A.2.2.3 Exoskeleton

A **steel exoskeleton** is placed outside the building in order to attract and transfer seismic loads to the foundation and provide lateral stiffness to the structure. Although this method is convenient in the case where interruption of use is not an option, and waste materials are minimized, it requires free external spaces in front of the facades, while local intervention in the beam-column joints is required, at places where the exoskeleton will be connected. While in some cases the aesthetics of the buildings are compromised (Figure A.2-4 Top), or most of the building has to be demolished and then rebuilt (Figure A.2-4 Middle), in some cases, such as in the Midorigaoka 1st building of the Tokyo Institute of Technology, a more holistic approach is adopted, including seismic resilience and energy upgrading by the use of glasses, louvers and a steel BRB frame -exoskeleton (Figure A.2-4 Bottom).



Figure A.2-4 (Top) Examples of seismic retrofitting with steel exoskeletons [20] (Middle) Steps of the seismic retrofit of the Magneti Marelli headquarters in Crevalcore, Italy [20], (Bottom) Midorigaoka-1st building after retrofit [18]

A.2.2.3.1 Peripheral frame buttresses

Peripheral frame buttresses can be used alone or in combination with viscous dampers to increase lateral stiffness. This method of intervention is externally applied in limited time, without interrupting the activities of the building. If viscous dampers are also used, then a large amount of energy is dissipated. The buttresses reduce the lateral sway, intending to leave the existing structural system to behave elastically. Figure A.2-5 shows a RC frame school in Camerino, built in the 1960s, that was retrofitted with the use of two steel braced towers connected to the floor slabs by steel trusses.



Figure A.2-5 Retrofit intervention by means of dissipative towers and viscous dampers in Camerino (Macerata) [18,21]

A.2.3 Change in capacity

A.2.3.1 Jacketing of concrete members

Concrete jacketing is one of the most common techniques for the seismic upgrading of RC structures. This technique is used in vertical slender members, with high axial load, that are most likely to fail in brittle manner, due to high compressive stresses, or beams and slabs. Additionally, it is used when an increase in stiffness is required, due to possible soft-storey formation during seismic excitation, for changing the shape mode of the lateral sway. Furthermore, it can alter the “weak column-strong beam” behavior, typical of old substandard structures, to the more ductile “strong column-weak beam” behavior. Jacketing usually results in change of the members’ cross-section, especially in the cases where additional reinforcement is placed around the members. The jacket material may vary based on the depth of the jacket, the necessary increase of strength, or the alignment of the member. Yet, in any case, the material must have good bonding properties with the substrate and non-shrinking properties. The jacketing is performed on the sides of existing members, with the addition of longitudinal and transverse reinforcement (Figure A.2-10). The new reinforcement has to be extended to the adjacent floors, or properly anchored, in order to be able to sustain stresses at the critical sections of the plastic hinge formation. Due to the increase of the axial and flexural strength, this type of intervention requires strengthening of the foundations of the columns.

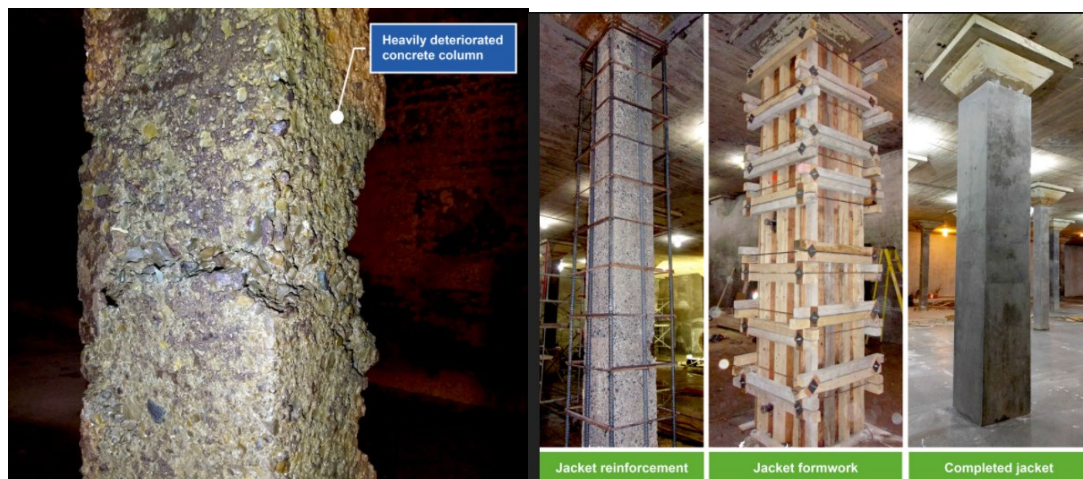


Figure A.2-6 Peterborough's 90-year-old reservoir and long-term rehabilitation project with self-compacting concrete jacketing [22]

A.2.3.1.1 Normal concrete

Normal concrete is a cheap and “known” material that can be used for jacketing. The properties of the new material vary significantly to those of historic concrete. The cement for historic concrete structures was of low quality (<32.5), while aggregates used at the time had grain sizes that are no longer permitted for use. The new concrete that may be used usually consists of early strength cement and an expansive component to prevent shrinkage cracks. The grain size of the aggregates in this type of material determines the width of the jacket cover, as spacing between forms, reinforcement and the existing column must be adequate for proper consolidation. Jacketing in this case cannot be less than $5 \text{ cm} + \text{rebar} + \text{stirrups diameter}$.

A.2.3.1.2 Shotcrete

Shotcrete, contrary to normal concrete that requires formwork to be poured in, is sprayed on the existing substrate, with pressure (Figure A.2-11). The water is mixed with the rest of the raw materials during the pressuring procedure by experienced personnel, at a low content, leading to a high strength, pressure applied material to fill the gaps, improving adhesion and compaction at the same time. This type of concrete can be applied to inclined or horizontal surfaces, such as slabs.



Figure A.2-7 Example of using sprayed concrete with a specially adapted repair concrete [12]

A.2.3.1.3 Self-consolidating concrete

- Self-consolidating or self-compacting concrete may be used where compaction of the concrete is not feasible due to the geometry of the reinforcement, or the thickness of the layer. In this case, coarse aggregates are of a maximum diameter of no more than 10 mm, allowing for thinner widths of jackets to be applied [23,24]. In the case of the Peterborough's 90-year-old reservoir (Figure A.2-110) [22], concrete was pumped in the formworks from the bottom and the middle of the height of the columns. The use of this technique allows elements with a texture similar to the original surface to be obtained (Figure A.2-112) [25].



Figure A.2-8 Formwork manufactured with wooden boards and finished product

A.2.3.1.4 High strength concrete and Ultra high-performance concrete

High strength concrete has compressive strengths higher than normal concrete, ranging between 40 to 130 MPa. Ultra high-performance concrete has even greater strengths (>120 MPa). It is usually achieved by selecting high-quality Portland cement, through the optimization of aggregates (strength,

size, bond with matrix and surface characteristics) and by the use of admixtures. The admixtures that are usually incorporated are pozzolans, such as fly ash or silica fume. The ultra-high performance concrete has, additionally to the above, tensile ductility that is provided by the use of short discontinuous fibers (carbon, steel, PVA, glass or in combination) within the mix. The specific gravity of these types of materials are lower than that of normal concrete, while the high compressive strength allows for the application of smaller covers around existing members. Additionally, its dense matrix results in low permeability and the protection of steel reinforcement. These types of materials, for the moment, are mostly used in large scale structures, such as bridges.

A.2.3.2 Shear Walls

Reinforced concrete shear walls may be placed in structures that have a significant lack of lateral stiffness, due to high mass and very slender column members. The shear walls are usually placed in areas of secondary importance to the historic context and are preferably hidden in spaces of previous masonry walls (Figure A.2-13). The RC walls must extend to the ground level and should be properly supported on new foundation systems, that are able to transfer their moment and shear to the ground. At the same time, proper connection must be made with the existing structural system, while the slab zones around the shear wall must be adequately retrofitted in order to support the transfer of loads when plastic hinges are formed.



Figure A.2-9 Steel reinforcement for the new shear walls, perpendicular to the windows, is being installed in this concrete-frame building [26]

A.2.3.3 Strengthening of masonry walls with FRPs/TRMs/FRCC

The use of infill masonry walls changes drastically the Base Shear capacity and lateral stiffness of a RC frame structure during seismic loading. The masonry units are stressed diagonally in compression within the frames, cracking and dissipating energy. By incorporating different techniques for the strengthening of the masonry walls, additional stiffness and strength is provided in the structural system. Materials used for this purpose are Fiber Reinforced Polymers (FRPs), Textile Reinforced Mortars (TRMs) and Fiber Reinforced Cementitious Composites (FRCC). While the FRPs are widely acknowledged and used, the latter two options are currently under experimental investigation and are more common in historic or normal masonry structures.

Part B: Examples of materials and techniques used for retrofitting in the partner countries




Part B of the report includes local case studies at the four participating countries of the CONSECH20 project. The partners' contributions focused on different aspects of the restoration, i.e.:

- a) TU Delft focused on the cleaning of concrete surfaces
- b) ITAM focused on the restoration of concrete as final surface layer
- c) UCY focused on the seismic upgrading of structures
- d) UNIGE performed a general overview of the materials and techniques for the conservation of historic concrete buildings

B.1 TU Delft

B.1.1 Introduction

In the collective imagination, buildings in concrete are grey, dull, massive and stand mostly in areas lacking green. It is our task, within the CONSECH20 project, at university, in our practice and in personal contacts to promote another image of concrete, recalling beautiful architectures (Figure B.1-1-1) and pleading for a good upgrade (Figure B.1-2) or transformation and re-use (Figure B.1-3) of the existing. In this part of the report, attention is specially focused on the cleaning of historic concrete buildings. An answer is sought to the questions of what needs cleaning, why and what are the consequences of a cleaning process. The aim is to form a picture of common visions, guidelines and practice in the Netherlands, trying to understand limits and strong points, and to further contribute to the international work within CONSECH20.

		
<i>Figure B.1-1. Sanatorium 'Zonnestraal', Hilversum, J.Duiker and J.Bijvoet, 1928</i>	<i>Figure B.1-2. House in Betondorp (concrete village), upgraded (insulated), Amsterdam, social housing 1920's</i>	<i>Figure B.1-3. Re-use of the former Van Nelle factories, L. van der Vlugt, Rotterdam, 1925</i>

B.1.2 Conservation approach to concrete

In this part of the study, historic concrete is defined, highlighting its characteristics in view of the suggestion of suitable cleaning methods. The focus is laid on the historic concrete buildings in the Netherlands. Beside the technical aspects of the application of cleaning methods on historic concrete façades, the impact on the authenticity and value of the construction and the material are dealt with. Buildings in concrete - being a relatively new material - have only been listed in the last decennia as monuments. Therefore, the criteria used in the conservation of traditional building materials (e.g. stone and brick), like authenticity and, more technically, compatibility and reversibility/retreatability, need to be carefully (re)defined when applied to concrete.

In the Netherlands, two easily accessible online sources for guiding cleaning interventions have been developed by expert institutions and are presented in this document: MDCS Cleaning of facades <https://mdcs.monumentenkenis.nl/wiki/page/30/cleaning-of-facades>, and the ERM guidelines for approaching the various phases and aspects of the conservation of historic concrete - <https://www.stichtingerm.nl/kennis-richtlijnen/brl2826-08>

B.1.2.1 Historic concrete

Within the CONSECH20 project, concrete has been defined as 'historic' when dating between the end of the 19th cent. and the 1960's. The choice of these time limits is based on the PhD study of H. Heinemann [27], showing that, in the aforementioned period, both the fabrication (composition) of concrete and the calculations concerning its load bearing structure were empirical. As a consequence, it can be stated that each building of that period is unique, though often sharing certain characteristics with its contemporaries, belonging moreover to the same country.

This means that, in general, a more in-depth investigation and assessment of the decay are needed for historic than for recent concrete buildings. This applies also in the case decisions about cleaning of historic concrete surfaces are considered.

B.1.2.2 Assessing the condition of the concrete: MDCS and ERM

Prior to taking any decision on cleaning, the condition of the concrete should be assessed, which means that the damage should be identified, and its severity evaluated. If deemed necessary, conservation interventions should be done before cleaning, as in some cases the cleaning process can induce further damage to the concrete.

The MDCS (Monument Diagnosis and Conservation System) includes a damage atlas for the uniform identification of damage types in historic concrete and is accessible on the site <https://mdcs.monumentenkenis.nl> (also in English). It also includes guidelines for cleaning façades made in different materials.

In the ERM Dutch guidelines for Quality in Conservation [28], quality is expressed in terms of maximum conservation and minimum intervention of the existing. Guidelines for investigation and sound, compatible interventions on monumental buildings have been developed by ERM both for the certification of the parties (like those of the architects or masons) involved in conservation and for controls. The guidelines concerning historic concrete are available for all actors in conservation on the ERM site (in Dutch) <https://www.stichtingerm.nl/nieuws/hoegaanwemet-historisch-beton>

B.1.3 Cleaning of the façades: decision making

The first step in the decision-making concerns the reason why cleaning is deemed necessary. Depending on the type of deposit, cleaning can be necessary for reasons ranging from eliminating matter which could be dangerous for the building or its users, to mere aesthetic reasons. In fact, a clean building suggests good care and feeds the sentiment that the building and the area where it is located are safe and looked after; thus, aesthetics can contribute to keeping/creating a safe and pleasant environment.

Once the decision is made towards cleaning, the first step to be taken is the identification of the type of deposit. If needed, each type of deposit can be eliminated with suitable techniques. The criteria for choosing a technique include its suitability to be used on the to be cleaned surface, the feasibility of the application of the technique itself on the specific substrate (considering both the material properties and its state of conservation), costs and consequences for the environment and the users. Beside the technical criteria, the question whether the cleaning could be detrimental for the building in terms of architectural values (e.g. material loss and change in the geometry/relationship between different elements), or monumental values (e.g. authenticity) should also arise.

B.1.3.1 The technical decision

The ERM guideline BRL 2826-08 [29], specifically dealing with the cleaning of façades, takes into consideration different building materials, including concrete. The same applies for the decision-making document contained in MDCS (Wiki section). MDCS and ERM summarize the suitability of cleaning methods for the type of deposit, and for the substrates, in tables: the tables of MDCS (& Table 2) and ERM (Table 4 & Table 5) are, in essence, comparable.

Table 1. Effectiveness of cleaning methods depending on the type of deposit (MDCS)

	brushing	washing	steam	abrasive	organic acids	inorganic acids	alkali	sequestering agents	soaps/ detergents	laser
dust	+	+	+	+	-	-	-	-	-	-
dry dep.	+	+	+	+	+ -	+ -	+ -	-	+ -	+
gypsum crust	-	+	-	+	-	-	-	+	-	+
biological	+	+	+	+	-	-	+	-	-	+ -
oil, fat	-	-	+	-	-	-	+	-	+	-
encrustation	-	-	-	+	+	+	-	+	-	-
rust	-	-	-	-	+	-	-	+	-	-
soluble salts	+	+	+	+	-	-	-	-	-	-

Table 2. Suitability of cleaning methods depending on the type of substrate (MDCS)

	brush	washing	steam	abrasive	organic acids	inorganic acids	alkali	sequestering agents	soaps/ detergents	laser
FC brick	+	+	+	+ -	+	+	+	+	+	+ -
CS brick	+	+ -	+	+ -	-	-	+	+	+	+
Tile	+	+ -	+	+ -	+	+	+	+	+	+ -
glazed tile	+	+	+	-	+	+	+	+	+	+ -
concrete	+	+	+	+ -	-	-	+	+	+	+ -
lime mortar	+	+ -	+	+ -	-	-	+	+	+	+ -
cement mortar	+	+ -	+	+ -	-	-	+	+	+	+ -
sandstone	+	+ -	+	+ -	+ -	+ -	+	+	+	+
limestone	+	+ -	+	+ -	-	-	+	+	+	+
granite	+	+	+	+	+	+ -	+	+	+	+ -
tuff stone	+	+ -	+	+ -	+ -	+ -	+	+	+	+ -
basalt	+	+	+	+	+	+	+	+	+	-

Table 3. Effectiveness of cleaning methods depending on the type of deposit (elaborated from ERM table, in Dutch)

color of deposit	type of deposit	mechanical						chemical				
		brushing	high pressure water				steam			alkali	sequestering agents	soaps/ detergents
			cold	warm	Dry (sand) blasting	Hydropneumatic (sand) blasting		organic acid	anorganic acid			
white	alkali sulfates	±	+	+	+	+	+	+	+	-	-	-
	chlorides, nitrates	±	+	+	+	+	+	+	±	-	-	-
	efflorescences	-	±	±	+	+	-	+	+	-	-	-
	gypsum forming	-	-	-	+	+	-	-	-	-	-	-
	droppings	±	±	+	±	±	+	-	-	±	-	-
grey	cement stains	-	±	±	+	+	±	±	+	-	+	-
	sulfation	-	-	-	+	+	-	-	-	-	-	-
black	gypsum crust	±	±	±	+	+	+	±	±	-	-	±
	oil	-	-	+	-	-	+	-	-	±	-	+
	soot	±	±	±	±	±	±	-	-	±	±	
black / green / brown	micro- organisms	±	±	+	±	±	+	-	-	±	-	-
green /yellow / orange	vanadium and chromium compounds	-	-	-	±	±	-	-	-	-	-	-
brown	deposition without chemical conversion	±	+	+	±	±	+	-	-	-	-	-
	rust	-	-	-	±	±	+	±	-	-	±	-
	manganese compounds	-	-	-	±	±	-	-	-	-	-	-
paint or coating	linseed oil	-	-	+	±	±	+	-	-	+	-	+
	graffiti	-	±	±	±	±	±	-	-	+	-	-

Table 4. Overview of cleaning methods in relation to possible risks to the substrate (elaborated from ERM, in Dutch)

substrate	mechanical						chemical				
	brushing	High pressure water		dry (sand) blasting	hydropneumatic (sand) blasting	steam	organic acid	anorganic acid	alkali	sequestering agents	soaps/ detergents
		cold	warm								
brick	+	±	±	±	+	±	±1)	±1)	+	-	+
lazed blrick	+	±	±	-	-	+	±	±	±2)	+	+
not glazed ceramic tiles	+	±	±	±	±	+	+	+	+	+	+
glazed ceramic tiles	+	±	±	-	-	+	±	±	±2)	+	+
concrete blocks	+	±	±	±	±	±	-	-	+	+	+
calcium silicate bricks	+	±	±	±	±	+	-	-	+	+	+
lime pointing	±	±	±	±	±	+	±	±	+	±	±
cement pointing	+	±	±	±	±	+	±	±	+	+	+
concrete	+	+	+	±	±	+	-	-	+	+	+
lime plaster and cement plaster	+	±	±	±	±	+	±	±	+	+	+
resin based plaster	+	±	-	±	±	-	-	-	-	+	+
cement plaster	+	±	±	±	+	+	-	-	+	+	+
sandstone	±	±	±	±	+	+	±	±	±	±	±
limestone	+	±	±	±	±	+	-	-	+	+	+
granite	+	+	+	+	+	+	+	±	+	+	+
tuff stone	+	±	±	±	±	+	±	±	±	±	+
basalt	+	+	+	+	+	+	+	+	+	+	+

B.1.3.2 Quality controls

Having selected one or more techniques for cleaning, these have to be tested (description of techniques and possible risks in their use can be found in ERM [29] pp. 51-63.

The following steps should be taken:

1. assess and record the characteristics of the concrete;
2. make test panels on the surface (preferably in less visible parts) to try out the technique;
3. assess the characteristics of the concrete again and compare the results (state before vs. state after cleaning).

ERM provides norms and guidelines for the inspection, the value assessment, the test panels and the quality control. ERM norms are used in the Netherlands for guaranteeing the quality of interventions. These norms can also be applied to assess the effect of the cleaning. They are addressed in the ERM document BRL 2826-08 [29]. According to this document, the comparison of the state of the façade before and after cleaning can be done visually. The basic controls of the cleaning performed are:

- color and structure of cleaned surface are similar to those of the test panel.
- no damage caused to the concrete façade (exterior of building);
- no damage caused to the interior of the building;
- no damage caused to the environment.

The short- and long-term effect of the cleaning needs to be stated. In some cases, the cleaning of part of the façade can only create a difference in color and texture, which could be experienced as disturbing. This difference could attenuate within short time (e.g. because of soiling). If this is not the case, a sort of ‘patina’ could be then artificially brought to the cleaned part.

When mechanical cleaning is performed with the use of sand (i.e., sandblasting), the grain size of the cleaning particles should be known and documented.

The following documentation concerning the cleaning process should be produced:

- name possible difference between work described in the contract and work actually done; include a description of work (phases), illustrations (sketches, drawing, photos);
- report damage and imperfections appearing on the concrete surface;
- carry out a water proofing control to check whether the concrete has to be waterproofed to avoid damage, before cleaning (CUR-61: 2013).

MDCS suggests to do some testing to assess the effectiveness of the cleaning method adopted (Table 5). Of course, the testing should be done before and after cleaning.

Microscopy (stereomicroscopy, Polarizing & Fluorescence Microscopy (PFM) and Scanning Electron Microscopy (SEM)) can be used to assess the level of cleaning and check possible loss of material caused by the cleaning. Besides, cleaning can also indirectly cause damage by increasing the water absorption of the substrate. To assess changes in water absorption, measurements by means of Karsten tube (on site or in laboratory on samples collected from the object) or capillary water absorption measurements (in laboratory on samples collected from the object) can be performed.

Table 5. Techniques for the assessment of cleaning effects (MDCS)

Assessment test area alterations	Evaluation technique
Cleaning effect	Visual assessment, use of magnifying glass and stereomicroscope (enlargement 8-60x)
Damage to surface	Stereomicroscope (enlargement 10-60x) PFM (enlargement 25-400x), SEM (enlargement up to 20.000x)
Alteration in water absorption	Karsten tube measurements, capillary water absorption measurements in laboratory.
Alteration in drying behaviour	Drying of samples under controlled climatic conditions (in laboratory)
Rests of chemicals	SEM-EDS (enlargement 2.000-20.000x)

B.1.3.3 How far to go with the cleaning?

Once the technical assessment of the concrete has been done and the material has been valued considering its present state and past aspect, the question arises on how far to go with the cleaning process. Even though, other than in the case of traditional materials like stone and brick, the so called ‘patina of time’ may be less evident and wanted, yet some effects of the environment (rain) could be foreseen/intended and thus need to be kept. This is for example the case of the Bijenkorf store building in Rotterdam by M. Breuer, who designed the geometry of the façade foreseeing the effect of the dirt deposition (Figure B.1-). Similarly, Brutalism urged designers to keep the signs of the formwork, as proof of the concrete being a genuine material (see the case of the TU Delft Aula Broek and Bakema, Figure 0.05). Other examples of concrete textures are the decorative use of the traces of the formwork (Figure B.1-6.), and the various ways of giving concrete a lively aspect (polishing, washing...) (Figure B.1-7).

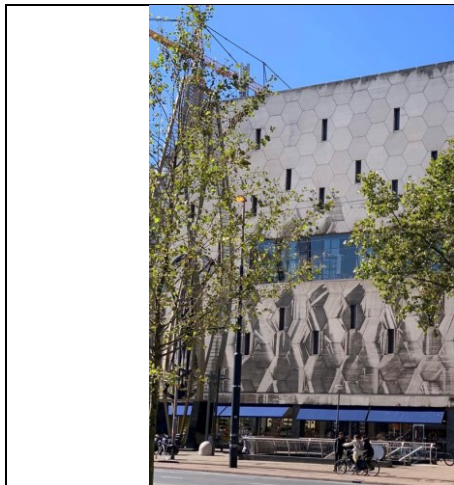


Figure B.1-4. Bijenkorf store, Rotterdam, M. Breuer, 1957



Figure 0.05. Brutalism (traces of formwork), TU Delft, Aula, v. de. J. Broek and J. Bakema, 1958-1966

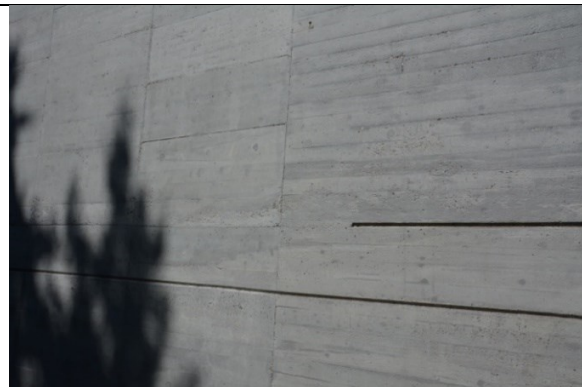


Figure B.1-6. Pattern on concrete, looking like wood, Stuttgart, Weißenhofsiedlung, erected in the 1927 under the direction of L. Mies van der Rohe



Figure B.1-7 Washing out concrete (Heinemann, 2013)

B.1.4 Case studies

A series of case studies are presented to expose the possibilities and limitations of different cleaning techniques used in historic concrete in the Netherlands.

B.1.4.1 The Cygnus Gymnasium



Figure B.1-8. Cygnus Gymnasium in Amsterdam

The Cygnus Gymnasium (Figure B.1-8), formerly known as the First Christian Lower Technical School Patrimonium, was built in 1956 by the architects Commer de Geus and Ben Ingwersen. The building displays an intense use of concrete, with massive columns at the ground floor and precast elements on the facades and throughout the interior in exposed walls, beams and slabs (Figure B.1-99). Inspired by the Unité d'Habitation of Le Corbusier, the Cygnus Gymnasium plays with concrete textures, bas-reliefs and shapes to furnish an open and bright space in the interior.

Intervention (based on interview with architect Wessel de Jonge on July 1, 2019 and publication [30]).

In 2013, a renovation campaign was performed to adapt the building to its new use and to restore affected areas. The architectural firm of Wessel de Jonge, was chosen to design and advise on the restoration of the buildings. One of the goals of the intervention was to restore the original aesthetics affected by previous intervention(s) and urban pollution.

In the interior concrete surfaces, a non-original bright color paint was applied on the exposed elements. As part of the original timber elements (floors, handrails, doors and windows, etc.) remained in the building, the cleaning method should minimize the use of uncontrolled water; thus, the option of peeling cleaning was chosen. The peeling process consists in applying a gel or peeling agent over the surface. The peeling agent is then removed after a controlled amount of time, and the dirt and particles adhered to the agent are removed in the process. The peeling agents had the benefit of minimizing water damage, but it was more time consuming and costly than more traditional cleaning methods. With the help of conservators, various chemical peeling agents were tested, whether in paste or in gel. After a few hours, each product was scraped off and removed by sponges. The chosen peeling agent was *Fluzaf Green*, pH neutral and biodegradable. However, this product, according to the manufacturer, should be removed by high-pressure steam jets and not by sponge, which was the agreed method. The use of steam jets was partially used due to schedule and cost, causing damage in floor finishes and increasing the water content in the concrete.



Figure B.1-9. Building interior - Cygnus Gymnasium.



Figure B.1-10. Coloured bass-relief.

In the interior, there were bass-reliefs that required the use of more careful cleaning methods. The bass-reliefs were the work of artist Harry op de Laak's (Figure B.1-10). The main art-work measured 8 by 28 m and it was located in the main staircase. It was originally unpainted concrete but later painted. It was not clear if the original artist participated in the painting. It was decided to preserve the colors in the grooves of the bass-relief, but to remove the orange paint covering the rest of the wall. The use of a peeling agent followed by steam blasting, used on the rest of the interior concrete surfaces, was not used in this area, as it could affect the polychrome in the grooves. With the help of specialized conservators, a trial with an innovative dry-cleaning process was performed, using dry ice and dry snow blast cleaning. These methods make use of carbon dioxide crystals that evaporate after the impact with the concrete surface. After various tests, dry snow blasting with fine ice crystals was chosen, as it appeared that the original concrete surface was not affected. The fine nozzles allowed to work within millimeters away of the paint of the bass reliefs, which was protected with rubber strings. The dry-snow cleaning process had the advantage of removing the risk of water damage. The main downside of this process was the slow pace and high cost, and the noise created, that limited the access to the stairs for weeks.



Figure B.1-11. Detail of the intersection between ground floor columns and first floor slab.

At the exterior, cleaning of the exposed concrete aimed at removing grime and dirt from pigeons dropping, stains of the anti-pigeon system glued in the window sills of the facades in 1999, and urban pollution. Based on the architect's experience and trials on site, low-pressure steam cleaning method was chosen. This technique minimized the impact on the concrete surfaces, and avoided an increase of surface porosity that could make the concrete more sensitive to further carbonation, water penetration and damage (Figure B.1-11).

B.1.4.2 The Kleiburg – Bijlmeer, Amsterdam



Figure B.1-12. The Kleiburg.

The Kleiburg (Figure B.1-12) is one of the biggest apartment buildings in the Netherlands, with 500 apartments, 400 meter long, and 11 stories high. Kleiburg is located in the Bijlmermeer, a residential expansion of Amsterdam designed in 1969 by Siegfried Nassuth. The Bijlmermeer had a very optimistic start, but soon it turned into a slowly disintegrating neighborhood due to bad publicity and poor maintenance. The Kleiburg is the last building in the area still in its original state, but there were plans to demolish it. A renewal operation of the entire area started in the mid-nineties, by which most of the original buildings were demolished. It was estimated that restoration of the Kleiburg would cost about 70 million Euros. Thanks to the social pressure, Kleiburg was offered for one Euro in an attempt to find alternative and viable plans. Over 50 ideas were presented. The chosen idea was to renovate the main structure -elevators, galleries, installations, but to leave the apartments unfinished and unfurnished: no kitchen, no shower, no heating, no rooms. The condition was that the owners had to finish the apartment after one year. This would minimize the initial investment and as such created a new business model for housing in the Netherlands. This intervention was awarded the Mies Van Der Rohe architectural award in 2017.

Intervention

The restoration and intervention conducted between 2015 and 2017 focused on connecting spaces within the building and improving the communication with the street and green areas. It also provided community spaces and improved thermal insulation of the facades and openings. Regarding the exposed concrete in facades and balustrades, the goal was to restore their original aspect. The prefabricated concrete panels of the balustrades (Figure B.1 & Figure B.1-1) were pressure washed to remove the paint and restore the solid appearance of the façade. In some areas, sandblasting was used [31]. The water pressure technique was chosen as the most effective, given the budget and extension of the surfaces. In addition, as the concrete was dense and well-compacted, there were no major concerns for further damage to the concrete caused by this type of cleaning technique. On the smooth polished surface of the exterior panels, the paint was removed easily. On rougher surfaces, as the underside of the slabs and cast-in-

place concrete beams, the removal of paint was more difficult². After the cleaning, a colorless impregnation was selected³.



Figure B.1-13. Prefab concrete balusters of the Kleiburg.



Figure B.1-14. Inside of the concrete balusters in the Kleiburg.

B.1.4.3 The TU Delft Aula – Delft



Figure B.1-15. TU Delft Aula Building.

The Aula of the Delft University of Technology (Figure B.1) is a 1966 building in Delft, designed by Jo van den Broek and Jaap Bakema of the Broekbakema office. It is one of the few Brutalist buildings in the Netherlands. The exterior concrete reveals different concrete textures: soft surfaces on the front columns, precise timber formwork on the inclined surfaces (Figure B.1), and smooth faces on the prefabricated elements of floor beams and slabs. It combines various concrete typologies: precast concrete on the floors, cast-in place concrete in the main body, combined with post-tensioned elements to create the cantilever at the front.

(Future) Intervention

² Interview with promotor architect Martijn Blom on November 9, 2021.

³ No details of the impregnation were provided.

In 2019, an assessment was carried out, within the Keep it modern project, financed by the Getty Trust, by TU Delft and TNO, to evaluate the condition of the concrete surfaces and advise on intervention and maintenance. In the preliminary reports, the state of the concrete is reported to be good and no general damage was observed [32]. The recommendations for maintenance do not include cleaning or surface treatments, despite some visible stains on parts of the building (Figure B.1). However, they do recommend the conservation of appearance (texture and color) of the concrete as part of the overall conservation management plan.



Figure B.1-16. Concrete texture at the underside of the building front.



Figure B.1-17. Concrete stains at the exterior stairs.

B.1.5 Discussion and Conclusions

Although historic concrete dating from 1900 ca. to 1960s is a relatively ‘young’ building material, guidelines exist in the Netherlands for carrying out the cleaning process on monumental concrete façades. These point at the need for assessment of the technical state of conservation of the concrete building and its heritage values, before starting the cleaning process. The cleaning needs to be further evaluated in technical terms and in respect to the preservation of the heritage value.

The case studies hereby presented display an arrange of different cleaning techniques used in young monuments in the Netherlands: from more aggressive but cost-effective methods, as sandblasting or water-pressure washing, to innovative methods, as dry-snow and dry-ice blasting. Other methods, traditionally applied to stone restoration, such as peeling, have demonstrated their possible application to historic concrete, as well. In other cases, like in the Aula building, no cleaning has been recommended to preserve the aging and Brutalist character of the building.

The Dutch guidelines are in accordance with the principles defined on a broad consensus basis. The selection of the proposed method will, therefore, depend on different factors. Regardless the method, this must try to reduce the amount of ingress water to the concrete and to not aggressively remove the exterior layers of the concrete, as this can increase its permeability for further damage.

B.2 ITAM

B.2.1 Restoration of concrete as a final surface layer

Until 1960s, concrete structures and structural elements in the Czech Republic were usually covered by a final coating layer, such as ceramic tiles, plaster or artificial stone. The use of structural concrete as a final surface layer (“architectural concrete”, “raw concrete” or “beton brut”) was rare in the Czech lands before 1960. In the interwar period, the reinforced concrete frames were usually coated with a finishing layer, even in cases the reinforced concrete structure was the main architectural motive of the building (e.g. Baťa memorial in Zlín or the tram stop shelter at Obilní trh in Brno) [33,34].

Uncovered structural concrete in the Czech Republic is present in industrial architecture, since its beginning in the first decade of the 20th century. But even in this type of structures, it is mostly found in the interior. Still, we can find some exceptions or special cases, such as precast elements, statues etc. Concerning the architecture of the 1960s (and later), the use of raw concrete (beton brut) is more common. But unfortunately, not many buildings of this period have been listed and the restoration of raw concrete is still in an experimental state. Still, though, there are some examples of exposed concrete surfaces that are presented in the following sections.

B.2.1.1 Restoration of vila Zikmund in Zlín

The residence of the famous Czech traveller Miroslav Zikmund was designed by architect Zdeněk Plesník in 1950s, as a reform of an older structure. The building contains precast elements, such as the handrails, balustrades and chambranles. In the restoration report, the material of these elements is described as “reinforced terrazzo”, a fine aggregate cement-based material. Contrary to many interwar modernist architectures, this design took into account the process of aging. The original drawings already showed the building covered with vegetation. The choice of long-lasting materials (e.g., natural and artificial stone) also corresponds with this tendency.

For these reasons, repair of the original concrete elements was chosen instead of their complete substitution. The intention was to preserve the patina of the original material. The patch repairs were left visible (Figure B.2-1). The restoration of the building was designed by an architecture studio specialised on restorations, atelier TRANSAT led by Petr Všecká [35,36].



Figure B.2-1. Restoration of vila Zikmund in Zlín [35,36]

B.2.1.2 Restoration of the statue of a musician by Alois Šutera, Přerov, 1965

The statue is situated on the Přerov cemetery. Its restoration was carried out in collaboration with the Conservation Faculty of the Pardubice University. Analyses of the original material were first carried out and an identical basaltic aggregate was found. The surface was cleaned from moisture-induced elements, the exposed parts of the reinforcement were cleaned from corrosion, and the cracked parts of

the statue were repaired. In contrast to the previous case, this one is an example of an “invisible” restoration, trying to hide the differences between the old and the new (Figure B.2-2). The statue was restored by Josef Červinka and Vladislava Říhová in 2019 [37].



Figure B.2-2. Restoration of the statue of a musician by Alois Šutera [37]

B.2.1.3 Restoration of the entrance shelter of the covered gallery of the Lucerna Palace in Prague

A special case of restoration of a glass brick shelter with a reinforced concrete frame was executed and described by sculptor and conservator Jiří Fiala [38,39]. In his report about the restoration of concrete sculptures and other architectural elements, Mr. Fiala underlines the importance of cleaning of the reinforcement from corrosion [40]. Another principal task is to find repair material identical or similar to the original one. In the case of the shelter at Lucerna Palace, special forms have been made to get the right shapes of the ribs (Figure B.2-3-6).



Figure B.2-3. Restored structure of the Lucerna Palace.

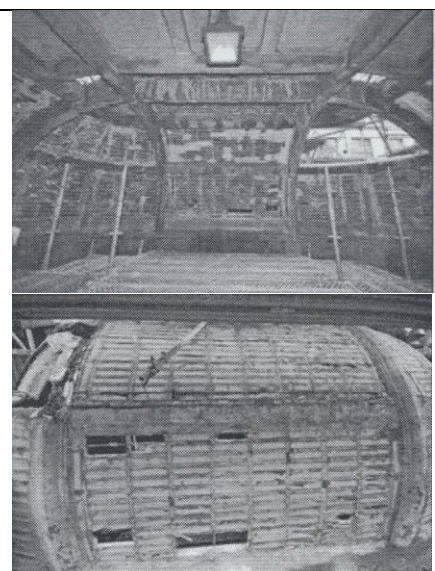


Figure B.2-4. The state before restoration

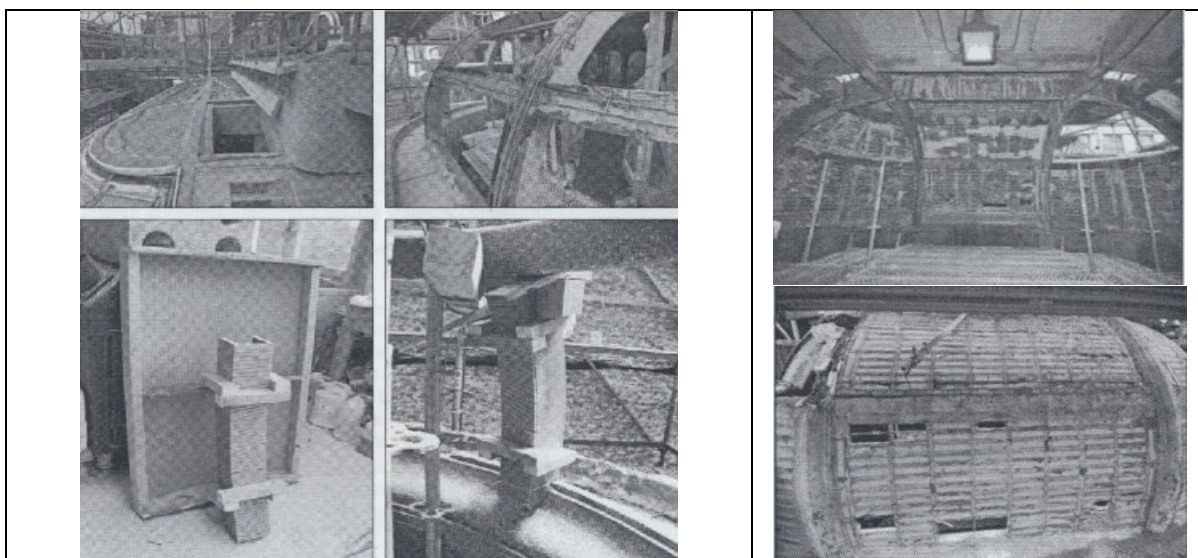


Figure B.2-5. The process of restoration

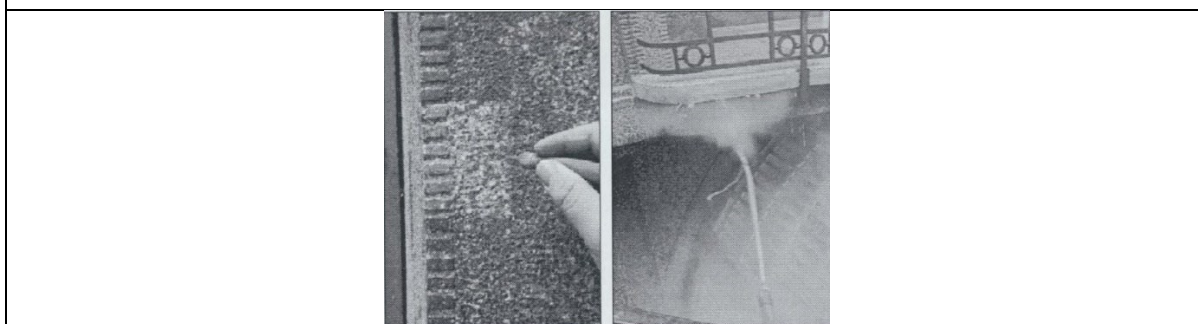


Figure B.2-6. Cleaning of the surfaces

B.2.1.4 The surfaces of the Libeňský bridge

The restoration of Libeňský bridge (by architect Pavel Janák and structural engineer František Mencl, 1925-1928) [41] has recently been researched in the Klokner Institute in Prague. Among other questions, such as the technical state of the principal structure (Figures B.2-7-8), the restoration of the concrete surfaces was also an important issue (Figures B.2-9-12).

Few words about the original technology of the bridge:

The visually exposed surfaces of the bridge were made of a special sort of concrete with a fine calcite aggregate. This material was applied in different ways:

- a) In the case of precast elements, such as the sidewall blocks, the surface layer was cast in formworks around the basic structural concrete, which was cast in the centre of the formwork. Afterwards, the surface was treated with a special hammer, similarly to the artificial-stone surfaces of the period.
- b) On other parts of the structure, this surface layer was applied afterwards in the way the artificial-stone facades were used to be made.

One issue during the restoration of the bridge was the cleaning of the original surfaces. Different methods, such as waterjet and vapor cleaning, have been applied.

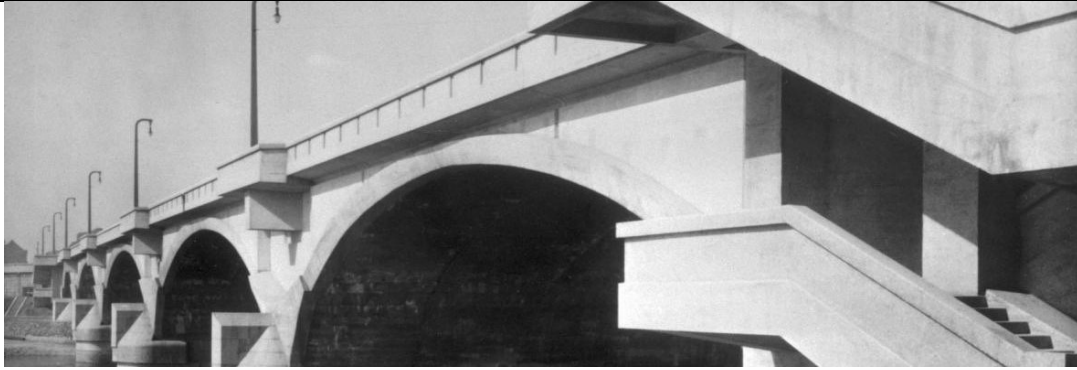


Figure B.2-7. The original state of the bridge



Figure B.2-8. State of the structure in 2018



Figure B.2-9 Sample (about 50 mm diameter) from the precast elements of the sidewalls



Figure B.2-10. Different cleaning methods were applied (vertical stripes)

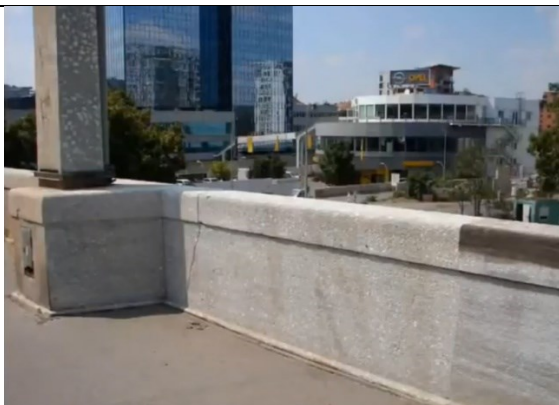


Figure B.2-11. Cleaning of the sidewalls



Figure B.2-12. Experiments with fine aggregate have been made to reach a surface similar to the original one.

B.3 UCY

B.3.1 Jacketing of R/C members with normal concrete

Figure B.3-1 depicts the Reinforced Concrete Jacket intervention performed in the Technical School of Nicosia, Cyprus, built in 1953 without any seismic provisions. In this case, the Jacketing width around the column led to the doubling of the members' cross-section. The jacketing was performed only in the lower floors of the three storey sections of the structure, leading to visual inconsistency of the architectural design. Also, in order for the jacket reinforcement to be able to sustain tensile loads at the top of the 1st floor, the steel reinforcement was anchored on the 2nd floor by performing a partial jacket up to approximately 1/3 of the columns' height.

Recommended solution for: Strengthening, Stiffness increase, Shear and Lap splice brittle failure prevention, decrease of v

Disadvantages: Visible changes on geometry, Necessity for strengthening of foundations, Irreversible



Figure B.3-1. Concrete jacket in the Technical School of Nicosia, Cyprus. Intervention performed in the general framework of seismic strengthening of educational facilities on the island.

B.3.2 Jacketing of R/C members with shotcrete

Figure B.3-2 depicts the steel reinforcement placed at the underside of slabs, beams and around columns, prior to the use of shotcrete for the strengthening of existing structural members in one of the Kyperounta Sanatorium buildings (as well as the actual shotcreting procedure and the finished elements). Prior to the application of the jackets, the cover of the re-bars of existing members was removed, and the surface was roughened and cleaned of dust and loose material. The execution of the jacket in this case was carried out to enhance the load bearing capacity of the members, as well as their resistance against lateral loads, due to the anticipated change in use of this historic reinforced concrete-load bearing masonry wall structure. The original use of the building was to host the nurses and doctors working in the Kyperounta Sanatorium, while in 2019 the building was retrofitted by the Public Works Department in order to become a Pneumonology Clinic.

Recommended solution for: Strengthening, Stiffness increase, Shear and Lap splice brittle failure prevention, decrease of v

Disadvantages: Visible changes on geometry, Necessity for strengthening of foundations, Irreversible, Increased CDW production



Figure B.3-2. Top: Preparation for shotcrete jackets on slabs, beams and columns. Middle: Shotcrete mixing equipment (left) and application of shotcrete (right). Bottom: Slab after shotcrete jacket (left) and waste material produced during the procedure (right)

B.3.3 Complete replacement of R/C members

While historic concrete structures and their materials ought to be preserved during structural repair interventions, sometimes their complete replacement is deemed easier and is possibly less expensive (than their repair/strengthening). In the case of the Kyperounta Sanatorium (Figure B.3-3), it was decided to completely remove the beams and columns of the historic concrete in one of the external porches of the building, made of R/C slab, beams and columns. The columns were supported on strip foundations (without footings) that were not able to sustain the new loads. Their strengthening did not have an easy, economic and quick solution. Therefore, it was decided to replace them with same geometry contemporary members and a new foundation system. This is not a recommended practice for historic structures.

Recommended solution for: Strengthening, Stiffness increase, Shear and Lap splice brittle failure prevention, decrease of axial load ratio (ν)

Disadvantages: Necessity for strengthening of foundations, Irreversible



Figure B.3-3. Replacement of the beams and columns in the external porch of Kyperounta Sanatorium Nurses and Doctors Residence Building by contemporary R/C members

B.3.4 Steel Encasement using angles and plates – steel caging

Figure B.3-4 depicts the steel encasement of rectangular R/C columns in a historic 9-storey building (Lyssarides Tower) in the center of Nicosia, during works carried out in 2020-21 for its structural upgrading. The external facades of the building, which was constructed within the walled city of Nicosia between 1950-1959, must be preserved, according to the demands of the Town Planning and Housing Department, since this was the first multi-storey building in the area. Initially, it was used as a clinic and offices for a local political party. Now, the building is due to be converted to a hotel and restaurant, and therefore the repair and strengthening of its lateral load resisting system is required. Steel encasement of columns is usually performed by four L-shape laminates applied on the corners of the column, and stirrup-type laminates along the height of the member. In order to leave intact the external façade and to not alter it by removing walls or even the cover of the reinforcement of existing RC members, round bars were inserted in holes opened through the column and anchored in the opposite vertical laminates of the two internal sides.

Recommended solution for: Shear and Lap splice brittle failure prevention, Increase of strength and ductility due to confinement, Reversibility

Disadvantages: Visible changes on members



Figure B.3-4. Steel encasement of R/C columns (and beam) in Lyssarides Tower, Nicosia

B.3.5 Textile Reinforced Mortar (TRM) for confinement

Figure B.3-4 depicts the confinement of a circular R/C internal column in the historic 9-storey Lyssarides Tower, in the center of Nicosia, during works carried out for its structural upgrading in 2020-21. The textile used in this case was PBO, with fibers working in both directions, but enhanced in the transverse to the longitudinal axis of the column. Two layers of TRM were applied on the member. The textile was applied with the use of a cementitious mortar consisting of short discontinuous fibers, provided by the manufacturer and mixed with water during the application. TRM is considered to be more fire resistant, compared to FRP confinement.

Recommended solution for: Shear and Lap splice brittle failure prevention, Increase of ductility due to confinement, Reversibility, Minimum changes in cross section

Disadvantages: No flexural strength increase





Figure B.3-5. PBO TRM confinement of beams, internal joints and circular columns in Lyssarides Tower, Nicosia

B.3.6 Fiber Reinforced Polymers (FRP) for confinement

Figure B.3-6 depicts the confinement of a rectangular R/C column in a historic multi-storey hotel in the center of Nicosia, during works carried out for its structural upgrading in 2021. The confinement was performed by the use of Carbon FRP wraps, with their fiber orientation transverse to the longitudinal axis of the columns. The FRP wraps were applied with the use of resins. The column's edges had to be curved in order for the wrap to be applied without the danger of rupture at the corners of the rectangular members.

Solution for: Shear and Lap splice brittle failure prevention, Increase of ductility due to confinement, Reversibility, Minimum changes in cross section

Disadvantages: Reduced fire resistance



Figure B.3-6. Carbon FRP confinement of rectangular columns in a historic multi-storey hotel, Nicosia

B.4 UNIGE

B.4.1 Introduction

The EN 1504 (2005) defines the procedures and characteristics of the products to be used for the repair, maintenance, and protection of concrete structures. This standard consists of ten parts, adopted and ratified by Italy between 2005 and 2017. Also, in Italy, as part of the restoration of reinforced concrete works, reference is made to other standards, and in particular Part 9 of EN 1504 (2009), which defines the principles and methods for the protection and repair of concrete structures and provides guidance on the choice of products and systems that are appropriate for the intended use. The approach to the restoration of reinforced concrete construction involves a series of methods that respect principles regarding both the preparation of the substrate consisting of concrete and steel reinforcement and its protection and repair.

B.4.2 General overview of standards materials and techniques for the conservation of historic concrete buildings in need of restoration (From EN 1504-9, Table 1)

B.4.2.1 Principles relating to substrate preparation:

CONCRETE

- **Cleaning:** the substrate must be free of dust, inconsistent materials, surface contaminants and materials that can reduce the adhesion or prevent the absorption or wetting of the surface with repair materials.
- **Hammering:** the texture of the treated surface must be appropriate to the products and systems to be applied and must be specified.
- **Micro-cracks:** the extent of micro-cracks on the surface of the substrate should be limited.
- **Removal of deteriorated concrete:** it must be kept to a minimum; it must not reduce structural integrity beyond the capacity of the structure to perform its function; it may require temporary support.

REINFORCEMENT




- **Cleaning:** rust, mortar flakes, concrete flakes, dust and other incoherent and deleterious materials capable of reducing adhesion or contributing to corrosion must be removed.




B.4.2.2 Principles and methods of protection and repair:



- Protection against penetration of agents (water, other liquids, gas vapour, such as carbon dioxide, chemicals, such as chlorides, and biological agents), through:
 - Hydrophobic impregnation with the application of a product to prevent or reduce the infiltration of water by coating the surface porosity with a material with hydrophobic properties.
 - Impregnation with the application of a product to reduce surface porosity and strengthen the surface by partially or totally filling the pores and capillaries.
 - Surface coating using a product that prohibits the ingress of agents.
 - Superficial bandaging of cracks in concrete through sealing.
 - Filling of the cracks.
 - Transformation of cracks into joints: this method uses existing cracks as an integral part of the structure.
 - Erection of external panels.
 - Application of membranes.
- Restoration of concrete, through:

- Application of restoration mortar by hand on the prepared concrete surface.
- New concrete or mortar cast by moulding and pouring method.
- Concrete or mortar treatment using a spraying technique.
- Replacement of elements.
- Structural consolidation, through:
 - Addition or replacement of embedded or external reinforcing bars.
 - Addition of reinforcement anchored in pre-formed or drilled holes.
 - Bonding plate reinforcement.
 - Addition of mortar or concrete.
 - Injection of cracks, voids or interstices.
 - Pre-stressing, post tensioning.
- Increasing physical resistance, through:
 - Coating.
 - Impregnation.
 - Adding mortar or concrete
- Resistance to chemicals, through:
 - Protective surface coating to reduce the penetration of chemicals into the treated concrete to prevent or reduce further deterioration.
 - Impregnation.
 - Adding mortar or concrete
- Preserving or restoring passivity, through:
 - Increase of the re-bar cover with the addition of mortar or concrete coatings.
 - Replacement of contaminated or carbonated concrete.
 - Electrochemical re-alkalization of carbonated concrete.
 - Re-alkalization of carbonated concrete by diffusion.
 - Electrochemical chloride extraction.
- Increasing resistivity, through:
 - Hydrophobic impregnation.
 - Impregnation.
 - Coating.
- Cathodic control, through:
 - Limitation of oxygen content (to the cathode) by continuous saturation with water or by a superficial coating.
- Cathodic protection, through:
 - Application of an electrical potential.
- Control of anodic areas, through:
 - Active coating of the reinforcement.
 - Barrier coating of the reinforcement.
 - Application of corrosion inhibitors to the concrete.

B.4.3 Overview of materials and techniques used for retrofitting in Italy

<p>Forced realignment of reinforced concrete floor, with the use of hydraulic jacks.</p> <p>Reinforcement of the reinforced concrete beams by the application of external post-tensioned cables and carbon fibres to the lower surface.</p> <p>Cladding with ceramic tiles.</p> <p>Aluminum structure that makes up the curtain wall and the glass.</p>		<p>Building: Grattacielo Pirelli [42]</p> <p>Architect: Gio Ponti - Pierluigi Nervi</p> <p>Year of Construction: 1956-1960</p> <p>Location: Milano</p> <p>Designer: Scientific technical commission</p>
<p>Repair of expelled concrete covers, by the use of cement mortar with single-component resin addition, trying to imprint the sign of the wooden boards of the formwork to make the reintegration homogeneous with respect to the original surface.</p> <p>Cleaning of surfaces performed at different levels to preserve the material as much as possible and maintain the existing “patina”.</p>		<p>Building: Tomba Brion [43]. San Vito di Altivole</p> <p>Architect: Carlo Scarpa</p> <p>Year of Construction: 1969-1978</p> <p>Location: Treviso</p> <p>Designer: Arch. Guido Pietropoli</p>
<p>Remaking of the vault and waterproofing.</p> <p>Consolidation of the reinforced concrete curb at the base of the semi-dome.</p> <p>Reinstatement of the degraded portion of the reinforced concrete ring beam.</p> <p>Construction of a slight slope for the run-off of water.</p> <p>Reconstruction of elements above the semi-dome as a structure simply leaning, overlapping, but not burdening.</p> <p>Insertion of a brick curtain supported by an underlying wall in reinforced concrete.</p> <p>1st stage: Extraordinary maintenance for the preservation of monumental structures and artistic apparatuses.</p> <p>2nd stage: Structural intervention carried out in the vicinity of the upper semi-dome</p>		<p>Building: Semi-dome of the Basilica of Maxentius [44]</p> <p>Architect: Sergio Musmeci</p> <p>Year of Construction: 1961-1962</p> <p>Location: Roma</p> <p>Designer: Arch. Giuseppe Morganti - Ing. Bellini</p>

<p>On going: Renovation of reinforced concrete canopies. Restoration of pillars (marble). Restoration of stone surfaces.</p> <p>1990: Restoration of stone surfaces.</p>		<p>Building: Palazzina Reale and train station of Santa Maria Novella [45]</p> <p>Architect: Gruppo Toscano, Giovanni Michelucci</p> <p>Year of Construction: 1935</p> <p>Location: Firenze</p> <p>Designer: Marco Dezzi Baldeschi</p>
<p>1999: Removal of stained concrete from the porch. Cleaning of steel reinforcement and protection with passive treatment. Restoration of the resistant conglomerate section.</p>		<p>Building: Ostiense Post office [46]</p> <p>Architect: Arch. Alberto Libera - Arch. Mario De Renzi</p> <p>Year of Construction: 1933-1935</p> <p>Location: Roma</p> <p>Designer: Sergio Poretti, Rinaldo Capomolla, Tullia Iori, Stefania Mornati, Rosalia Vittorini</p>
<p>Integration of metal reinforcement where damaged or missing. Finishing with neoplastic plywood shrinking mortar. Reinforcement of pillars by applying carbon fibre fabric.</p>		<p>Building: "Palazzaccio" LL.PP. Del Comune di Torino [47]</p> <p>Architect: Mario Passanti</p> <p>Year of Construction: 1961</p> <p>Location: Torino</p> <p>Designer: Ing. Gian Battista Quirico, General director; Ing. Franco Farina Sansone; Ing. Claudio Beltramino; Ing. Rocco Pietrafesa</p>

<p>1996: Reconstruction of the roof cover protection. Reinstatement of concrete cover and of some details in visible concrete surfaces.</p>		<p>Building: Chiesa di Sant'Alberto [44] Architect: Sergio Musmeci Year of Construction: 1969-1972 Location: Sarteano, Siena Designer: Arch. Fabrizio Bardelli</p>
<p>November 2002 - July 2004: Reconstruction of exposed concrete surfaces and elements. Intervention on exposed supporting structure: repair of all the affected parts and new total surface finishing with special mortar for cement repairs. Removal of deteriorated concrete. Treatment of the reinforcement and protection, following mechanical brushing and removal of oxidation. Reconstruction of thicknesses up to 2,5 cm. Surface finishing up to 3 mm. Intervention on prefabricated parapet elements: complete replacement with elements that meet the modern requirements and standards. Use of R'ck500 class prefabricated concrete, cast in a vibrating five-sided steel mould, with plasticizer to increase workability and reduce porosity. Use of mesh reinforcement of small diameter (2-5 mm) placed centrally to maximize the cover of the metal reinforcement elements. Intervention on the undersides of the cornices: cleaning by means of brushes and high-pressure with subsequent grey glaze, with a silicate base, of the portions which appear too dark or whitish, in order to avoid the application of the finishing and not to alter the appearance of concrete, characterized by the sign of narrow wooden boards. All the concrete elements were coated with a colourless protection based on siloxane resin in order to make the surface water-repellent and increase its durability. Restoration of coloured backgrounds.</p>		<p>Building: Sede INAIL [48] Architect: Giuseppe Samonà Year of Construction: 1959 Location: Venezia Designer: Head of Proceedings: Ing. M. Barelli Technical office INAIL; Project e D.L.: Ing. M. Capriuoli Technical office INAIL; Contributor to the project: Geom. Luca Bellesso Technical office INAIL; Executor of works: Pouchain s.r.l. Roma; Technical consultants: Ing. Nicola Berlucchi, Arch. Cecilia Catacchio</p>

<p>Reinstatement of the colour only in the gaps, not with full shades, but with successive glazes based on silicate paints. The colour was defined on the basis of chemical-physical investigations (FTIR), carried out on original colour samples taken on site. The technique of the glazing allowed not to cover the original colours, respecting, at least in this case, the historic appearance of the surfaces and, at the same time, reviving the important chromatic effect of the façade.</p> <p>Restoration of glass panes.</p> <p>Complete replacement of the most deteriorated windows with recovery of all the intact elements ; reconstruction with prefabricated elements with panels characterized by larger joints than the original ones, in order to ensure better thermal expansion.</p> <p>Timely integration of the least deteriorated windows, with careful removal of individual broken glass, and replacement with the original one, following its recovery from places where it has not been possible to maintain the original detailing and to insert cement mortar consisting of the traditional Portland type cement, class 32.5.</p>		
<p>December 2015 - June 2016:</p> <p>Restoration and conservation work on vertical and sub-horizontal supporting elements. Use of a casting mortar in wooden formwork, made with boards of the same size as the original, assembled by means of steel plates.</p> <p>Demolition of damaged concrete by hydrogasification to achieve cleaning of the reinforcement completely, even at points where concrete was completely intact - at least 10-15 mm depth.</p> <p>Cleaning of reinforcement by means of a metal brush mounted on a drill and application of protective treatment according to EN 1504-7, taking care not to stain the concrete surrounding the reinforcement.</p> <p>Assembly of the formwork with boards of the same width as the original ones, taking care, by means of a band of pressed chipboard (faesite), to keep the formwork away from the original surface by at least 10-15 mm. The</p>		<p>Building: Church-Tenda [49]</p> <p>Architect: Pino Pizzigoni</p> <p>Year of Construction: 1963-1966</p> <p>Location: Longuelo, Bergamo</p> <p>Designer: Director of works: Luigi Coppola Artistic director: Paolo Belloni RUP: Diego Pasta - Alex Servizi security coordinator: Arch. Roberto Gritti Client: Parish of Beata Maria Vergine Immacolata, Longuelo, Don Massimo Maffioletti</p>

formwork was wrapped with strips of metal foil, the heads were sealed with an easily removable plaster/mortar, and before proceeding with the jet it was completely filled with water to saturate the concrete substrate. The casting was carried out with a pourable mortar, in accordance with EN 1504-3 class R4. The wooden formworks, which before assembly had been treated with disarming oil to facilitate their removal without damaging the surface of the restored element, were removed not before 4-5 days from the jet, to ensure a prolonged wet maturation.

Interventions on thin vaults:

Zones in good condition (south-west facing): Simple shaving with low-modulus cement mortar, two-component class R2, according to EN 1504-3



Zones of the collapsed vaults and of the portal: Manual removal of the concrete in order to completely free the reinforcement, without damaging the intact conglomerate; Cleaning of reinforcement with mechanical brush; application of protective treatment (EN 1504-7); Reconstruction of the section with two-component thixotropic mortar class R4 applied in horizontal strips 1 m wide; shaving on the entire surface of the portal with two-component mortar class R2 (the same used for the vaults of the south-west facade) to conceal the bands of the reconstruction carried out.

Waterproofing of all points where rain water streams through the structure by the application of a polyurethane sealant, after application of the primer to facilitate the adhesion to concrete, freshly and blasted in order to then apply an elastomeric waterproofing membrane (EN 1504-2/C)

Interventions for protection and decoration:

Modification of the particle size curve of a Class R2 shaving mortar by adding aggregates larger than 0.5 mm. Protection of the entire surface of all external elements with a coloured acrylic coating meeting the requirements of EN 1504-2/C



<p>early 2000s: Electrochemical re-alkalization with current density of 1 A/m² (compared to the reinforcement surface) for a period of three weeks. An activated titanium mesh and cellulose pulp soaked in sodium carbonate solution were used as an anode system. Water-repellent treatment carried out on the pillars of the church, using a commercial product based on silicone resins.</p>		<p>Building: hospital church San Carlo Borromeo [50] Architect: Gio Ponti Year of Construction: 1964 Location: Milano Designer: Coordination: arch. Carla Di Francesco, Regional Director for Cultural and Landscape Heritage of Lombardia. Director: arch. Daniela Lattanzi Studies on reinforced concrete: Politecnico di Milano, Department of Chemistry, Materials and Chemical Engineering (prof. Luca Bertolini, ing. Elena Redaelli, Franco Traisci, Morgan Amerio, Marco Gaudiano) Ministry of Cultural Heritage, Regional Directorate for Culcural and Landscape Heritage of Lombardia Region (Experimental construction site for preliminary studies and inquires for the conservation project of the facades of the Church ...”.</p>
<p>early 2000s: Restoration of missing concrete cover: application of protective hydrophobic layer on the surface of the outer panels.</p>		<p>Building: Church of San Gregorio Barbarigo [51] Architect: Giuseppe Vaccaro Year of Construction: 1968-1971 Location: Eur, Roma Designer:</p>

Intervention on the reinforced concrete columns-slabs: preparation of surfaces with removal of degraded material; restoration and reconstruction of the re-bar cover layer and integral protection of the reinforcement through the application of a migrant corrosion inhibitor. Subsequently, when the restoration mortar had matured, structural reinforcement intervention was carried out through the application of epoxy resin and carbon fibre fabric. Surface finish through the application of plaster on all treated surfaces.



Building:
ex warehouses Ligabue (IUAV
University) [43]

Architect:

Year of Construction:
1929

Location:
Venezia

Designer:

<p>2014: Interventions on reinforcement cover located mainly at the lower parts of the walls: application of a covering product on the exposed concrete that constitutes the pillar-floor system and the roofing structure.</p>		<p>Building: Japan pavilion – Giardini della Biennale [43] Architect: Takamasa Yoshizaka Year of Construction: 1956 Location: Venezia Designer: Toyolito</p>
<p>2013-2014: Application of protective products on exposed reinforcement bars.</p>		<p>Building: Brazil pavilion -Giardini della Biennale [43] Architect: Amerigo Marchesin Year of Construction: 1964 Location: Venezia Designer: Ing. Sebastiano Steffinlongo; Arch Nicola Tonutti</p>
<p>1994: External walls repaired and repainted with quartz varnishes of the original color (Bayer).</p>		<p>Building: Church of San Gregorio Barbarigo [51] Architect: Giuseppe Terragni Year of Construction: 1936-1937 Location: Corso Giuseppe Garibaldi, 87, 20822 Seveso, Monza-Brianza Designer: Mario Vender</p>

B.4.4 Case Studies from Italy

B.4.4.1 Controlled deformation of reinforced concrete elements [42]

Grattacielo Pirelli, Milano.

On April 18, 2002, a private airplane crashed into this building, designed by Gio Ponti. The explosion resulting from the impact caused considerable damages to the reinforced concrete elements (slabs, beams and columns) (Figure B.4-1). In particular, the central span of the 26th floor underwent a downward deformation of about 25 cm, while the horizontal elements of the 27th floor showed a 6-7 cm upward shift.

Despite the damage suffered, the restoration plan did not suggest the replacement of elements; the objective was to preserve the existing structure and material. The first step was, therefore, to realign the decks of the 26th floor, forcing them, by means of hydraulic jacks, to a controlled upward movement (Figure B.4-2). Subsequently, the horizontal structure was reinforced through the use of post-tensioned steel cables, positioned on the outside of the beams, hooked to the headboard, with a load deflection function. The trellis was made like a “swing”, so as not to compromise the section of beams.



Figure B.4-1 Damage caused by the accident [42]

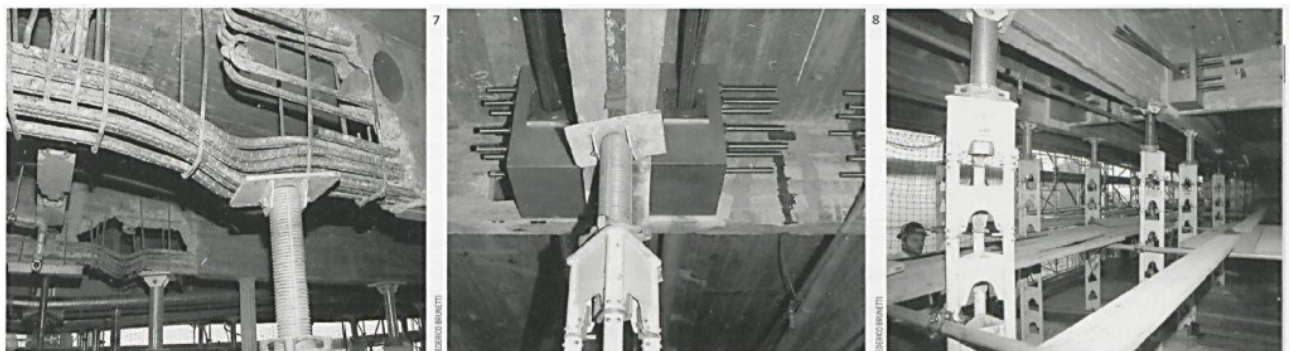


Figure B.4-2 Realignment of the reinforced concrete structures of the 26th floor. [42]

B.4.4.2 Cleaning of surfaces at different levels to preserve the material [43]

“Tomba Brion”, S. Vito di Altivole, Treviso.

Cleaning of concrete surfaces of the monumental “Tomba” (Tomb) of Brion Family, designed by Carlo Scarpa, was carried out with techniques tested both in the laboratory and in situ.



Figure B.4-3 View of the exterior [43]



Figure B.4-4 View of the exterior [52]

Based on the preliminary test results and the specific characteristics of the concrete, the conservation strategy started with the least intruding interventions possible, to be repeated in the short term, such as cleaning tests carried out at different levels to maintain the existing “patina” (Figures B.4-3-5). The interventions were classified according to the structural role of the element to be restored, the type and level of damage, and the potential impact of the intervention on the form and “meaning” of the work (Figure B.4-6-7).



Figure B.4-5 External front [53]



Figure B.4-6 Maps of external surfaces: Surveying, characterization of material, characterization of degradation and intervention [53].


ELEMENT CODE	CHARACTERIZATION OF THE MATERIAL AND THE DECAY	SAMPLES OF CLEANING	FACTOR OF CRITICALITY
MOB_SV01	<p>DIAGNOSTIC</p> <p>ENVIRONMENT CHARACTERISTICS</p> <ul style="list-style-type: none"> external environment internal environment physical parameters concentrations of pollutants <p>MATERIAL CHARACTERISTICS</p> <ul style="list-style-type: none"> mix design, tests of mechanical strength, porosity pachometer radar thermography microseismic tests endoscopy chemical tests cracks monitoring cyclical visual inspection depth of carbonation <p>ELEMENT LOCALIZATION</p> 	<p>SAMPLE CODE</p> <p>SAMPLE CLEANING E</p> <p>SAMPLE CLEANING E</p> <p>SAMPLE CLEANING D</p> <p>SAMPLE CLEANING C</p> <p>SAMPLE CLEANING B</p> <p>SAMPLE CLEANING A</p> <p>CLEANING PROCEDURE</p> <p>PRODUCTS</p> <p>APPLICATION METHOD</p> <p>PRODUCTS</p> <p>APPLICATION METHOD</p> <p>PRODUCTS</p> <p>APPLICATION METHOD</p> <p>PRODUCTS</p> <p>APPLICATION METHOD</p> <p>PRODUCTS</p> <p>APPLICATION METHOD</p> <p>MONITORING</p> <p>depth of carbonation</p> <p>chemical tests</p> <p>cracks monitoring</p> <p>cyclical visual inspection</p>	<p>EXTRINSIC FACTORS</p> <ul style="list-style-type: none"> previous interventions of plaster replacement since 2001-2 Exposure to the environment: external environment, north, summit surfaces runoff, humidity <p>INTRINSIC FACTORS</p> <ul style="list-style-type: none"> "defects" of realization (cfr diagnostic): absence of summit concrete protection from rain with consequent runoff and humidity absence of expansion joints and consequent cracks to verify and to differentiate from failure <p>EXTRINSIC FACTORS</p> <ul style="list-style-type: none"> previous interventions of plaster replacement since 2001-2 Exposure to the environment: external environment, north, summit surfaces runoff, humidity <p>INTRINSIC FACTORS</p> <ul style="list-style-type: none"> "defects" of realization (cfr diagnostic): absence of summit concrete protection from rain with consequent runoff and humidity absence of expansion joints and consequent cracks to verify and to differentiate from failure

Figure B.4-7 Sample of survey characterizing the concrete and its degradation, with planning of diagnostic, assessment, and testing program [43].

B.4.4.3 Formwork with wooden boards [49]

Church-"Tenda", Longuelo-Bergamo.

The church, located in Longuelo district in Bergamo and designed by arch. Ing. Pino Pizzigoni, is one of the greatest examples of structures with concrete thin vault in Italy (Figure B.4-8-9). Built in the 1960s, the church-tent represents the point of arrival of a series of studies conducted by its designer on thin reinforced concrete structures, started in the 1950s. The church consists of four equal and independent parts, joined by a complete separation joint that allows each part to have a statically independent behavior. The supporting structure of the church consists of vertical and sub-horizontal columns with circular section, connected by thin vaults with double curvature. These elements were made by on-site concrete casting [49]. The slenderness of these structures and the scarce means available at the time of construction produced some defects that led to maintenance problems due to the particular vulnerability of reinforced concrete elements to aggressive environmental actions [49].





Figure B.4-8 External views of the main portal of the church [49]



Figure B.4-9 View of the interior.

During the restoration, the formwork was assembled with wooden boards of the same dimensions as the original ones, taking care, by means of a band of pressed chipboard (faesite), to keep the formwork away from the original surface by at least 10-15 mm (Figure B.4-10). The formwork was wrapped with strips of metal foil (Figure B.4-11), the heads were sealed with an easily removable plaster/mortar (Figure B.4-12) and, before proceeding with the jet, it was completely filled with water to saturate the concrete substrate. The casting was carried out with a pourable mortar conforming to EN 1504-3 class R4.

The wooden formworks, which before assembly had been treated with oil to facilitate their removal without damaging the surface of the restored element, were removed not before 4-5 days from the jet, to ensure a prolonged wet maturation.



Figure B.4-10 Wooden formwork detached from the concrete substrate by at least 15 mm [49].



Figure B.4-11 Wooden formwork with "funnel" for the casting of the pourable mortar [49].



Figure B.4-12 Detail of the sealing of the formwork with mortar based on binding plaster [49].

B.4.4.4 Control of anodic areas [50]

Church -Hospital San Carlo Borromeo, Milano.

The church (Figure B.4-13-14), dedicated to Santa Maria Annunciata, is located in the area of the San Carlo Hospital in Milan. The church was designed by Gio Ponti between 1960 and 1963, and was completed in 1967. The structure of the church consists of a system of twenty pillars of exposed reinforced concrete façade that support ten trusses (also of reinforced concrete). The degradation of the columns was caused mainly by the corrosion of the steel reinforcement that caused the spalling of the cover layer (Figure B.4-15). The building is located in an urban environment free of chlorides, so, in this case, the corrosion of the reinforcement was mainly due to carbonation of concrete [50].



Figure B.4-13 External views



Figure B.4-14 View of the interior

During the restoration, the anode system was applied through a cellulose layer and activated titanium mesh (Figure B.4-16). The objective of the restoration was to return the concrete to the initial alkalinity state, thus reinstating the passivity of the reinforcement. In addition, these conditions allowed the corrosion rate to be kept low, even in the presence of moisture (Figure B.4-17).

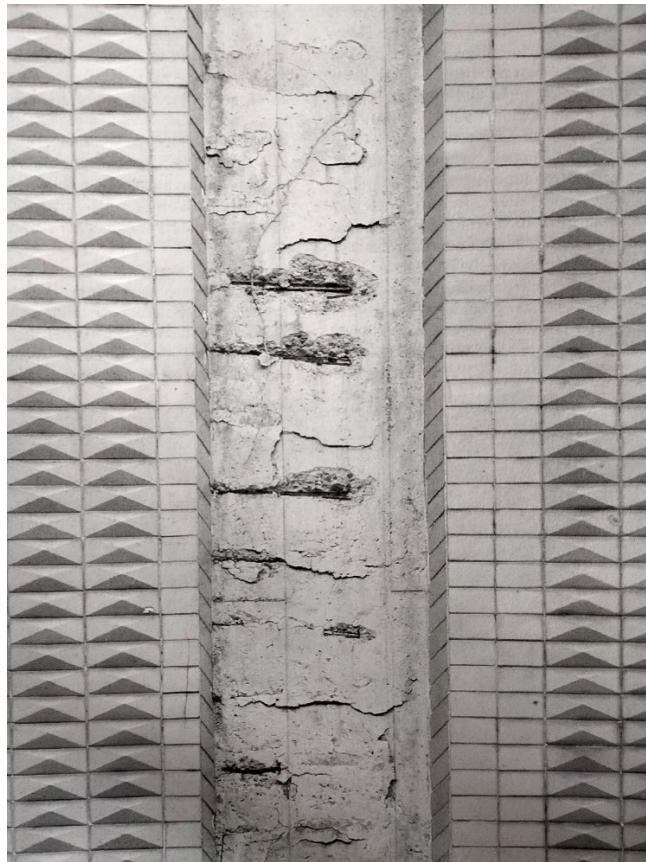


Figure B.4-15 Cracking and expulsion of cover caused by corrosion of reinforcement bars.⁴

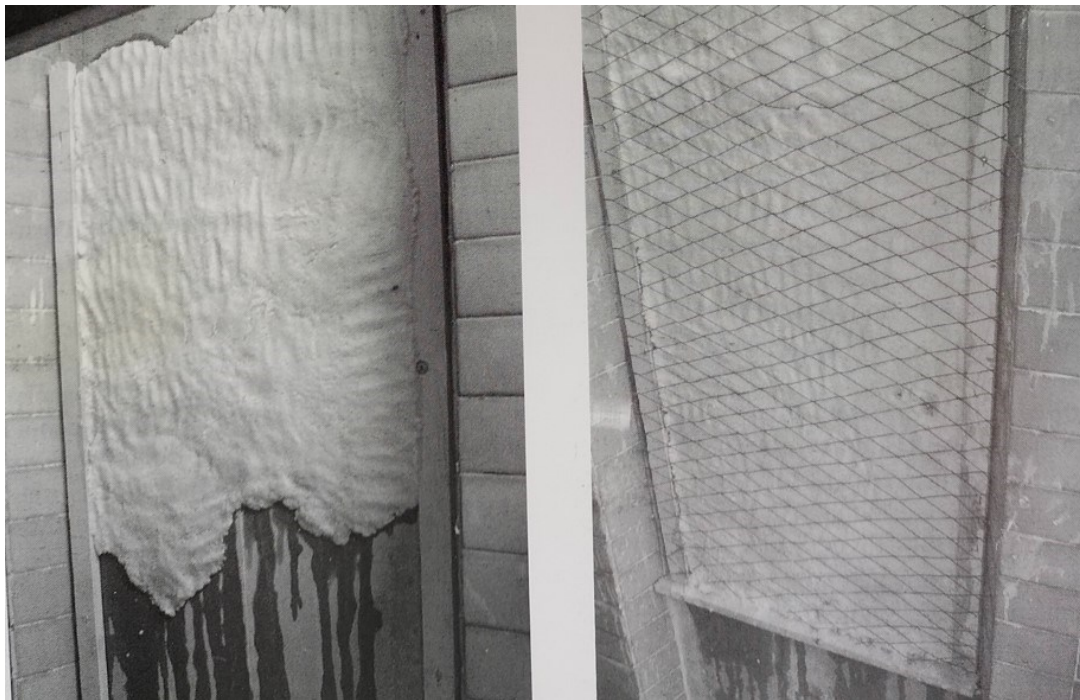


Figure B.4-16 Anode system: cellulose pulp layer on the left, titanium mesh on the right [50].

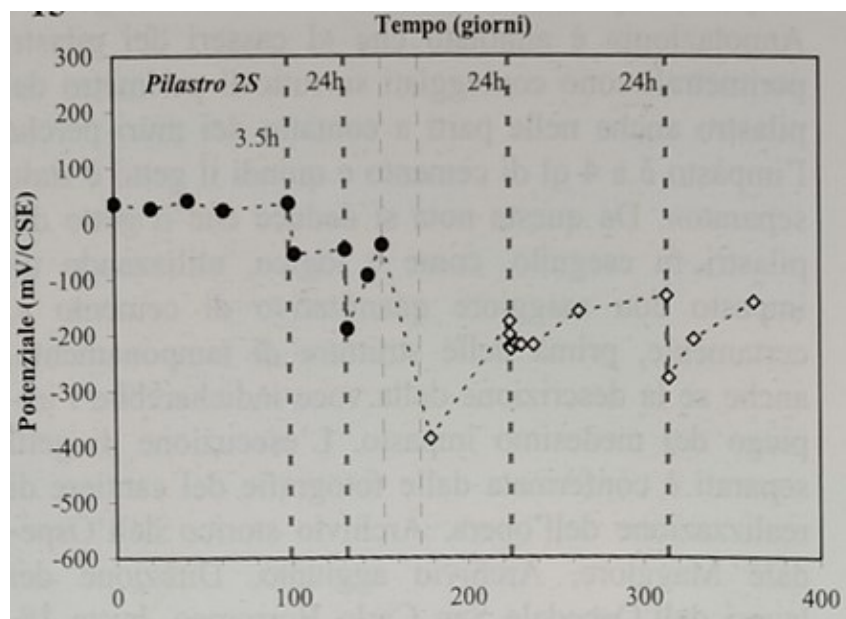


Figure B.4-17 Evolution over time of the mean potential values of the reinforcements subjected to electrochemical re-alkalization treatment [50].

⁴ L. BERTOLINI, D. LATTANZI, E. REDAELLI, *Le strutture di calcestruzzo armato a vista della Chiesa dell'ospedale San Carlo Borromeo a Milano: diagnosi e conservazioni*, in, C. DI BIASE, *Il degrado del calcestruzzo nell'architettura del Novecento*, 2009, Santarcangelo di Romagna, Maggioli Editore, pag. 462.

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