

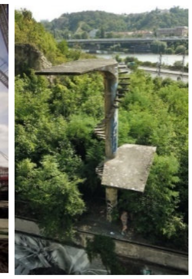


Report on Conservation Proposals

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Abstract

This report includes: (a) General guidelines for the repair and strengthening of historic reinforced concrete (RC) structures, and (b) Proposals for the restoration of selected case-studies in the four participating countries of the consortium. The report fulfils the obligations of Work Package 4, Task (iii) and is expected to contribute in practical conservation.

Contents

Part A: GENERAL GUIDELINES ON PRESERVATION

A.1 INTRODUCTION

The restoration of reinforced concrete buildings, as indeed of all historical and monumental structures, must follow a set of general principles that guarantees successful intervention(s) and allows the structures in question to be preserved, enhanced, used and maintained over time.

These principles are:

- consistency in design choices at all scales of intervention: architectural, functional, decorative, etc.;
- preservation of historical traces as evidence of the phases of construction and modification of the building over time;
- recognizability of new interventions;
- compatibility of the materials used in the new interventions with the authentic ones.
- retractability of the parts and elements involved in the interventions (incl. functional changes) through the use of materials that allow to future interventions, without compromising their status or preventing new restorations;
- “minimal intervention”.

Before proceeding with any type of restoration, in order to guarantee the result and the sustainability of the intervention(s), it is necessary to proceed with a specific, detailed and analytical-diagnostic study through:

- a preliminary survey of the building, its construction, the techniques adopted, the construction phases and its status;
- in-depth analysis of the state of conservation of the building and diagnosis of the phenomena and processes of decay in progress;
- identification, elimination or mitigation of any ongoing causes of decay and instability, through emergency interventions that avoid irreversible damages;
- physical-mechanical analysis of materials to identify their specific characteristics, both in situ and in the laboratory, giving priority to non-destructive inquires and limiting interventions (e.g., sampling) to those strictly necessary.

In Italy, the context of the restoration of reinforced concrete buildings is described in UNI EN 1504 [1], and in particular Part 9 which defines the principles and methods for the protection and repair of concrete structures and provides guidance on the choice of the products and systems appropriate for the intended purposes. In the field of historic reinforced concrete buildings of cultural interest, the interventions can be divided into:

1. Interventions on the structure	2. Interventions on surfaces
• **structural reinforcement / restoration** of **bearing capacity**	• cleaning of existing surfaces
• **treatment of reinforcement and** of its **cover**	• new realizations

A.2 INTERVENTIONS ON THE STRUCTURE

A.2.1 Structural reinforcement / Restoration of bearing capacity

These interventions involve the reinforcement of existing concrete elements using additional concrete, the thicknesses of which exceeds the reinforcement cover, thus also partially affecting the core of the damaged structural element which is subjected to repair. The partially reconstructed section, together with the non-damaged part of the original element, are intended to work together to repair the damage, restore the acceptable load bearing capacity under static conditions, or increase the bearing capacity of the element, in particular, and of the structure in general.

A.2.1.1 Reinforcement of beams and columns by the application of FRP sheets

This method involves the confinement of a member to increase its ductility (Fig. A.1-1). The composite systems used in Italy, made of carbon fiber fabrics, FRP (Fiber Reinforced Polymer), foils or resins, must have the "Certificato di Idoneità Tecnica all'impiego" (CIT).

FRP systems are classified in:

- in situ impregnated systems, that is fabrics impregnated and glued to the substrate with resins;
- pre-formed systems, that is sheets prefabricated in the factory by pultrusion and glued to the element of intervention.

The application steps for in situ impregnated systems are:

STEP 1: CLEANING AND PREPARATION OF THE SUBSTRATE

- Removal of degraded concrete by hand or electric hammer;
- Removal of the corroded layers of reinforcement and mechanical cleaning from dust, grease, and other contaminants through the use of metal brushes or by sandblasting or hydro-sandblasting;
- Replacement of any failed, damaged or strongly corroded reinforcement;
- Application by brush of a corrosion inhibitor on the exposed reinforcements;
- Restoration of the reinforcement cover with cement mortar of adequate thickness and compatibility with existing member geometries.

STEP 2: INSTALLATION

- Processing of the edges of the member to be repaired to smooth them to avoid rupture of the fabric (provide minimum radius of curvature of 20-30 mm);
- Application, by roller or brush, of epoxy primer;
- Levelling of the intervention surface area;
- Application of two-component epoxy resin;
- Laying of fabric strips/net by hand or roller;
- Impregnation of fabric strips/net with two-component epoxy resin.

STEP 3: FINISHING

- Sandblasting of the intervention surface with quartz sand to make it rough and facilitate the clinging of the next layer of plaster;
- Substrate preparation;
- Realization of the FRP strips cover.

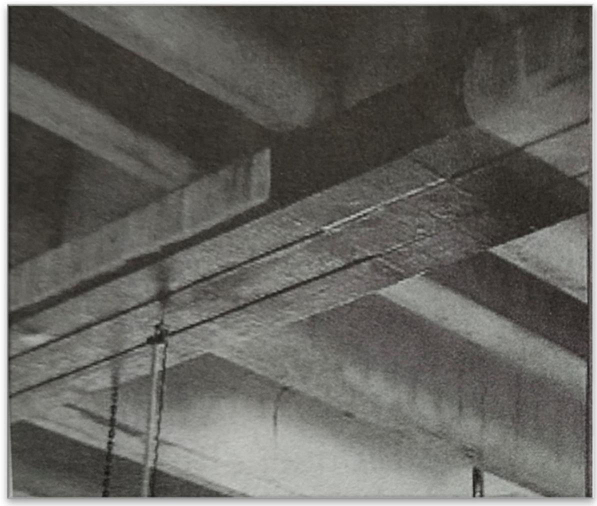
a.  b. 

Figure A.2-1 a. Column shear strengthening with carbon FRP; b. Strengthening of beams with carbon FRP

A.2.1.2 Treatment of reinforcement and cover

A.2.1.2.1 Restoration of the reinforcement cover

This method involves the re-casting of the reinforcement cover (Fig. A.1-2) and includes the following steps of processing:

STEP 1: CLEANING AND PREPARATION OF THE SUBSTRATE

- Removal of degraded concrete by hand or electric hammer;
- Removal of the corroded layers of reinforcement and mechanical cleaning from dust, grease, and other contaminants through the use of metal brushes or by sandblasting or hydro-sandblasting;
- Replacement of any failed, damaged or strongly corroded steel reinforcement;
- Application by brush of a corrosion inhibitor on the exposed reinforcements;
- Restoration of the reinforcement cover with cement mortar of adequate thicknesses and compatibility with the existing member geometries.

STEP 2: RESTORATION OF THE COVER AND OF THE INTEGRITY OF THE ELEMENT

- Cleaning and humidification (without saturation) of concrete;
- Application of thixotropic mortar, after making state-of-art wooden or plywood formwork, in successive layers of 20-30 mm, for interventions that require large thicknesses of the new material;
- Finishing of the reconstructed part with cement mortar with fine grain size.

Figure A.2-2 a. Preparation of the intervention area through scarification and iron cleaning; b. brush application of the protection for the reinforcement; c. area ready for integration with mortar. Chiesa-Tenda, Longuelo, Bergamo

A.2.2 Concrete re-alcalization

Electrochemical re-alkalization is a restoration technique used for reinforced concrete structures affected by carbonation/corrosion (A.2-1). The objective is to restore high pH values through the application of a cathodic current to the reinforcement.

This method also allows to electrochemically remove chlorides from the reinforcement through the use in the anodic system of an electrolyte consisting of calcium hydroxide or lithium. Chloride ions are attracted to the anode and removed from the reinforcement. Subsequently, they are eliminated through the circulation of a solution containing the electrolyte or by using demineralized water.

STEP 1: CLEANING AND PREPARATION OF THE SUBSTRATE

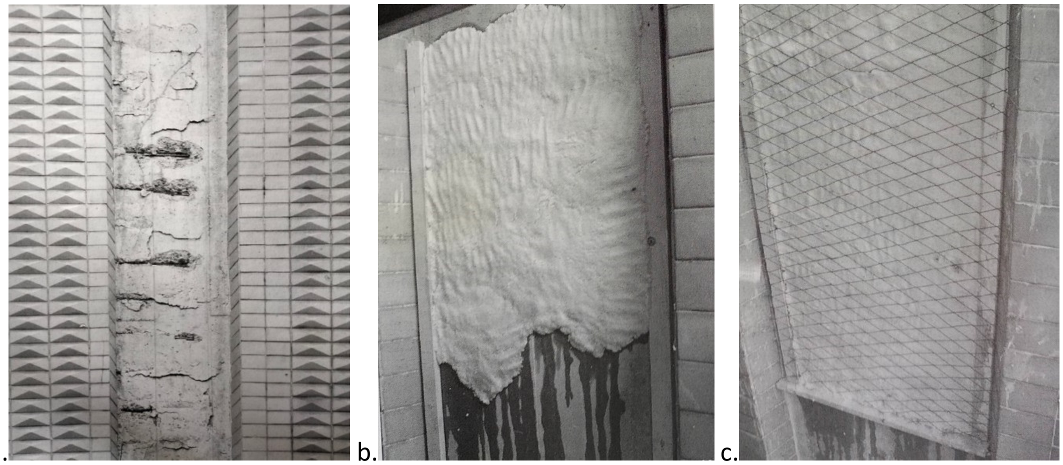
- Removal of degraded concrete by hand or electric hammer;
- Removal of corrosion products present on the surface of reinforcements and mechanical cleaning from dust, grease and other contaminants through the use of metal brushes or by sandblasting or hydro-sandblasting;
- Replacement of any failed, damaged or strongly corroded steel reinforcement;
- Application by brush of a corrosion inhibitor on the exposed reinforcements;
- Preliminary covering of concrete and reinforcement with cement mortar, leaving a portion uncovered to be connected to the electrical system.

STEP 2: ELECTROCHEMICAL RE-ALKALINIZATION OF REINFORCED CONCRETE

- Reinforcement connection to the electrical system;
- Covering with cement mortar of the part subject to intervention.
- Application of the anode system through titanium electrodes and cellulose pulp compresses with OH^- ion solution;
- Connection of cables to the control unit.
- Removal of anode system at the end of treatment and finishing of concrete surface.

STEP 3: CHECK OF CONCRETE ALKALINITY

- Punctual investigation through the creation of a hole in the steel cover;
- Spray application of pH indicator.



a. b. c.

Figure A.2-1 State of facts before intervention (a); application of anode system: cellulose pulp layer (b), titanium net activated (c). Chiesa Ospedale San Carlo Borromeo, Milano.

A.3 INTERVENTIONS ON SURFACES

A.3.1 New realization

For cortical interventions (i.e., intervention that affect thicknesses up to the steel cover, without involving the steel reinforcement) on reinforced concrete elements, it is possible to proceed with the construction of a state-of-art wooden formwork for the reconstruction of the missing layer of concrete, and the subsequent casting of mortar (Fig. A.3-1). These interventions help ensure the integrity of the element, but are not properly structural.

STEP 1: ASSEMBLY OF THE WOODEN FORMWORK

- Use of wooden boards treated with disarming oil for the realization of the formwork of the same size as that originally used;
- Assembly of the wooden formwork at a minimum distance of 10 - 15 mm from the scarified surface using a strip of pressed chipboard wood;
- Bandage of wooden boards with strips of metal foil able to adequately counteract the thrust exerted by the castable mortar jet;
- Sealing of the formwork head with easily removable gypsum mortar to prevent the cement mortar escaping during the casting phase.

STEP 2: CEMENT MORTAR PREPARATION AND CASTING

- Filling the formwork with demineralized water until saturation of the substrate;
- Emptying of the formwork and casting of the pourable cement mortar through a funnel on the upper part of the formwork.

STEP 3: DISASSEMBLY OF WOODEN FORMWORK

- Disassembly of wooden formwork no earlier than 4-5 days from casting.

a. 
b. 
c. 

Figure A.3-1 Steps of realization of the wooden formwork: assembly at a minimum distance of 10 – 15 mm from the substrate (a); completion of the wooden formwork with strips of metal foil and funnel for casting (b); filling of the formwork with plaster mortar (c). Chiesa-Tenda, Longuelo, Bergamo

A.3.2 Cleaning of existing surfaces

Cleaning operations directly affect the surface of the concrete element, without involving the inner layers, thus ensuring almost total material preservation. The purpose of cleaning is to remove consistent or inconsistent deposits, biological colonization, salt efflorescence, black crusts, films or protective substances applied in previous interventions, stains, etc.

Cleaning operations require a series of operations that, if not carried out in a workman-like manner, can be harmful and irreversible or may modify or eliminate portions of the surface of the element, depriving it of part of its formal architectural identity. Therefore, the interventions must be carried out not before an accurate, targeted, specific scientific knowledge of the causes that have caused the forms of alteration of the surfaces of the cement conglomerate has been acquired and only after the implementation of measures that can eliminate or at least slow down the current decay phenomena (Fig. A.3-2,3).

Appropriate techniques of intervention shall be identified, based on both in situ and laboratory previously conducted background investigations and tests. Cleaning operations must not be generalized; they cannot be traced back to a single intervention for all parts of the building because the conditions of reality can be very different.

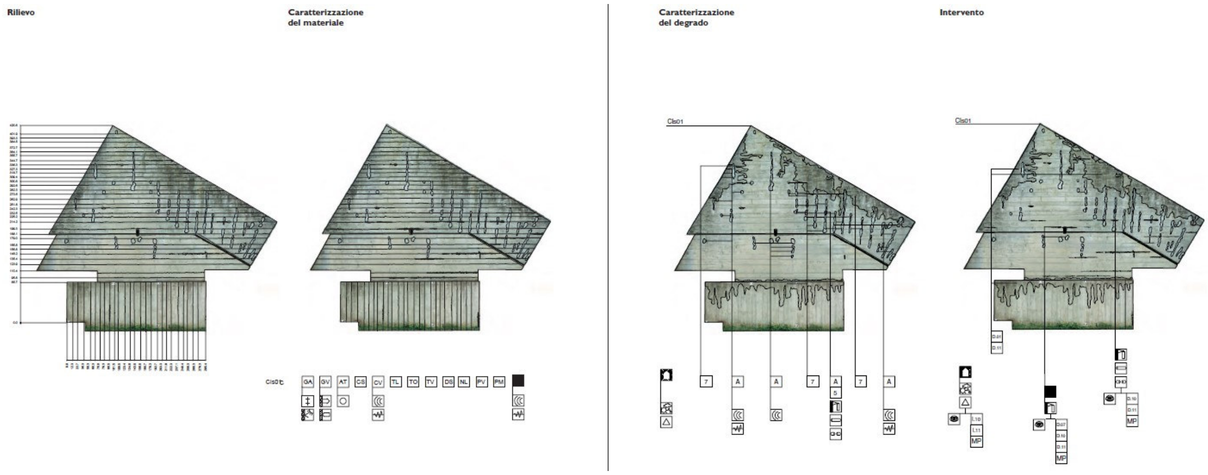


Figure A.3-2. Map of external surfaces: Surveying, material characterization, decay characterization and intervention. Tomba Brion, Altivole, Treviso.

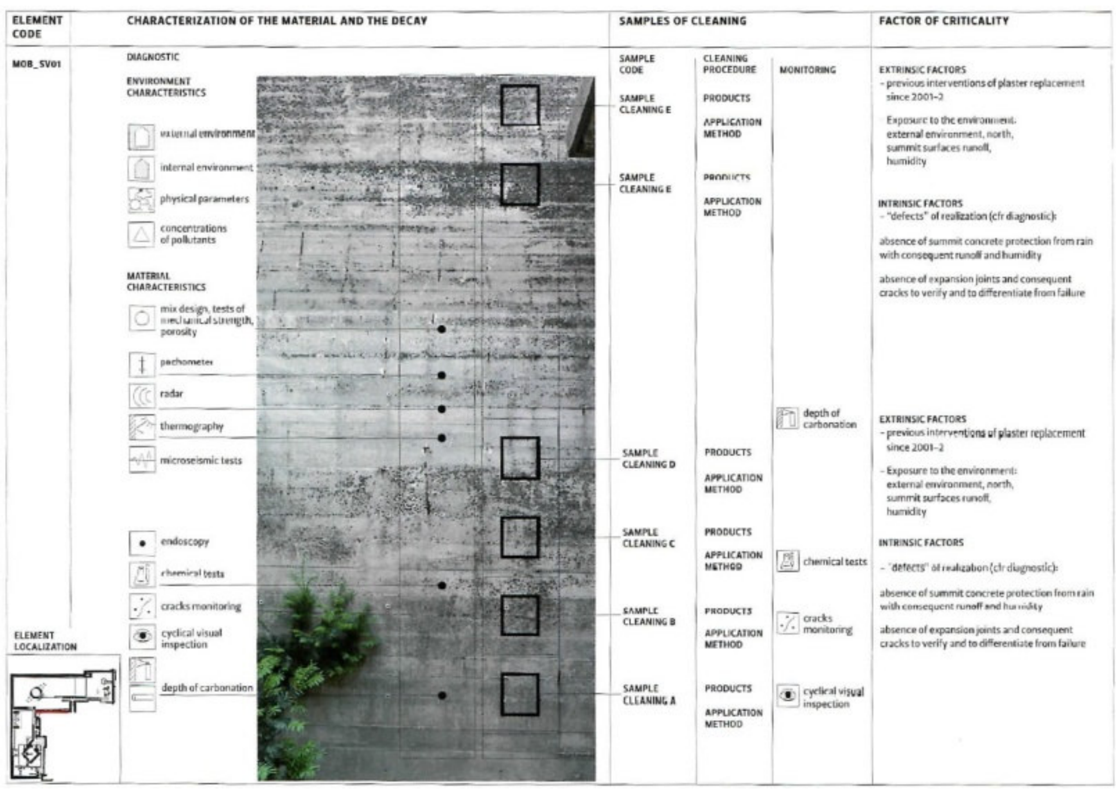


Figure A.3-3. Analysis of concrete decay. Tomba Brion, Altivole, Treviso.

Surface cleaning of concrete elements made of reinforced concrete can be carried out through different techniques:

A.3.2.1 Mechanical cleaning with stiff bristle brushes

This technique can be implemented if the alterations affect small areas and the deposits to be removed are poorly attached to the substrate.

STEP 1: CLEANING

- Manual brushing with brushes.

STEP 2: PROTECTION

- Protective water-repellent treatment.

A.3.2.2 Pressure water, mist, steam cleaning

The technique is based on the use of water for the treatment of concrete surfaces affected by poorly adhesive deposits of low thickness.

STEP 1: CLEANING

- Provision of appropriate systems to protect the areas not affected and to collect and dispose of the water deriving from the process to prevent the formation of runoff or stagnation that can promote unfavourable conditions and decay;
- Treatment of the surface with:
    - pressure washer or pressure washer equipped with water heating for temperature regulation;
    - sprayed water through the use of irrigation bars;
    - steam jet through a system equipped with nozzles;
- Manual brushing with metal brushes or by cup drill.

STEP 2: PROTECTION

- Protective water-repellent treatment.

A.3.2.3 Cleaning with compresses

This technique makes use of cellulose pulp or adsorbent clay with solvents for the treatment of low thickness contaminant layers and contaminants slightly adhering to the concrete surface. It is possible to remove oily substances, saline efflorescence, stains and impregnating film-forming layers.

- Implementation of all safety measures for both operators and the environment related to toxicity issues and the identification and disposal of waste products;
- Application of the mixture impregnated with water solution EDTA (ethylene-diamine-tetraacetic acid) on the affected surface or with ammonium carbonate;
- Final manual brushing with brushes of medium hardness for the removal of residues of the mixture.

A.3.2.4 Disinfection and disinfection by biocidal products

This technique is based on the use of biocidal products, such as, for example, those based on quaternary ammonium salts for the treatment of biological colonization.

- Implementation of all safety measures for both operators and the environment related to toxicity issues and the identification and disposal of waste products;
- Application of the biocidal product by spray or brush on the affected surface, ensuring effective action times;
- Final manual brushing with metal brushes or through cup drill.

A.3.2.5 Extraction of soluble salts

Extraction of soluble salts by compresses allows the removal of saline efflorescence (Fig. A.3-4) both from the surface of the product and from the immediately underlying layers.

This technique avoids the abrasive action of brushes and sponges, since the soluble products are conveyed by the solvent inside the material. The technique involves the use of substances with high absorbent capacity, such as cellulose pulp or clays such as bentonite, sepiolite, and attapulgite.

Figure A.3-4. Salt efflorescence on the surface of a reinforced concrete structure. Ex hotel Marinella, Genova.

STEP 1: CLEANING AND PREPARATION

- Removal, before proceeding with the cleaning operation, of the deposits of the most conspicuous salts through the use of soft brushes or air flows of weak power;
- Preparation of the mixture with deionized water and adsorbent material, and possible spraying of deionized water combined with brush application of a very fluid aqueous clay suspension.

STEP 2: APPLICATION OF THE MIXTURE

- Application of the mixture using a brush or spatula in thicknesses ranging from 1 to 3 cm;
- Protection of the mixture through the application of nylon, gauze and polyethylene nets;
- Application times vary from 48 hours to weeks, depending on the type and quality of salts present, and the storage conditions of the material (to be determined following specific tests carried out on-site before the start of work);
- Removal of compress by washing and brushes of soft nylon bristle, or using soft cloths or sponges to avoid abrasion of the surface. The removal of the mixture must take place only when the adsorbent material is dry, scaly and inconsistent, detached from the affected surface.

STEP 3: COMPLETION CLEANING

- Mild final cleaning through the use of soft brushes and final rinsing with deionized water nebulized to facilitate the dissolution of salt efflorescence.

Part B: PROPOSALS FOR RESTORATION OF LOCAL CASE STUDIES

This part of the report includes proposals for the restoration of selected case studies in the four participating countries of the CONSECH20 project. The contributions of the partners focused on the following case-studies:

a) TU Delft: Fenix II, Rotterdam
b) ITAM: Restaurant of the Winter Stadium at Štvanice and Barrandov Swimming Stadium
c) UCY: Principal’s Mansion at the Melkonian Educational Complex, Nicosia
d) UNIGE: Hennebique Grain Silos, Genoa

B.1 TU Delft: Fenix II

B.1.1 Introduction

Based on the results of the investigation carried out in WP2 [2], the conservation strategies for the Fenix II building (Fig. B.1-1) are hereby discussed. The report is divided in 3 parts:

- Proposal for conservation intervention
- Maintenance plan
- Risk assessment of climatic events

Proposal for conservation intervention

The Fenix II building is still in a functioning state. However, its south façade, constructed in 1918, suffers of extensive damage due to carbonation-induced corrosion of the concrete reinforcement [2]. In the past, there was an attempt to address the causes of the corrosion, but this has proven to be insufficient, as the damage persevered. The first part of this report is focused on discussing what would be the most efficient ways to tackle the problem of corrosion.

Maintenance plan

Besides a proposal for intervention on the damaged parts, a maintenance plan is presented in the second part of this report. The maintenance plan considers both the non-damaged and the repaired areas of the building.

Risk assessment of climatic events

The Fenix building is a few meters from the waterfront at the shores of Rotterdam. This location exposes the building to several climatic events (e.g., flooding, impact of waves etc.). Because of climate changes, the harshness of climatic events is expected to increase in the future. The third part of the report is dedicated to the study of the impact of harsher climatic events on the building.

Figure B.1-1. View of the south wall of the Fenix II (2019)

B.1.2 Intervention plan

The focus of the intervention plan is the south façade. The rest of the structure does not show relevant damages. For details of the damage and its causes refer to the in-depth report prepared in WP2 [2].

The south façade is affected by heavy corrosion damage caused by carbonation. The existing render applied in the 1980s is cracked and spalled, as well as the original concrete cover. The cause of the corrosion seems related to the fact that the carbonated concrete was not properly removed when applying the render. This is confirmed with the carbonation tests carried out on these columns (Fig.

B.1-2). Consequently, the corrosion has proceeded, likely due to the high relative humidity due to the rainy weather in the Netherland and the close proximity of the building to the waterfront. In addition, the early cracks in the render eased moisture ingress into the concrete. The low permeability of the render may have further caused a barrier effect to drying, thus trapping moisture in the concrete surrounding the reinforcement. This effect has likely increased the corrosion rate of the reinforcement.

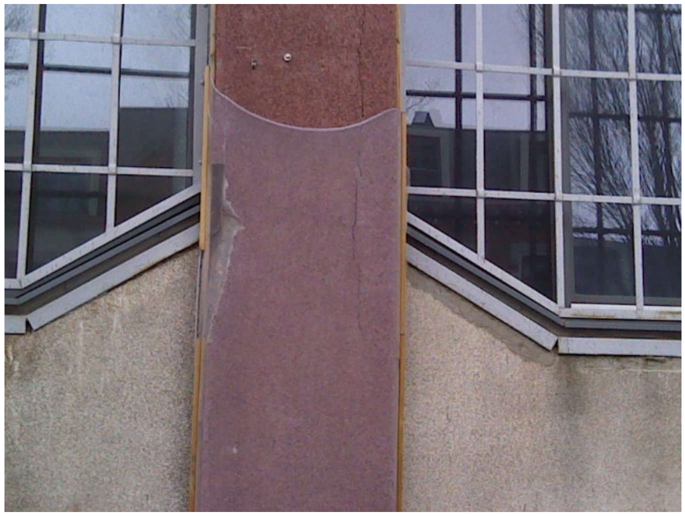


Figure B.1-2. Close up picture of the south facade columns in the Fenix II.

B.1.2.1 Solution proposal and discussion

According to the manual for concrete repair CONTECVET [3], four types of repairs are recommended to palliate this type of damage mechanism: patch repairs, concrete re-casting, electrochemical re-alkalization and surface treatment. Table B-1, shows an overview of the pros and cons of each method.

Table B-1. Evaluation of different repair techniques.

	Easiness of application	**Cost**	**Efficiency**	**Durability**	**Aesthetic Impact**	**Easiness of removal**
	From difficult to easy		*Low to High*	*Low to High*	*Low to High*	*From difficult to easy*
Patch Repairs	+++	$	++	++	++	++
Concrete recasting	+	$$	++	+++	+++	+
Re-alkalisation	++	$$	+	+ (**)	+	++
Surface treatment	++	$	+ (*)	+	+	++ (***)

(*) Low efficiency if it is not combined with other type of repairs.

(**) Unsure efficiency in the long term

(***) Depending on the surface treatment

Patch repair and concrete recasting are in principle the same type of repair. The difference lies in the size of the repair; patch repairs being more local and recasting being more extensive. The repair principle is to remove the loose and carbonated concrete and install new fresh concrete to provide a new passivity layer to the reinforcement and to surround the reinforcement with a new alkaline medium. This solution is effective as it will stop corrosion. Although simple in theory, the repair is not always successful and the majority of repairs show signs of failure in about 10 years of age. The origin of this failure is usually the incompatibility with the existing concrete and/or an incorrect surface preparation.

Electromechanical re-alkalization is based on increasing the pH of the carbonated concrete. It recovers the alkalinity of the concrete around the reinforcement, thus stopping corrosion. It is a quick solution (the process takes about two weeks) and the impact on existing concrete is minimum, but it has several disadvantages. If the concrete is already cracked or spalled, it still needs to be repaired, therefore electromechanical re-alkalization does not remove the need for patch repairs. Lastly, and most important, this process may accelerate the corrosion rate in the long term, as it changes the chemical composition of concrete [4].

Surface treatment provides a barrier to reduce the moisture content of concrete, and/or block gas diffusion (O_2 or CO_2) into it. Water repellents are used, depending on the type of repair needed. They are usually accompanied by a previous surface repair (i.e., patches or recasting) and preparation of the surface. There is no unanimous agreement in using surface treatments in historic concrete, as these are in general not reversible and can also favour the increase of moisture content in the concrete (in the case water penetrates the concrete through cracks, the presence of a water repellent would delay drying).

In the next paragraphs, the different options mentioned in the CONTECVET guidelines will be analysed with reference to the case of the Fenix II building.

In general, the application of re-alkalization in historic concrete should be limited to extreme cases, when no other solution is applicable, because of the reasons mentioned above. In this case, re-alkalization of the concrete would also require to remove the historically valuable 1980s render, as this is partly detached from the concrete underneath.

In the case under study, patch repairs are economical, but in large areas this solution is not recommended, as it is more time consuming and less suitable aesthetically than recasting.

Based on the above reported considerations, as the 1980s render must be removed in any of the scenarios, the most feasible option is to use concrete recasting. For recasting, the following procedure is recommended:

- The existing plaster and the contaminated concrete must first be removed, as recommended per CUR Recommendations 53 “Sprayed Concrete” and CUR 54 “Concrete repair with polymer-modified repair mortars”. This can be done with pressured water-jets (Fig. B.1-3).
- Once the existing concrete/plaster is cleaned, the new concrete can be shotcreted (Fig. B.1-4) or poured. The thickness of the new concrete render should be enough to provide 2 cm cover, measured from the most exterior part of the reinforcement, i.e., the stirrups. The connecting parts to window and door openings should be considered as well, as an increase/decrease of the wall thickness can affect the watertightness.
- The new concrete can be treated with a surface treatment to prolong its durability, but this must consider the requirements of compatibility, reversibility and retreatability. Among the different surface treatment options, in this case it is recommended to apply a hydrophobic treatment, as it reduces the moisture content in the concrete, while allowing normal carbonation. However, some considerations are to be taken; slight movements of the building can lead to cracks whereby the water can penetrate. In addition, the joints between the concrete elements and the rest of the components of the façade are so numerous that they can hardly be successfully treated. The risk exists that water can penetrate though these “weak points” and the water-repellent treatment could make a barrier effect to prevent drying of the wet concrete. Therefore, the recommendation is to apply a hydrophobic treatment that allows normal drying of the concrete.

Figure B.1-3. Jet blasting to remove carbonated concrete in the Fenix II.

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

Next to the solutions mentioned in the CONTECVET guidelines, it is interesting to discuss another technique, i.e., cathodic protection. Cathodic protection is based on switching the cathodic-anodic reaction in the reinforcement. By introducing a less noble material in the same electrolyte as the reinforcement, the steel is converted into the cathode and the new metal becomes the anode that will corrode. In the last decade, there have been great advances in this technology, using for instance induced electrical currents (by a power source) to increase the area of action, or using long-lasting metals, such as the titanium in anodes. The metallic anode may comprise by a mesh attached to the surface of the concrete. This mesh can be covered by the new concrete recast (Fig. B.1-4). This option guarantees that no corrosion will happen, as long as the cathodic protection is maintained. This solution is interesting if, for instance, the new recasting cannot provide a sufficient concrete cover. For the building under investigation, as a minimum concrete cover of at least 20 mm can be achieved, there is not a motivated reason to increase the cost with the installation and maintenance of cathodic protection.

B.1.2.2 Conclusion

Concrete conservation strategies should be developed by balancing the best practices for concrete repair, treatment and maintenance. Among them, **periodic maintenance and monitoring are essentia**l for prolonging the effectiveness of the conservation work and for sustaining the building [5]. It has been proven that a well-maintained building can last for over a century with no major intervention work [6].

B.1.3 Maintenance plan

A maintenance plan should include maintenance activities. For example, it should include the careful monitoring and maintenance of repairs, like patches, which are very often the weakest points where corrosion and other damage can occur. The maintenance plan should also include documentation and tools to implement it. According to the guidelines for concrete preservation of the Getty Conservation Institute [5], the maintenance plan should include, in addition to the maintenance activities, a pre-approved list of specialists (consultants and contractors), and a tool for recording the maintenance activities. As part of the maintenance plan, a monitoring plan must be included to inspect not only the repaired areas but also the surrounding parts [5].

In this section, the main aspects of the monitoring and maintenance plan are drawn for the Fenix II building. The recommendations given are oriented to furnish the basic concepts for a successful maintenance of this building in the coming years.

The first step in the decision-making concerns the reasons why cleaning may be 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 regarding 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), the cost 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 value (e.g., material loss and change in the geometry/relationship between different elements), or monumental value (e.g., authenticity) should also arise.

B.1.3.1 Monitoring plan for the Fenix II

1. **Inspections of state of conservation, focused mainly on repaired areas.** A basic inspection of the south façade must be performed at least every 5 years to detect visible types of failures. Visual and photographic inspection, possibly supported by some simple on-site measurements (such as measurements of crack width and movements, assessment of debonding by hammer sounding and thermal camera, etc.) is recommended. The common types of failures in concrete recasting are cracking and debonding. Initial cracking due to shrinkage (AKA crazing) can develop in the first weeks after installation. Cracking due to on-going corrosion is difficult to predict, as it depends on multiple factors (humidity, concrete composition, concrete cover, O_2 and CO_2 availability, etc.), but it can appear after approximately 5 years. Failure by debonding can happen a few weeks after the new concrete

is applied, mainly due to improper surface preparation. Debonding can also appear after a longer period of time, due to the expansion force of rebar corrosion. Debonding may not be visible, so other methods such as hammer sounding and thermal camera may provide a better estimation.

2. **Monitoring of corrosion**. Corrosion is the most likely damage to re-appear in the repaired areas of the Fenix II building. As most of the contaminated concrete has been removed and replaced by a new concrete recast, the use of embedded sensors to monitor corrosion is a feasible option. Sensors are able to detect the state of the steel inside the concrete, the main cause of the corrosion, as well as the evolution of the corrosion over time [7]. There are different types of sensors to monitor corrosion. The traditional ones are based on electrochemical techniques. The mass loss of corrosive reinforcement has a linear relationship with the voltage increment due to the variation of magnetic induction surrounding the corroded reinforcement [8]. The advantage of embedded electrochemical sensors is given by the possibility of assessing corrosion continuously, accurately and for long time periods [7]; this enables accurate measurement of the rate of corrosion and intervention at an early stage. The main constraints are linked to durability, sensitivity to electromagnetic interference and stability of the sensors over time. Open circuit potential (OCP) based sensors, for instance, are highly influenced by coated concrete surfaces and by humidity and concrete composition [9]. Other electrochemical sensors, based on electrochemical impedance spectroscopy (EIS), potentiodynamic and potentiostatic, also have limitations in the long term, such as instability of the pulse and underestimation of the corrosion rate [7].
   Fiber-optical sensors (FOS) (Fig. B.1-5) are a new alternative to electrochemical sensors developed in recent years. They are small, lightweight, robust, corrosion resistant, immune to electro-magnetic interference, highly sensitive, and can be tuned to detect different signals. They allow a continuous and permanent observation of the corrosion conditions [10], including strain, temperature, refractive index, concentration of chloride ions, and pH value [11]. The FOS, as most of the sensors, are wired and connected to a data logger. The wiring can have a visual impact (see Fig. B.1-5), although the sensors may be inserted inside the new recasting concrete.
   A more recent field of exploration is the micro-electrochemical systems (MEMS) for RC monitoring. MEMS technology has the potential to measure the properties of corrosion inside the concrete [12]. However, MEMS are still in the early stages of development.
   In the case of the Fenix II, a FOS system seems to be the most suitable option. The installation of FOS can be embedded in the new recast concrete and may be connected into a data logger connected to the energy supply of the building. This system will allow tracking of the corrosion process and anticipated remediation actions before more severe damage occurs.

Figure B.1-5 Installation of optical sensors in a bridge.

Source: https://www-smartinfrastructure.eng.cam.ac.uk/news/fibre-optic-sensors-installed-m6-concrete-bridge-part-csic-multi-sensing-systems-integration

B.1.3.2 Protocol for periodic maintenance activities.

Protocol for periodic maintenance activities.

i. **Façade cleaning**. This will remove aesthetical stains, soiling and/or biological growth, and ease the visualization of small cracks and other damage.
Action: Cleaning of the façade with low pressure water jets to remove soiling and biological growth.
Periodicity: Every 10 years.

ii. **Gutter cleaning**. The roof only drains by the south side of the building, so these gutters should remain clean (e.g., from leaves and dirt) to allow for proper drainage of rainwater and for preventing run offs. Preventing water run offs over the façade will reduce the water content on the exposed concrete.
Action: Clean roof gutters for a good drain and to avoid water ponding and overflow.
Periodicity: Yearly.

iii. **Surface treatment**. Maintenance of the surface treatment, such as of the water repellent on the façade, according to the prescription of the manufacturer. If patch repair has been done or cracks have been repaired, these parts should be treated as well.
Action: Re-apply surface treatment according to the manufacturer directions. Prior removal of the existing treatment might be necessary, depending on the type of treatment/coatings.
Periodicity: Refer to manufacturer directions, typically after 10 years.

iv. **Carbonation depth check**. The newly casted concrete is to be checked to control the rate of carbonation. With these checks, it can be predicted when the carbonation front can reach the reinforcement, and therefore when corrosion may take place.
Action: 10 mm diameter drills in 5 mm steps to a maximum depth of 40 mm. Collect powder and spray with phenolphthalein to check for carbonation. Select at least 10 locations in exposed columns and beams.
Periodicity: Given the thickness of the new concrete (over 20 mm), a single check every 10 years should suffice.

B.1.3.3 List of specialists

Company requirements. Maintenance should be performed by a specialized company in concrete restoration and maintenance. Any repairs must be carried out by a certified company in concrete repairs having the accreditation BRL 3201 (in the Dutch territory) or equivalent.

B.1.3.4 Record of maintenance activities

In some countries, like Spain, a building book is required by law for any new or restored building[1]. In this book, the repairs are noted, specifying dates, companies, as well as products and materials used. In the Netherland, such a book is not required by law, but its use is recommended. Currently, there are different online platforms that offer a digital version of this book, as part of the overall building management. Another option is to have a hard copy maintenance book in the building itself.

B.1.4 Extreme event assessment

B.1.4.1 Understanding the building structure

The building geometry in its current configuration is as follows: 154.8 m long (east-west direction), 47.35 m wide (north-south direction), 15.85 to 17 m tall (as the flat roof slopes towards the south).

[1] Ley 2/1999 del 17 de marzo, de Medidas para la Calidad de la Edificación

The building has two floors (Fig. B.1-6). There are expansion joints every 6 bays, thus every 51.6 m. The building structure comprises of a column and beam frame with one-way slabs. There are no interior shear walls. The distance between the girders (running north south) is 8.6 m, the distance between the columns in the same direction is 10.11, and 10.24 m in the south and north bays, 13.5 m in the two interior bays. The floor beams running east-west are spaced between 3.4 to 4.5 m, depending on the length of the main beams connected to them.

At the moment of the design and construction of the building (1916-18), the development of Dutch building codes was still in its infancy. Each city had its own regulations; these were often copied from each other and were often based on German codes. At that period, the buildings constructed in the Netherlands were very often low-rise with heavy masonry bearing walls. Thus, horizontal (wind) loads were often neglected, as they did not have a great impact over the structure. The first official Dutch code specifying wind loads was the N 790, published by KIVI in 1933.

Due to the absence of interior shear walls and the non-structural character of the façade walls, the stability of the building against lateral forces relies on the rigidity of the connections between beams and columns. The main beams (running north-south) increase their section at the connection with the column (Fig. B.1-7). This higher thickness at the ends of the beam increases the rigidity of the connection. The moments and forces derived from lateral forces are transferred from the floor beams to the columns. On the other direction, east-west, the floor beams (secondary beams) also have this increase of section at the ends. In this sense, any lateral forces in the building will be transferred first to the floor slab that acts as horizontal diaphragm. The floor distributes the load to rigid elements connected to it; in this case, to the beams and from there to the columns.

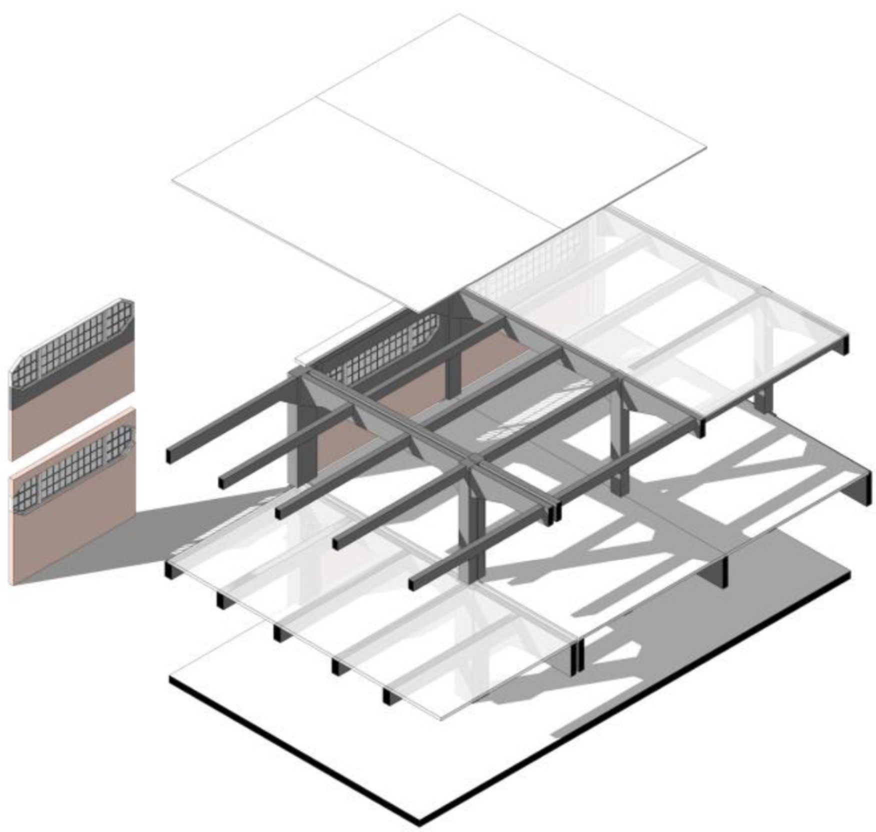


Figure B.1-6. Axonometry representation of a representative part of the building structure. Source: Final work in the course AR0141 CSI – Heritage Conversation, Survey, Investigation of the Built heritage. Authors: Mingyu Kim, Jonathan Connerney, Saskia Tideman, & Cher van den Eng.

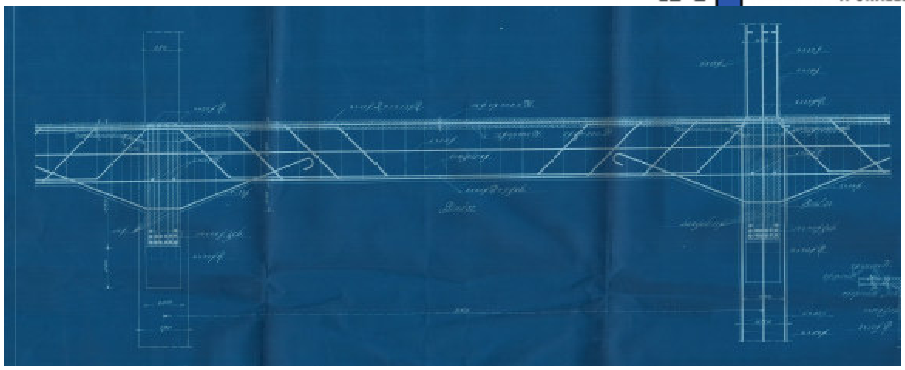


Figure B.1-7 Typical main beam from the original structural drawings (1916).

In the original structural calculations from 1916, there is no evidence of lateral forces taken into account, whether wind, floods, or seismic loads. The plans show only uniform forces - the *eenzijdige belasting* (uniform load) for the *moerbinten* (main beams) (Fig. B.1-8). The formulas reveal that this load results from gravity loads acting on the main beams.

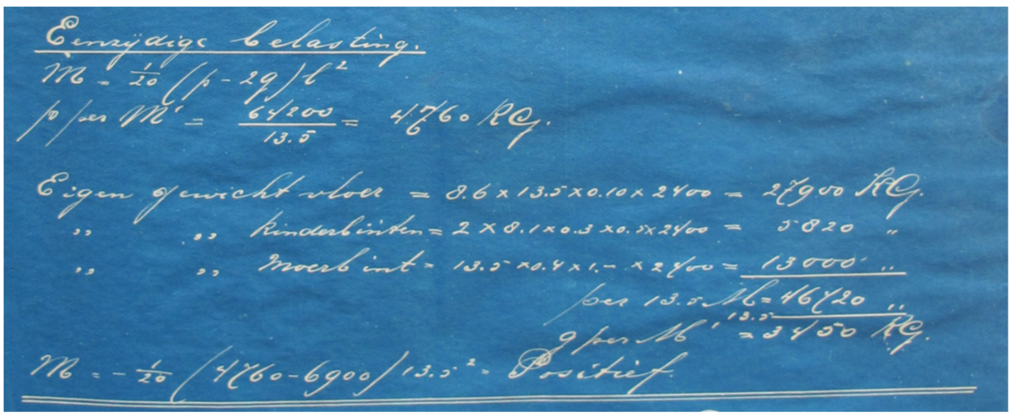


Figure B.1-8 Extract of the original structural calculations (1916)..

It is therefore assumed that horizontal loads were not considered when designing the structure. However, there is a question that remains unclear: what were the parameters considered during the design of the building to achieve its structural stability? The answer may be in the dimensions of the building and its elements.

B.1.4.2 Load and structural analysis

The building comprises of three independent buildings, separated by expansion joints. Each of these sub-buildings measures 51.6 m x 47.35 m x 17m (b x l x h); this results in a slenderness (ratio between height and width) of 17/47.35 or, in other words, close to 1/3 (0.33). That is a very low slenderness ratio. A structural stability principle is that any building structure with a slenderness ratio lower than 1 is by definition stable (e.g., the great pyramid of Gyza has a slenderness ratio of 0.5). However, that does not mean that in the event of a high lateral impact load, the structure will remain stable. Its stability will depend on how the forces are distributed within the structure and whether each affected component will be able to carry the corresponding forces.

In the following paragraphs, the risks for the stability of the structure due to horizontal loads, as an effect of floods, are discussed.

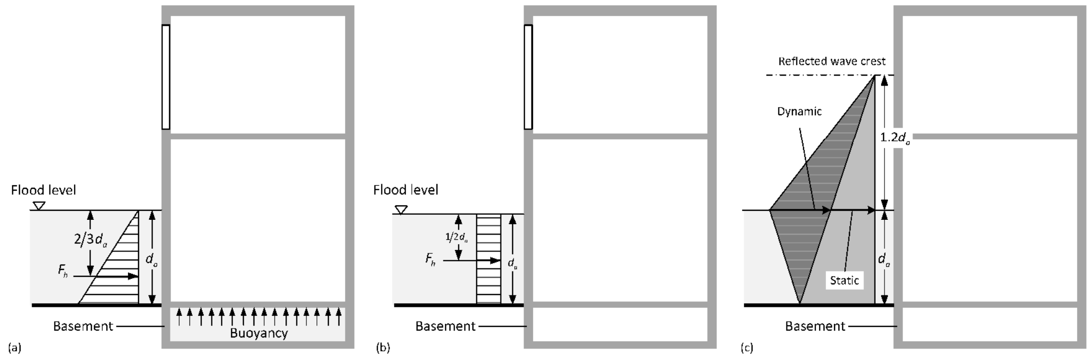


Figure B.1-9. Schematic understanding of flood loads in buildings. a) Hydrostatic load pressure, b) Hydrodynamic load on buildings; (c) Horizontal breaking wave impact load on the external wall. Retrieved from: [13]

According to the Authority of Rotterdam[2], the sea level is expected to rise up to 85 cm by 2.100. The same authority also argues that the port of Rotterdam will not be affected by this rise thanks to the dike infrastructure and the storm surge barriers. For the purpose of this investigation, it will be assumed that the dikes and storm barriers can eventually fail. The current building elevation at the ground floor is 2 m above sea level. The tide can vary about 2 meters[3]; therefore, it can be assumed that the rise in sea level can impact the building. For the sake of this investigation, a flood level of 1 meter above the ground floor is considered (in fact, this should be 0.85 m, but 1 meter is more conservative).

There are three types of horizontal loads derived from floods:

- *Hydrostatic load*: (Fig. B1-9a). It is the load pressure of static water against a vertical surface. This load has a triangular distribution, being 0 at the top of the level reached by water and maximum at the base. Buoyancy is the upward hydrostatic force acting on the bottom side of a submerged object, in this case the base of the building.
- *Hydrodynamic loads* (Fig. B1-9b): Hydrodynamic loads derive from the combination of inertia and drag and generally depend on both the kinematics of the flow and the geometrical and dynamic characteristics of the structure [14]. These loads have an even distribution along their height. The equation to calculate them is:
  $F_h = ½\ C_D*Ro*h*u^2$
  Where h is the water depth at the structure, u is the intensity of the velocity component orthogonal to the structure, and C_D is the drag coefficient, which varies depending on both the structure geometry and the local flow conditions.
- *Wave-induced loads* (Fig. B1-9.c): This type of load derives from waves impacting on the vertical surfaces; it depends on factors such as the building geometry and the surrounding terrain. This type of load occurs in offshore constructions, within a few hundred meters from the coastline. In the case of the Fenix II, where the coastline is about 30 km away, this type of load is very unlikely to occur. Therefore, it is dismissed for this analysis.

Taking into account the above references, the hydrostatic load acting on the building walls is at its peak <u>997 kg/m^2</u>, the buoyancy is equal to the maximum hydrostatic load, 997 kg/m^2. The hydrodynamic load equals to <u>498.5 kg/m^2</u>, assuming a high flow velocity of 1.0 m/s, as per the data obtained by [15]. The **flood load** pressure in the structure results in a total applied force of **997 kg per**

[2] https://www.portofrotterdam.com/en/building-port/safe-port/flood-risk-management
[3] https://waterinfo.rws.nl/#!/thema/Waterveiligheid/

linear meter applied at 0.5 m from the ground, creating an **overturning moment (OM)** on the building of **498.5 kgm/m**.

Before analysing the whole structure for hydrostatic loads, other horizontal loads that have been applied to the building until now are assessed. Then, by comparison it can be assessed whether the flood loads may be higher, thus requiring a more intensive analysis.

Rotterdam is a windy city, especially near the waterfront, as indeed is the case of the location of the Fenix II building. According to EN 1991-1-4:2005, the basic wind speed for Rotterdam is 30 m/s, resulting in a wind pressure on the walls of approximately 145 kg/m^2 [13]. As the wind is applied to the entire height of the wall, i.e., 17 m, that results in a horizontal **wind load** of **2,465 kg/m applied at 8.5 m above the ground**, creating an overturning moment of 20,952 kgm/m.

The wind load (2,465 kg/m) to which the building has been subjected until now without problems is almost 2.5 times higher than the load derived from the flood (997 kg/m). In addition, the wind load is applied to a higher elevation, which causes a higher overturning moment in the structure (i.e., 42 times higher than the overturning moment caused by the flood loads).

Both loads, wind and flood, can occur at the same time, but it does not make a big difference in terms of the global stability of the structure. In this scenario, the wind load cannot be applied to the surface the flood is happening. Even though the distributed flood load is higher than the wind load, the lower location of the force minimises the effect of the resulting overturning moment on the overall structure. When comparing overturning moments, the OM of the flood loads is about 2% of the OM of the wind load, therefore it is not significant.

Regarding the buoyancy loads (997 kg/m^2), the upward force produced is typically counteracted by the weight of the structure. The current structure, with floor slabs between 15 to 20 cm thick, has an estimated weight of 1,700 kg/m^2. Applying a safety coefficient of 0.6 to the weight, results in buoyancy loads which are not enough to lift the structure (1,700 * 0.6/997 = 1.02).

Based on the aforementioned, it can be concluded that the global structure of the Fenix II building is expected to remain stable in the case of a flood event. Particular areas, such as the wall of the ground floor, may require a more specific analysis to confirm that no local failures would occur.

B.2 ITAM

B.2.1 Restaurant of the Štvanice Winter Stadium

The former restaurant building of the Winter Stadium at Štvanice island went through several transformations during its 90 years of existence. Although this modernist building has been listed as an immovable cultural monument (catalogue number 1000163277_0002) since 2000, previous adaptations affected its original appearance, and its technical state is unsatisfactory. The east and south facades with large stripe windows were its original design's most significant architectural elements [16,17]. This study aims to describe and investigate the structure of the lintel walls framing these windows, which are unusual for their architectural and structural design, and to outline aspects to consider in their restoration.

B.2.1.1 Brief description of the south and east facades

The current state of the building follows various interventions and renovations made during the past 90 years (Figures B.2-1 and 2). The windows on the ground floor of the south and east façades were recently blinded with plywood boards. A steel structure gallery was built in the interior space between the east and south windows during the conversion of the space into a music club in the 1990s. Figure B.2-3 shows the location of the gallery in the building's cross-section.

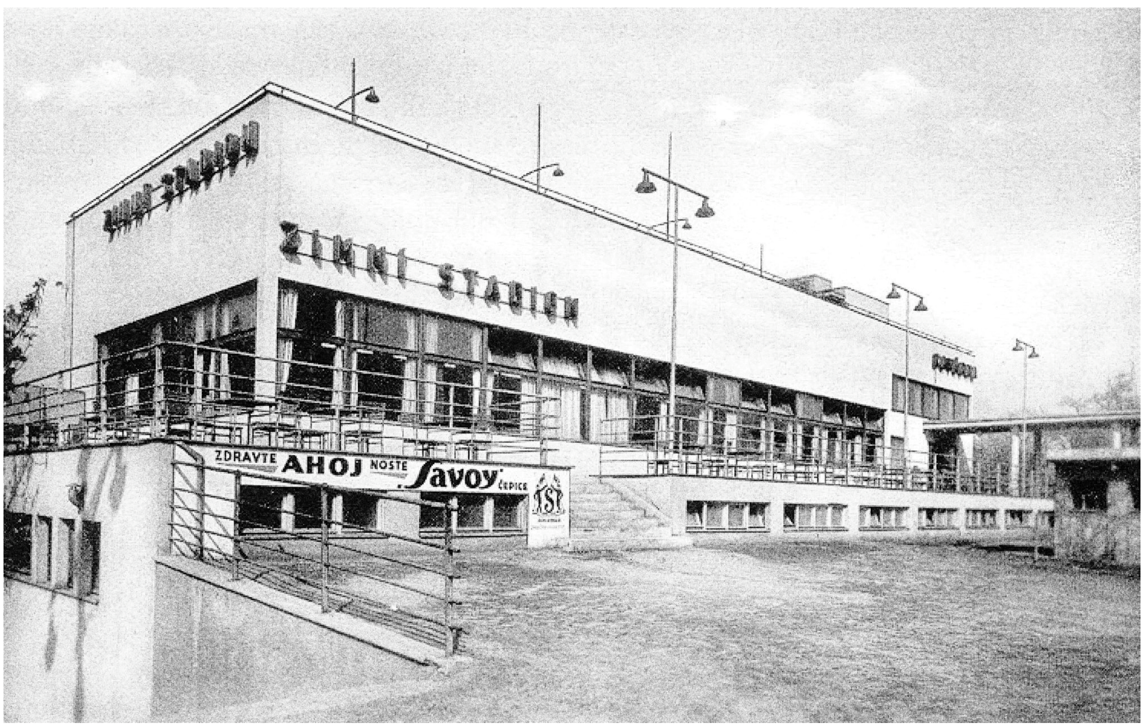


Figure B.2-1 Original state in the 1930s.

Figure B.2-2 View of the main façade of the Fuchs restaurant (photo taken on 15. 9. 2019).

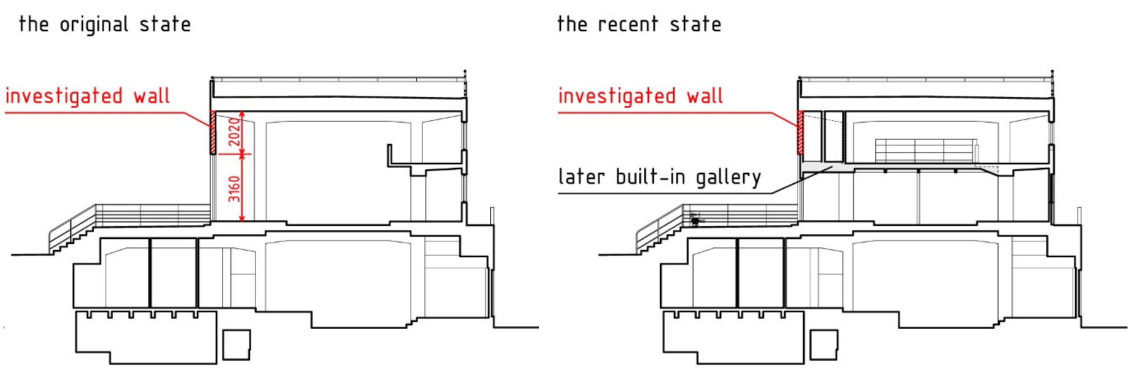


Figure B.2-3 Cross-section, original and current state.

The original layout of the façades and of the interiors was altered in 1949, following the re-organization of the stadium facilities. A new entrance was opened in the middle of the main façade, and the stripe window was divided with columns defining the new door. The window's width on the south façade was also reduced with brick infills.

Originally, the stripe windows on the ground floor measured 26.80 m (east façade) and 9.23 m (south façade) in width, with an equal height of 3.16 m (Figure B.2-4); these two windows were divided by a corner column measuring 230 x 380 mm.

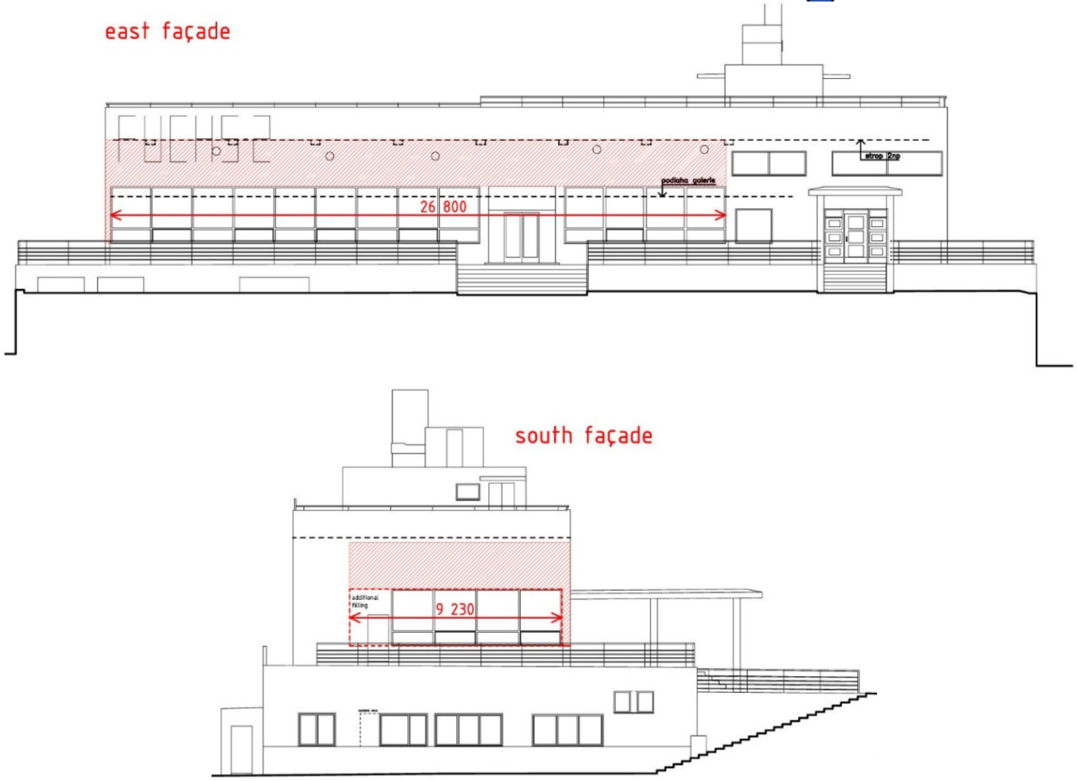


Figure B.2-4 East and south façade (current state) showing the original span of the lintel walls (marked in red).

The original design of the façades played an important role in the building's architectural expression. The architectural language of the building exteriors moves away from the traditional tectonic system (grid of load-bearing elements) towards maximal lightweightness and free composition of the envelope openings.

The restaurant interiors were initially designed as an open space, reaching two-floors in height (5.35 m), with a gallery attached to the west façade. The space was lit by two superposed stripe windows situated on the ground floor and the gallery of the west façade opening to the ice rink. Two other stripe windows were placed on the ground floor level of the east and south façades, opening to the terrace and the access from the nearby bridge level (Figure B.2-5). The principal load-bearing structure of the building (reinforced concrete frame with two rows of columns, Figure B.2-6) is detached from the façade and situated in the interior; the distance between its columns and the envelope wall is 1.64 m. This configuration means that there was a 2.20 m high lintel wall above the stripe windows, with no support elements below, except for the slim corner column (230 x380 mm, Figure B.2-7).

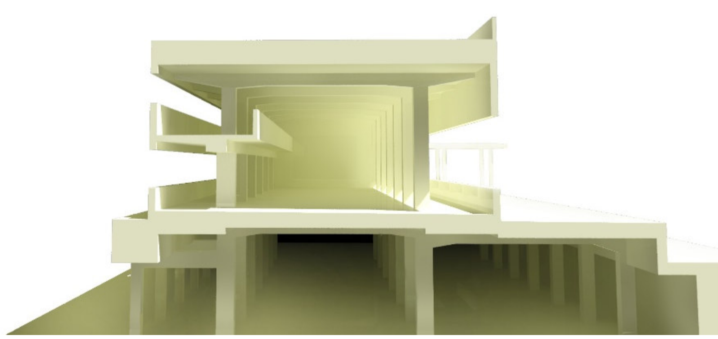


Figure B.2-5 Original spatial layout of the restaurant.

Figure B.2-6 Ground and first floor plans with the studied windows and lintel walls marked in red.

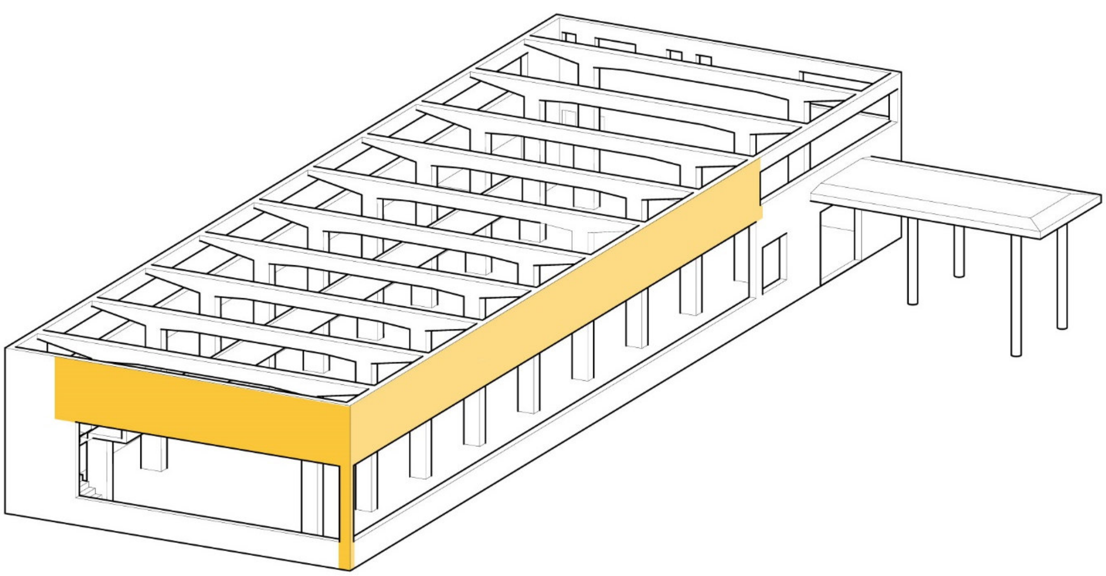


Figure B.2-7. Original span of the lintel walls.

The structure of the lintel walls is remarkable, because it is solely founded on the demands of architectural expression; the significant architectural elements of the modernist era were transformed into a reinforced concrete structure without compromise.

Although the stripe windows were among the typical architectural elements of the interwar avantgarde architecture, the Fuchs case differs from the common forms of this element. Therefore, stripe windows and lintels of large span can be found on many buildings of the 1930s and 1940s in Czechoslovakia [16,18–20] (Figure B.2-8). However, the usual height of the lintel between the top of the window and the ceiling oscillates from 0.3 to 0.8 m. In this case, the lintel walls reach a height of 2.02 m due to the unusual concept of the interior space. The span (26.80 and 9.23 m) also stands out from typical architectural production.

Figure B.2-8. Examples of the late 1920s and 1930s Czech architecture with stripe windows.

B.2.1.2 General considerations

Within the last decade, the Fuchs has been the subject of an investigation focusing on the technical condition of the building, as well as on its history and heritage values; these studies were conducted to support a restoration project. The original documentation on the building has not been preserved, but there are a few relevant documents [21,22]; the main drawings though are missing. A digital survey of the building [23] was made in 2015.

The original structures are distinguished from later interventions in the construction history survey [21,22]. These highlight the valuable architectural details and their similarities with other buildings by the same architect (e.g., the handrails of Veletržní Palác in Prague).

The technical survey [24] revealed the reinforcement of the principal elements of the original load-bearing structure (i.e., the columns, the beams, the floor slabs). The material analysis of the structural concrete revealed that its quality and composition are not stable and vary in different parts of the structure, independently of the structural element type (i.e., similar structural elements are made of different (not very high) quality concrete mixed on site). The composition of the flat roof is also described. The technical state of the building has been declared as very poor. The most severe damages were detected in the ceiling structure, which is composed of a reinforced concrete slab and ribs between the elements of a permanent ceramic formwork. Water infiltration via the terraces into the roof structure caused the disintegration of the ceramic components and exposed the ribs and their reinforcement.

A study on the structural and technical aspects of the restoration [25] was also performed. The study involved a simple structural assessment [26], i.e., the calculation of the capacity of three spans of the main frame, based on the findings of the technical survey. The assessment concluded that the structural stability of the examined part of the building was satisfactory but close to the limits of its load-bearing capacity. The data obtained in this study were taken into account in a feasibility study [27] outlining the building restoration and its adaptation to a café and sports equipment rental.

During the preliminary archive investigation for the present report, a fragment of the execution documentation (formworks drawing of the upper floor, dated 1932) was found in the Construction Agenda Archive of the Prague 7 Municipal Office (Figure B2-9).

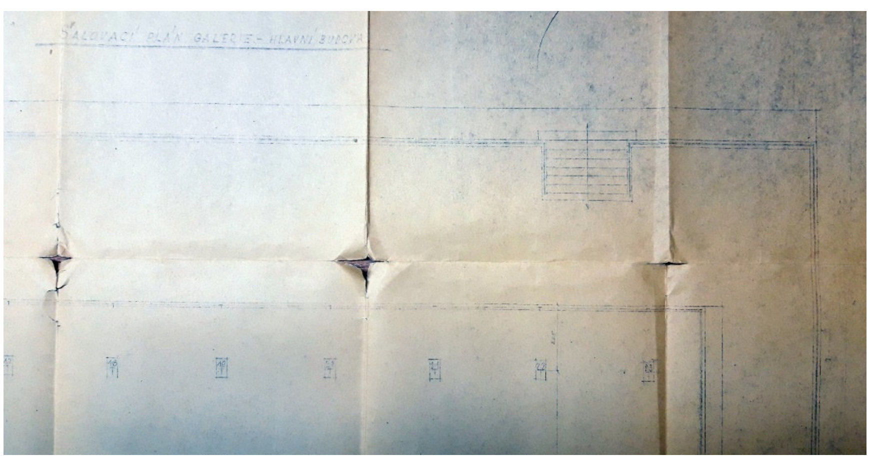


Figure B.2-9. Drawing with a detail of the formwork drawing of the upper floor (1932).

The visual inspection of the building brought new information on the structure of the lintel wall. Its composition is revealed in six perforations (perimeter circa 400 mm) made into the east façade during the last intervention to install the ventilation system (Figure B2-10). The wall consists of exterior plaster, 120-150 mm of reinforced concrete, 45 mm of insulation, and 45 mm of additional concrete layer and plaster on the interior side. Both the horizontal and vertical reinforcement bars are visible in the section through the main concrete layer.

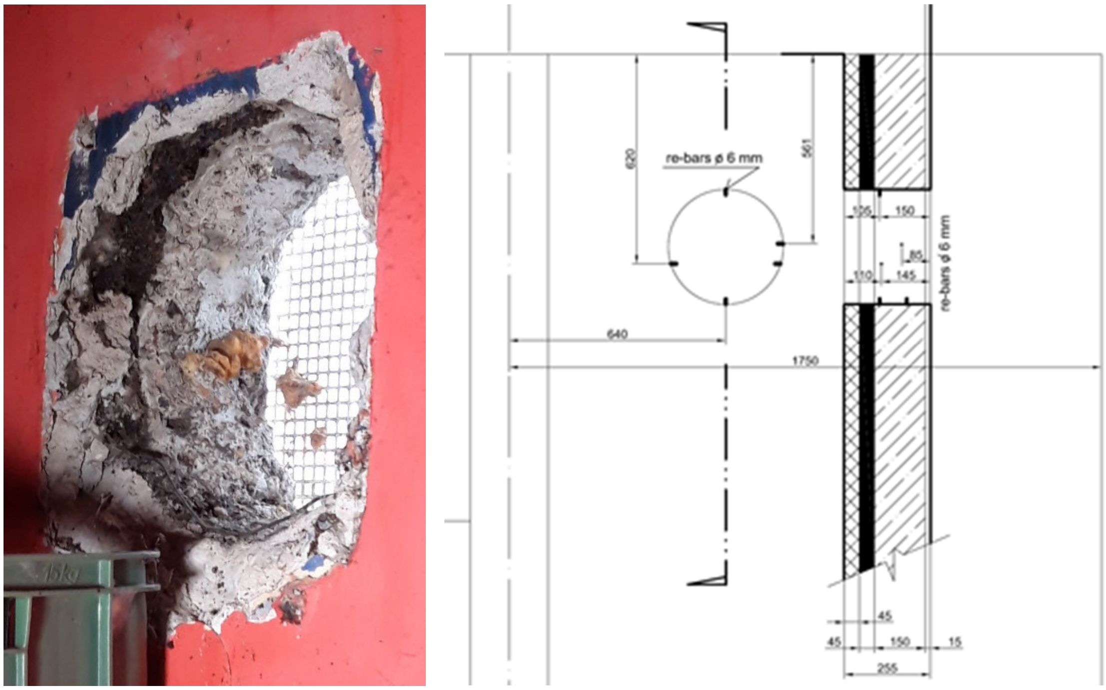


Figure B.2-10. Detail of the ventilation hole on the lintel wall and cross-section drawing of its layout.

B.2.1.3 Restoration concept

The present restoration concept is based on the aforementioned architectural studies [27] and previous research studies [21,22]. The restoration of the stripe windows on the east and south façades is necessary for the restitution of the original spatial concept of the restaurant's interior; it is also crucial for the restitution of the original expression of the 1930s exteriors.

The architectural study aims toward the restoration of the building's original state. However, there are no sources documenting the original state of the building interiors: the original spatial concept is easy to be reconstructed, but the historic interior refurbishment remains unknown. Additionally, the radical transformation of the surroundings can pose issues on the idea of the original state restoration:

1) The central part of the original complex (the ice rink) is missing. During decades, it underwent many interventions and it was finally demolished in 2011.
2) The nearby bridge was enlarged to double its original width and became part of the principal north-south cross-city express road, with a daily frequency of up to 100 thousand cars. Due to these factors, the lower floor of the building, which is open to the island level, recently became more appealing.

B.2.1.4 Structural risks related to the restitution of the original state

B.2.1.4.1 Removal of the later added elements (columns and infills)

The span of the window on the south façade has been reduced with a brick infill. The window on the east façade was divided by two columns marking the new entrance during the reform in 1949. The ageing of the original structure may have undergone deformation (deflection) and a slight decrease (in the 0.1 mm scale). Although the later added elements were not intended to have a load-bearing function, the original structure may rest on these elements with part of its weight. If the later-added elements are removed, cracks may develop via additional deflection of the original structure.

Therefore, the connection areas between the original and the later added elements should be inspected before considering their removal.

B.2.1.4.2 Restitution of the stripe windows

If replicas of the original windows are installed, their stability must be assessed. The position, number and shape of the anchoring elements must be designed, considering the quality of the 90-year-old concrete and the distribution of its original reinforcement. The 2.35 m high wooden window frame would be anchored to the lintel, and the horizontal wind load on the window would be transferred to the anchoring points. The composition of the lower edge of the lintel wall is unknown; the thickness of the reinforced concrete layer is supposed to be 120 mm, but the lintel edge can also extend to the thickness of the entire wall (240 mm).

Besides the new insulation layer and plaster, other elements should be fixed to the east façade: the neon lights on the south and east façades would require anchoring to the lintel wall. The positions of the reinforcement and the thickness of the wall must be considered. The anchoring may also cause thermal bridges, leading to water condensation inside the wall's structure.

B.2.1.5 Additional insulation

The application of additional insulation will be necessary if the operation of a restaurant during the entire year is intended in the future. Although heritage buildings lose part of their authenticity with additional insulation, heritage protection authorities have found it tolerable in other cases (e.g., Lída Baarova House, Palička House, Edison Transformer Station in Prague).

Particular aesthetical criteria must be considered concerning this intervention; the dimensions of the insulating elements (e.g., the thickness of the corner column, the layout of the window edges), and the position of the original steel handrail of the attic (if 150 mm of an insulation layer is applied, the handrail would have to be placed deeper). The choice of the plaster, the treatment of its edges, and the exterior paint should also be selected in line with both heritage protection and technical criteria. Changes in the structure's physical properties (water permeability, condensation inside the structure) connected with the application of the insulation and with its anchoring must further be considered.

Local thermal bridges are also an issue to be considered. Anomalies caused by thermal bridges can occur in the connection areas of the uninsulated elements and the insulated envelope. Some of the original elements standing out of the insulated envelope (e.g., the reinforced concrete slab of the entrance porch) are supposed not to be insulated, primarily due to aesthetical reasons (increment of the slab thickness). The anchoring of newly installed elements (e.g., neon lights) can cause similar effects.

B.2.1.6 Acknowledgements

The authors are thankful to Prof. Miloš Drdácký for his valuable assistance and comments.

B.2.2 Barrandov swimming stadium diving tower

B.2.2.1 Introduction

This report focuses on the conservation of the diving tower of the Barrandov swimming stadium (designed by architect Václav Kolátor in Prague). The structure of the swimming stadium and, in particular, the diving tower is one of the brightest examples of interwar Czechoslovak architecture dedicated to sports.

For decades, the site and the swimming stadium have been left without maintenance. Therefore, the stadium, including the diving tower, has deteriorated, and its future remains unclear. No renovation or rehabilitation project has been planned. The possibility of deterioration to the point of complete loss of the structure is not improbable.

B.2.2.2 Aim and objectives

The aim of this study is the conservation of the Barrandov diving tower. To achieve this aim, the following objectives have been defined:

i) Conservation via documentation of the structure;
ii) Understanding of the materials and damage processes;
iii) Definition of heritage values;
iv) Approaches for the conservation of the structure.

B.2.2.3 State of the Art

The swimming stadium *pod Barrandovskými Terasami* has been the subject of several research studies. The stadium complex has been listed as a cultural monument, together with the restaurant *Barrandovské terasy* located at the top of the cliff above the swimming pool (catalogue no. 1000156754). Unfortunately, the protection of this monument and of many others was deemed invalid by the Supreme Administrative court in 2020, due to a "legislative gap", and the complex has lost the status of a cultural monument. A new registration proposal has already been submitted.

The complex continues to be under protection as part of the Barrandov Heritage Zone (catalogue no. 1000084407), encompassing the interwar development of the Barrandov district. However, the zone protection has a lower grade and does not guarantee the protection of unlisted buildings from demolition. The National Heritage Institute prepared the documentation of the Barrandov district and its protection status and conditions during the registration process.

Turjanicová made the most detailed architectural study of the Barrandov swimming stadium in her thesis on the Architecture of the Swimming Pools and Baths in Interwar Czechoslovakia [28]. The results of this author's research were published in an anthology on the architecture of sports in the Czech lands [17], which aided in defining the protection status of the site.

The structure and its architect are also recalled in older works, e.g., in the catalogue exhibition on Czech functionalism 1920-1940 by Vondrová [19] and in the Czech architectural avant-garde by Nový [20].

B.2.2.4 Investigation of the diving tower

B.2.2.4.1 History: archival survey

There are different versions of the detailed structural calculations of the diving tower. These were presented in three sets of documents: two simple folders and one (probably the final version) bound in a paper cover (Figure B.2-11). The dimensions of the stairs missing in the executive drawings are mentioned in the calculations. The intended dimensions of the steps were 60 cm in length, 25 cm in width on the outer side, and 10 cm on the side attached to the pillar.

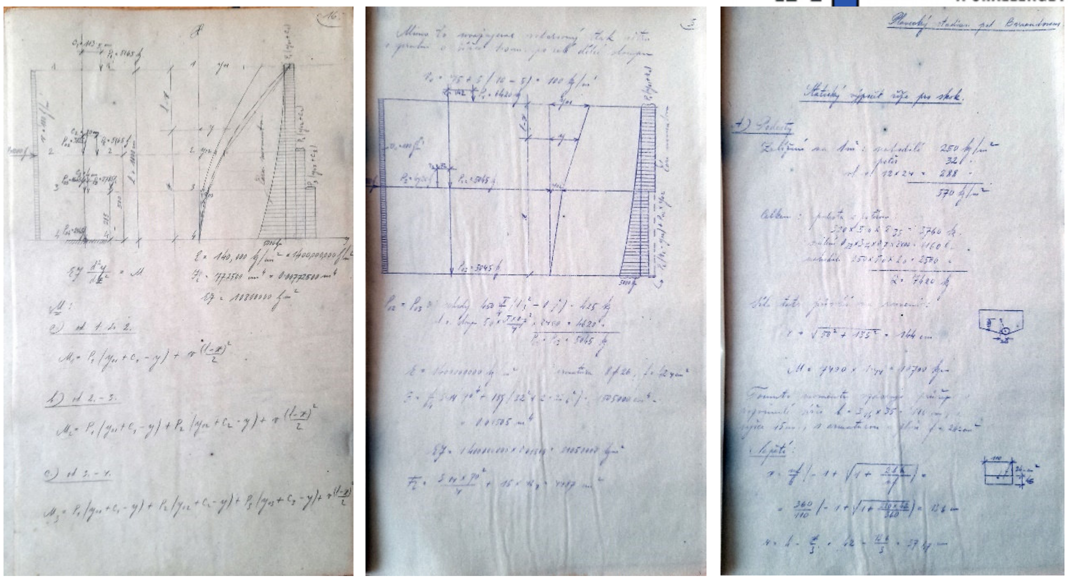


Figure B.2-11. Pages from the structural calculation reports.

The executive drawings contain the plan of the reinforcements of the diving tower foundations (Figure B.2-12), the plan of the formworks, and the reinforcement of the diving tower (Figure B.2-13). The geometry of the tower, the pillar, and the platforms are well described, including the detailed dimensions of the organic-shaped bottom sides of the platforms. The drawings do not include the spiral stair; this is only mentioned in a note:

"L-shaped holes shall be cut into the formworks of the pillar corresponding with the shape of the steps. Two steel L-profiles 35/50/6 shall be installed into each of these holes before casting the concrete pillar."

In one of the copies of the plan of the formworks and of the reinforcements, the handrail is hand-drawn, and the positions of the handrail poles are marked.

The aforementioned documents comprise part of a proposed budget, so there is no evidence that the works were actually executed according to these documents. Nevertheless, the description of the materials' composition and of the surface treatments are a precious supplement to this study. They have been considered in interpreting the analyses performed in this work.

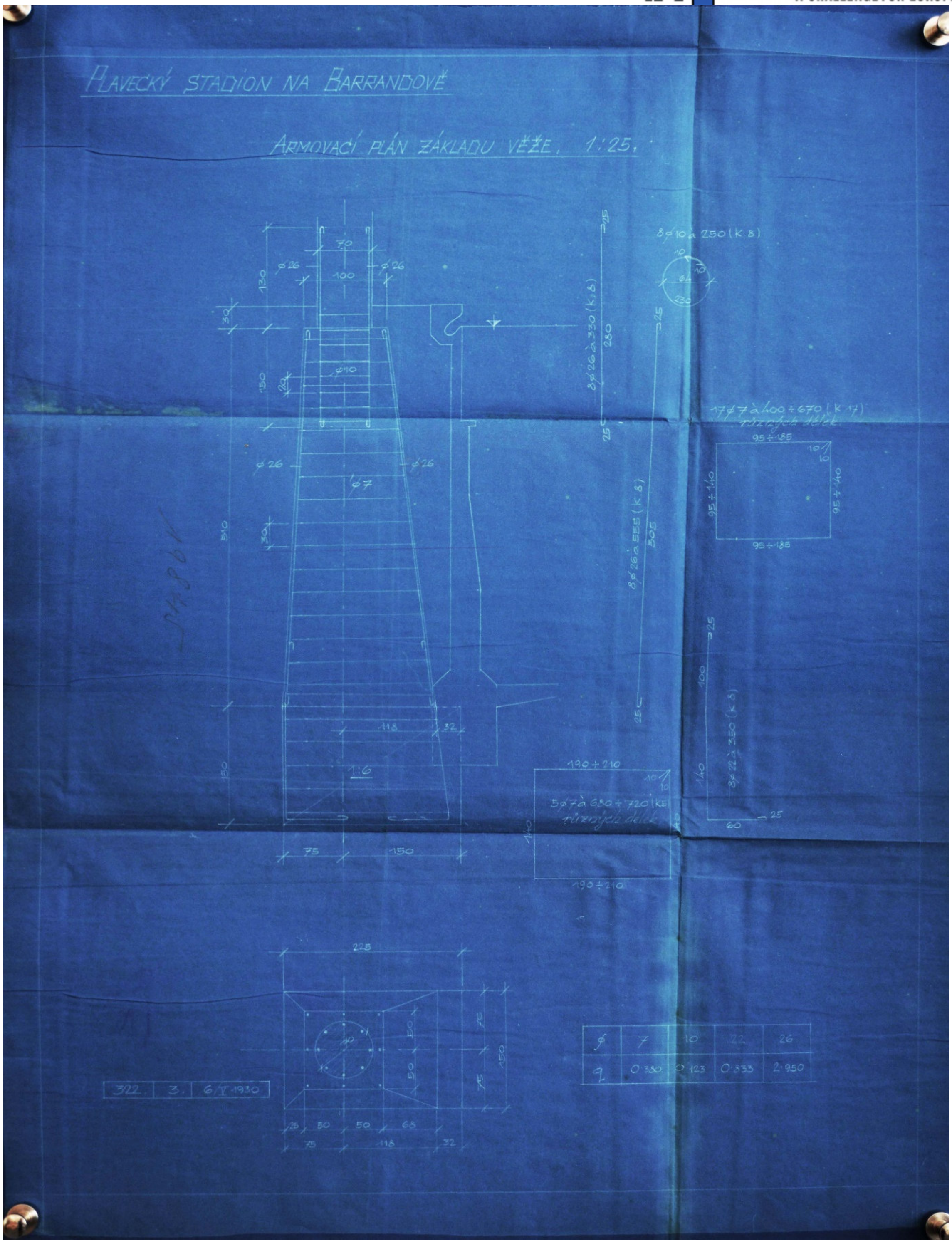


Figure B.2-12. Plan of the reinforcement of the diving tower foundations in scale 1:25.

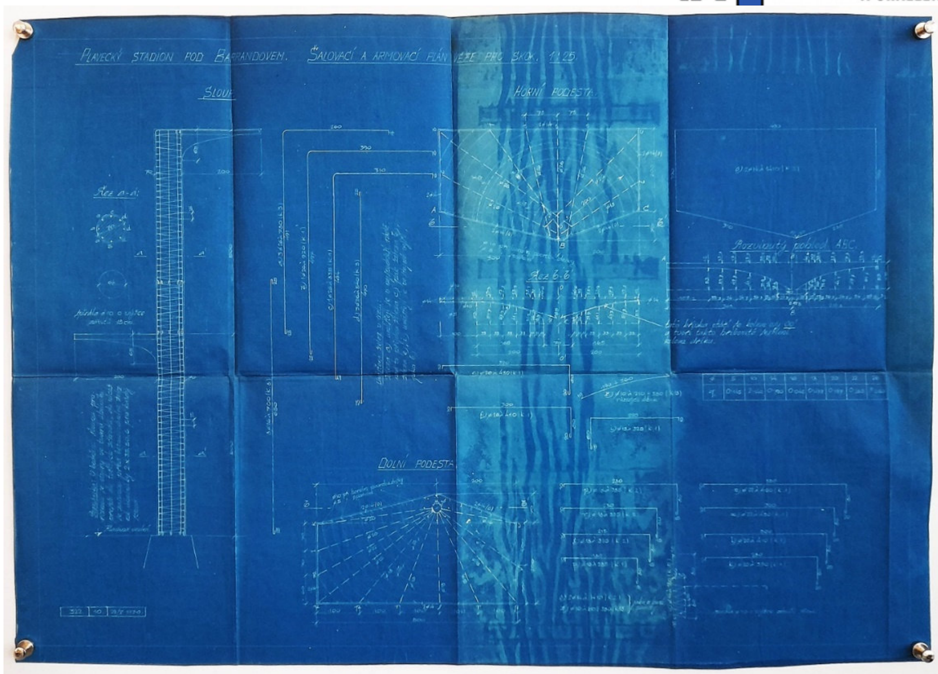


Figure B.2-13. Plan of the formworks and reinforcement of the diving tower in scale 1:25.

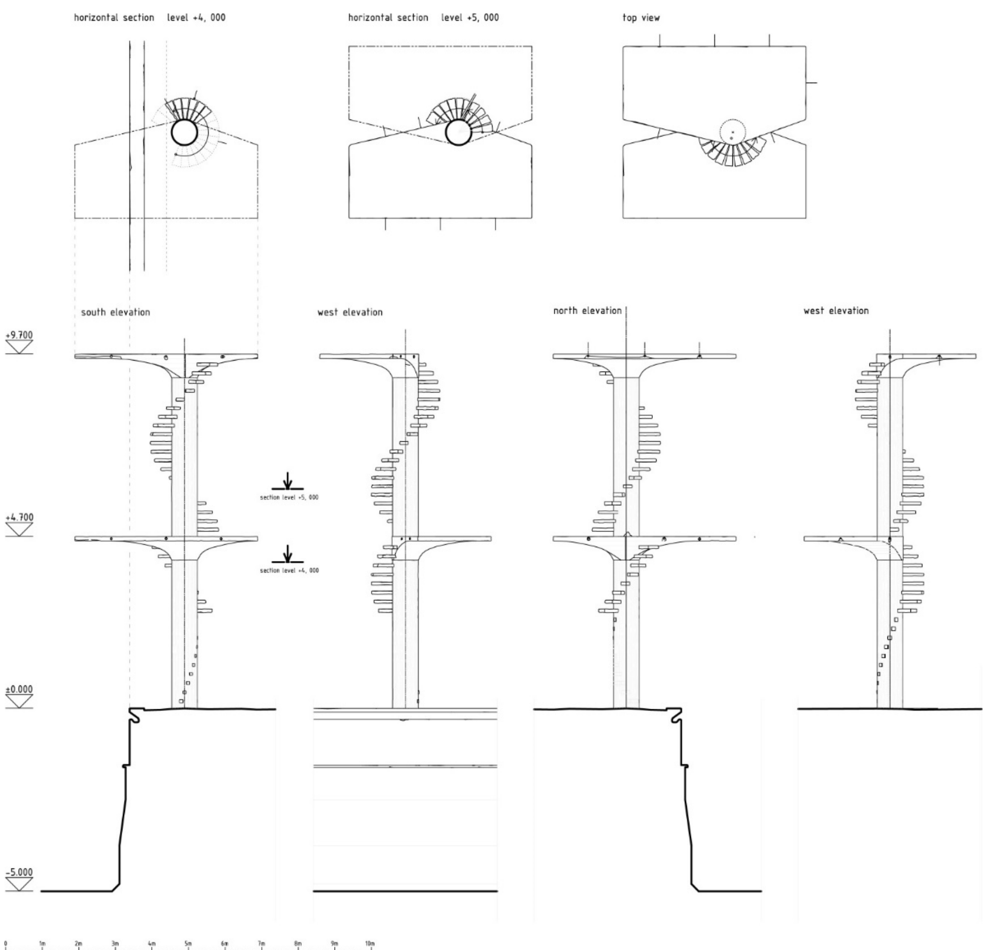


Figure B.2-14. Drawings of the recent state.

B.2.2.4.2 Documentation of the recent state

A drone was used to take photographs of the inaccessible parts of the structure. The photos were used as input to produce a close-range photogrammetric model (point cloud). Conventionally measured dimensions and historical plans and documents were used to make drawings of the current state (Figure B.2-14).

B.2.2.4.3 Description of the damages

The visual inspection of the structure was performed on 21.7.2020, when vegetation was flourishing (Figure B.2-15a) and on 27.2.2020 when the surrounding vegetation was naked (Figure B.2-15b). The description of the damage types was done according to the MDCS atlas [29]. Figure B.2-16 shows the south elevation drawing of the tower with the indication of the main damages observed.

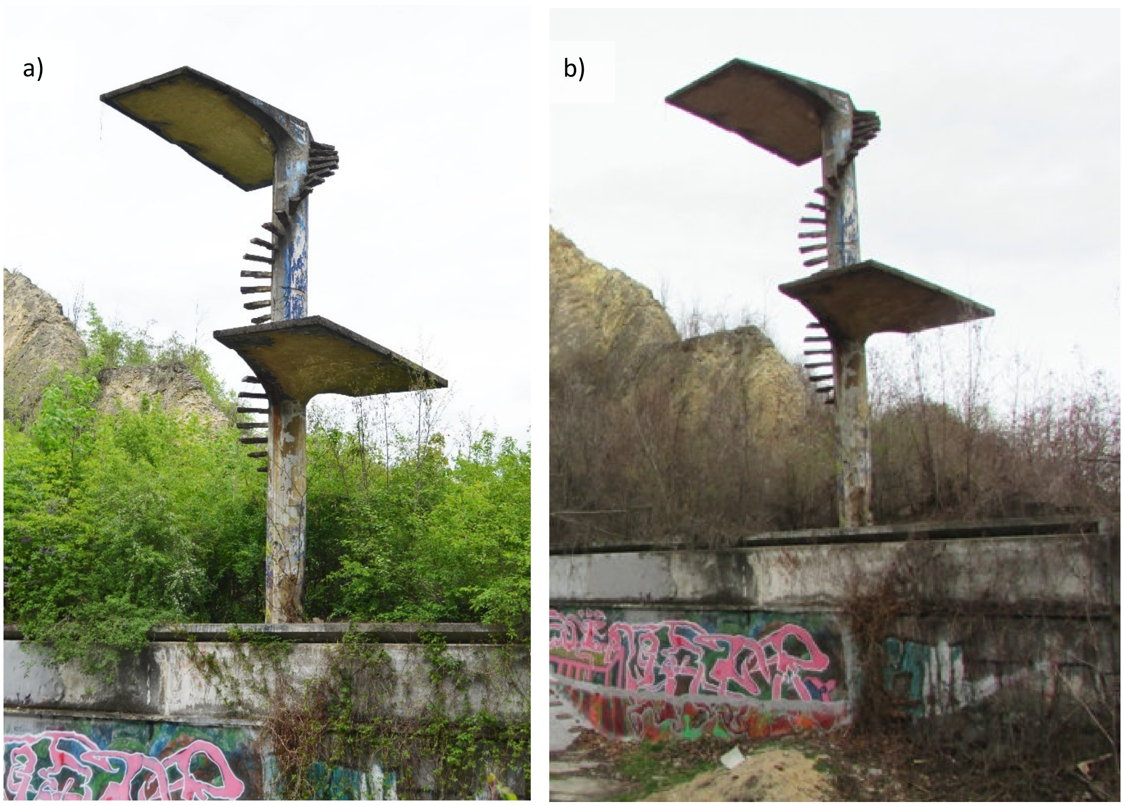


Figure B.2-15 General view of the diving tower: a) Photo taken on 28.4.2020, b) Photo taken on 27.2.2020.

Four main categories of material damage were registered:

- i) Surface discoloration: soiling, graffiti
- ii) Biological colonization of concrete
- iii) Corrosion of steel reinforcement
- iv) Detachment and features induced by material loss, mainly disintegration

The pillar of the diving tower is the only element that does not show signs of structural damage, though higher plants with roots adjacent to the pillar might grow, affecting its stability (Figure B.2-17a). The first ten steps have been cut-off in the past (unknown date), probably for safety reasons, so only fragments of the fixing points to the pillar remain (Fig. B.2-17a). Apart from the almost complete loss of the original surface coats that once covered the pillar, the most common deterioration patterns registered on the pillar are surface discoloration due to soiling and graffiti (Figure B.2-17a, b).

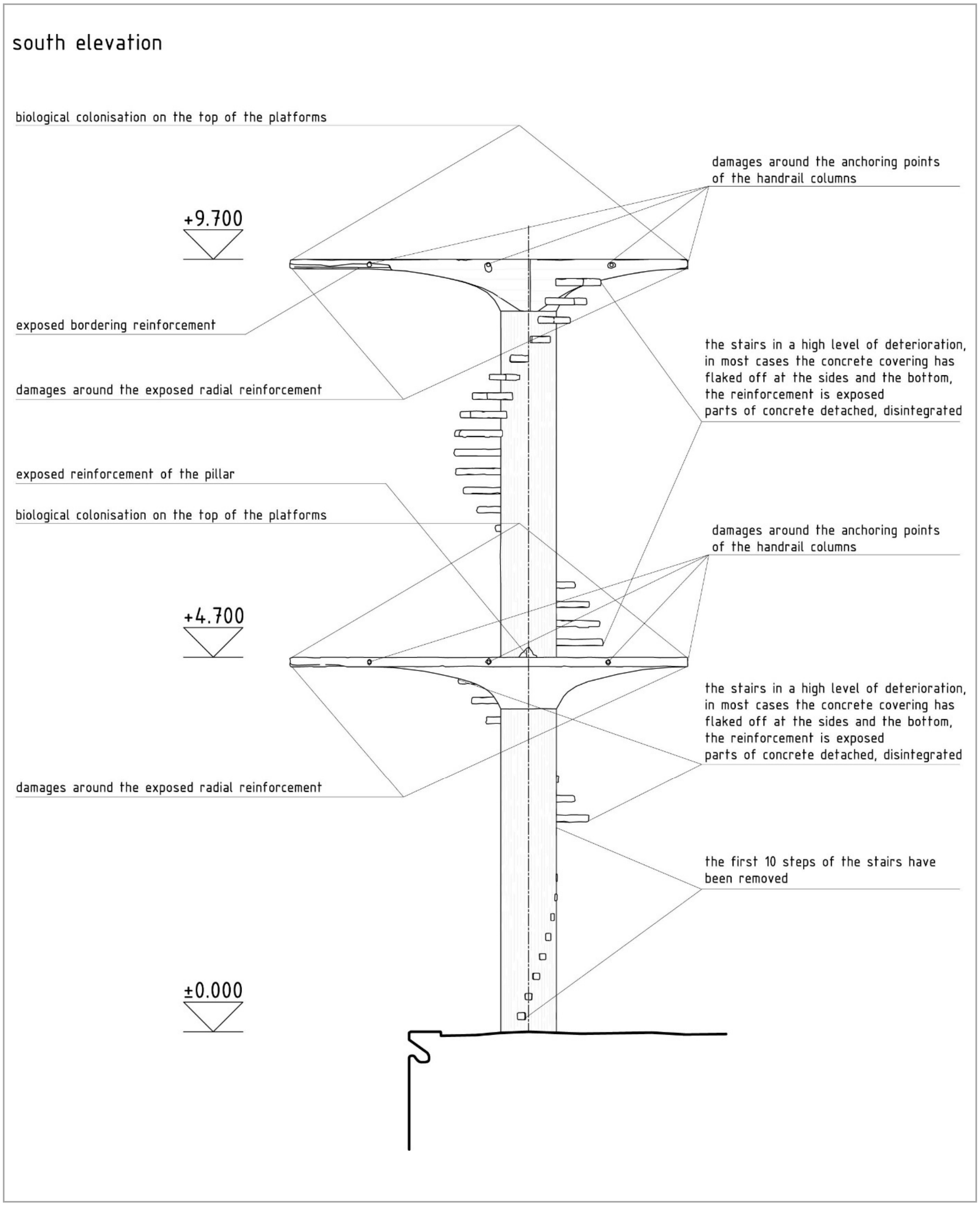


Figure B.2-16. South elevation with the indication of the most important damages.

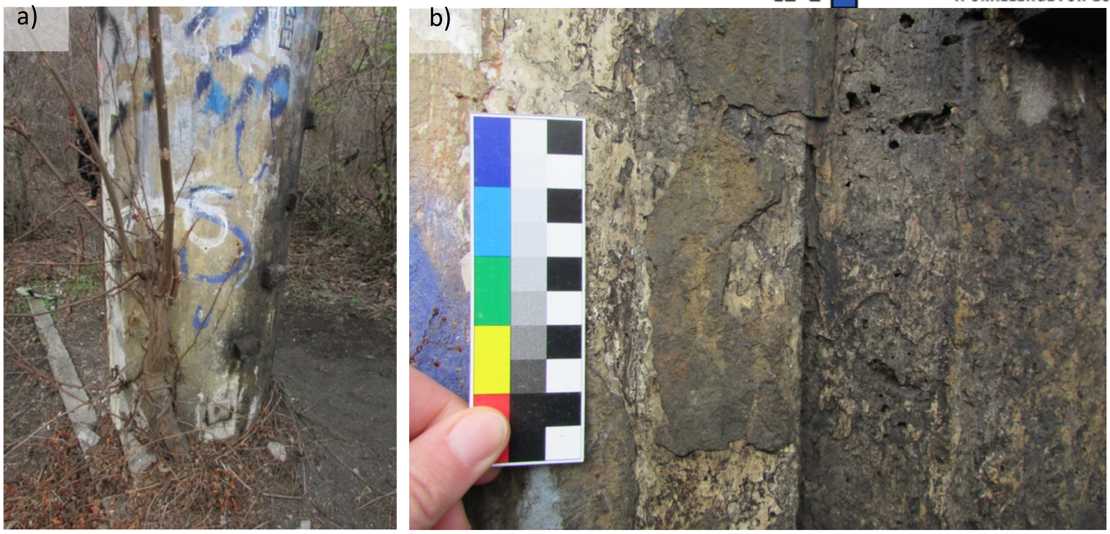


Figure B.2-17. Detail of the pillar at the ground level: a) Graffiti and higher plant growing adjacent to the pillar, b) Reminiscences of finishing coats (blistering) and soiling.

The stair steps have lost most of the concrete cover triggered by the corrosion of the reinforcement (Figure B.2-18a). In general, concrete surface layers remain only on the top of the steps (Figure B.2-18b). The handrail that once spiraled along the stairs is absent.

Figure B.2-18. Details of the stair steps: a) View below the steps to the lower platform, b) Top view of the steps to the highest platform.

The diving platforms show biological colonization on the top, e.g., lichens, mosses (Figure B.2-19), and corrosion of the reinforcement mostly visible underneath (Figure B.2-20a, b), enabling visualization of its radial layout (Figure B.2-20b).

Figure B.2-19. Top view of the platforms showing biological colonization.

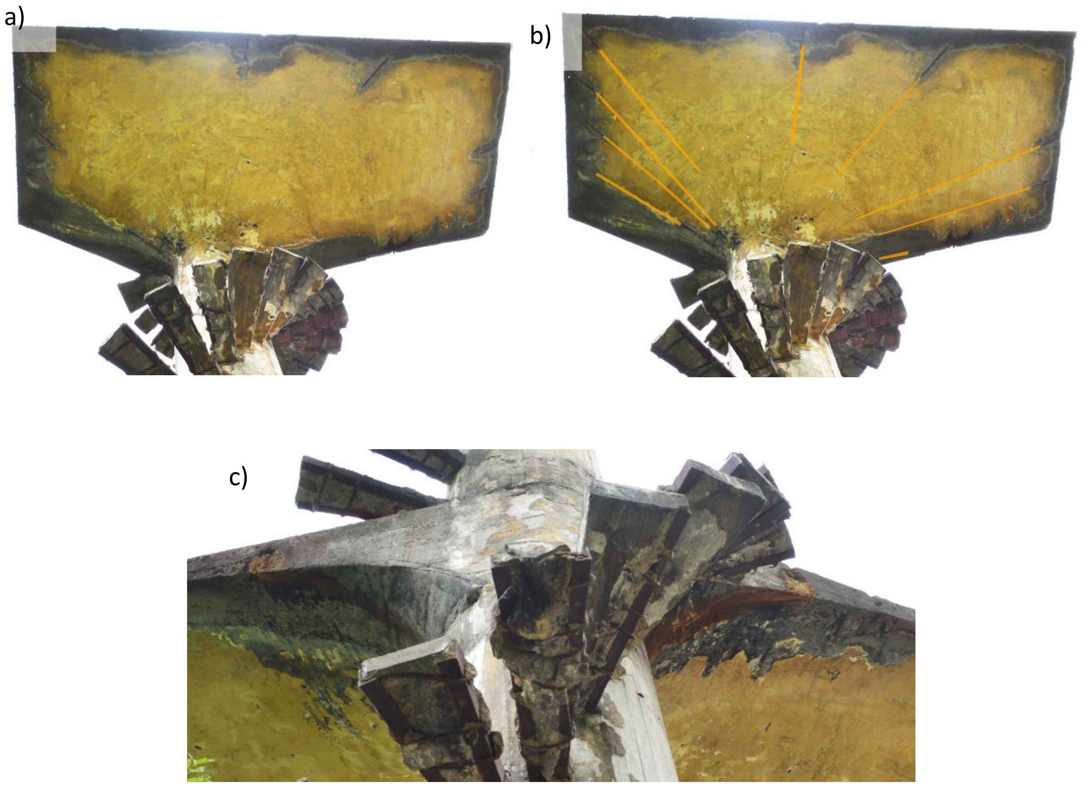


Figure B.2-20. View of the platforms: a) Bottom view of the highest platform showing corrosion of the reinforcement; b) Indication of the layout of the reinforcement in the highest platform (orange lines); c) Detail of the staining resulting from the corrosion of the exposed anchoring points of the removed handrail on the lower platform (both on the right and left side of the pillar).

The possible sources of the deterioration patterns observed comprise of a combination of factors mostly related to water and aerosols: carbonation-induced corrosion, frost action, acid chemical pollution attack (proximity to high traffic roads), and biological colonization.

B.2.2.5 Assessment of the heritage values

B.2.2.5.1 Urban scale

The former swimming stadium was part of a broader development plan for the Barrandov settlement. To understand its urbanistic qualities, it is necessary to perceive it in this broader context, i.e., in relation to the buildings of the *Barrandovské terasy* restaurant and the neighbouring residential district. The original context has changed throughout time, mainly via urbanistic reconfigurations of the area (Figure B.2-21).

Figure B.2-21. Aerial photos comparing the urban context between 1945 and 2021 (source: IPR Praha).

The site's surroundings have lost most of their idyllic natural atmosphere with the construction of the Barrandov bridge (built between 1978 and 1988) and of a highway between the riverbank and the site. Another elevated road serving the 1980s housing estate (*Sídliště Barrandov*) has been erected in the proximity of the *Barrandovské terasy* restaurant.

Recently, the original building of the *Barrandovské terasy* restaurant was restored after decades of neglect. The restaurant's site has been transformed; the open terraces of the restaurant, serving initially as a viewpoint towards the city, are now occupied with new buildings, i.e., an apartment house on one side and a hotel on the other (Figure B.2-22). Surrounded by new voluminous structures, the original restaurant building with a lighthouse-like tower has lost its original landmark meaning. The new buildings are also visible from the former swimming stadium site.

Figure B.2-22. Aerial photos comparing the site and its surroundings between 1966 and 2021 (source: IPR Praha).

Despite the changes mentioned above, the principal components of the original interwar urban development are still legible: the garden city with the constructivist villas on the ridge of the Barrandov hill, the viewpoint restaurant on the edge of the cliff, and the site of the swimming pool below. From a closer view, the unique relationship between the restaurant building and the swimming pool site is still present. Moreover, the limestone cliff, the most important natural component of the scene, protected as part of the National Natural Heritage *Barrandovské skály*, remains unchanged (Figure B.2-23).

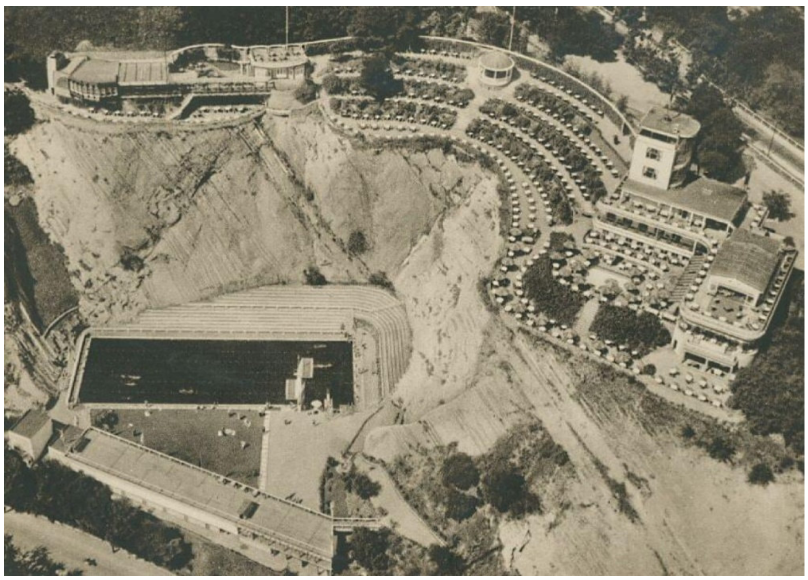
Figure B.2-23. View of the Barrandov hill from the other side of the river Vltava with the new buildings under construction.

B.2.2.5.2 Swimming stadium site

The swimming stadium is currently in ruins; since the 1960s, it has not been serving its original function. According to aerial photographs, the wooden structure serving as changing rooms was destroyed between 1975 and 1990 (still present in the 1975s photo and missing in the 1990s photo). The site has been overtaken by vegetation and higher plants and, as a result of this, the original elements of the swimming stadium have severely deteriorated, i.e., the tribunes at the bottom of the cliff are crumbled at large by trees growing between the concrete blocks of the tribune steps (Figure B.2-24). The topography has been altered in several parts of the site. Due to these changes, the original general spatial layout of the complex is no longer clear. Figure B.2-25 shows how the changing rooms of the stadium have been altered after a fire in 1934 that damaged them; this structure no longer exists (Figure B.2-26). The terraces on the northern side of the complex have been overtaken by nature.

Figure B.2-24. Aspect of the current state of the tribunes of the swimming stadium: a) General view from the diving tower; b) Detail of higher plants growing in the tribunes. Photos taken on 29.4.2020.

a)



b)

Figure B.2-25. Historical 1930s photos showing the layout of the stadium: a) View of the structure of the changing rooms that was extended after the fire can be seen; b) Photo before the fire that damaged the changing rooms (winter 1934) [30]

Figure B.2-26. General view of the current state of the swimming stadium. The building of the changing rooms no longer exists, and the site's topography has been altered (photo taken on 3.2.2020, source: Klub za starou Prahu).

B.2.2.5.3 Swimming pool

On the east side wall of the swimming pool, an opening has been made in its central part (Figure B.2-26). Some of the original elements of the swimming pool are still present, such as the pool ladders and "start swimming blocks" (Figure B.2-27). Near the southeast corner of the swimming pool, a small round basin is still preserved (Figure B.2-26).

Figure B.2-27. Details of the swimming pool: a) Ladder at the right corner of the diving area; b) "Start blocks" on the southeast side of the pool. Photos taken on 29.4.2020.

B.2.2.5.4 Diving tower

The concrete structure of the diving tower remains in a state of ruins. Due to safety reasons, the stair steps have been removed up to 2.5 m in height. Also, the steel tube handrail, a crucial component of the structure's architectural expression, has been removed.

Important components of the diving tower structure are missing, but the general architectural qualities of the structure are still noticeable, like its elegant geometry; in particular, the organic forms viewed from under the platforms, the dynamic feature of the spiral stair steps, etc. (Figures B.2-5, 8, and 10).

Besides the architectural qualities of the swimming stadium and its placement in the Czech interwar architecture, this complex is also important for its historical aspects – a landmark of Prague's interwar culture. Additionally, it has links to Václav M. Havel (last president of Czechoslovakia and first president of the Czech Republic) and his family.

B.2.2.6 Intervention proposal

B.2.2.6.1 Site context: original and recent state and future possibilities

This section targets possible intervention approaches to the most valuable architectural element of the site, i.e., the diving tower. However, the proposed approaches cannot be planned without a conservation plan for the entire swimming stadium site. A detailed study of each possible plan described below is nevertheless beyond the scope of this work.

B.2.2.6.1.1 Adaptation and conversion of the site

There is no current plan to restore the site to its original state and re-establish the original function of the swimming stadium. A swimming pool of this size would not fulfil the current requirements, and it would suffer from lack of direct sunshine during the afternoon, one of the reasons that might have influenced its original loss of function.

The social activities emerging spontaneously at this site during the last three decades have shown that the site, though in a ruined state, still has social potential. For about 10 years, a seasonal bar has been opening at the site. The empty area of the concrete pool was also used for private musical parties. Recently, a wooden tribune has been installed in the diving area of the swimming pool to provide an auditorium for theatre performances during the warm season (Figure B.2-28). The proximity to a highly frequented cycle route (A111) leading from Hlubočepy, Malá Chuchle, and out of Prague has promoted visits to the site. A poster briefly describing the site's history has been installed at the entrance to the site. The site plan with its legal and topographic borders, the 1930s plan, overlaid on a recent aerial view of the site, is shown in Figure B.2-29.

The natural geological features of the site, its architecture, and its genius location remain despite its abandonment. The site has potential as an architectural, cultural and touristic landmark that can be supported by commercial and non-commercial facilities, e.g., a place for cultural events, a sculpture garden, and a refreshment point. Analogous cases can be found in the Czech lands and abroad (e.g., the harbour crane *Żuraw M3* in Gdansk, Poland). A cultural promoter, an architect and a landscape architect should be involved in such a project. The restoration costs for such an architectural monument would require financial support from the state or local authorities.

B.2.2.6.1.2 Conservation of the remaining structures of the swimming pool

Minimalist interventions and conservation of the site in the state of ruins seem more meaningful in the current context and recent use. The concrete tribunes are in such a highly advanced state of degradation due to the growth of vegetation (Figure B.2-24) that efforts to preserve them seem unrealistic. The concrete pool structure should be stabilised to be protected from further degradation. The structure of the diving tower is the most precious architectural element of the site and efforts should be undertaken to preserve it.

B.2.2.6.1.3 Accessibility to the site

The accessibility to the site and the diving tower is a crucial point to consider. Due to the loss of the load-bearing capacity of the structure, the stairs and the platforms of the diving tower are not deemed accessible. The load-bearing capacity of these elements requires a detailed assessment. The protection of the structure from unauthorized access must result from the conversion concept of the entire site, and its planning should consider the preservation of the original architectural qualities.

Figure B.2-28: Aspect of the wooden tribune built during summer (photo taken on 17.7.2020).

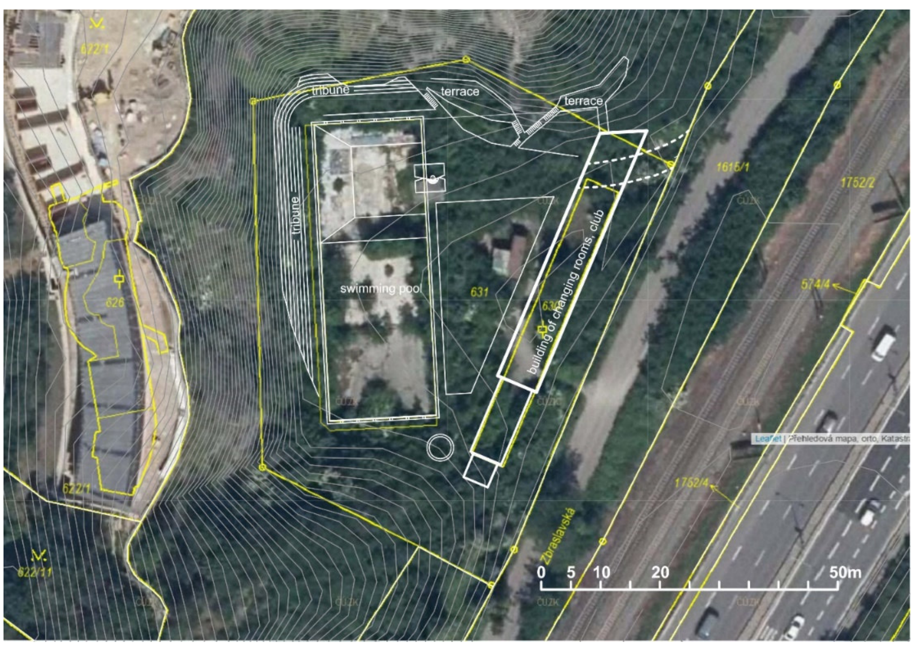


Figure B.2-29. Site plan of the swimming stadium: recent aerial photo showing the recent state, approximate drawing reconstruction of the 1930s state (white colour), land registered plan with the plot borders outlined in yellow, and the topography outlined in grey.

B.2.2.6.2 The diving tower: concept of proposed conservation

The conservation of the diving tower requires a use plan for the entire site. Several approaches for the restoration can be outlined, taking into account the heritage protection theory [31–33], and the qualities of the architectural object. Any conservation intervention is a unique creative task, and the application of common guidelines does not translate to the correctness of the approach. The current Czech heritage protection methodology describes the main treatment options and the presentation of a historic structure.

The possibilities for conserving the structure were discussed with a specialist in restoration of historic concrete monuments (sculptures and particular architectural elements) and a structural engineer specialised in historic concrete. The opinions of the two specialists are contrasting; one was optimistic, while the other was skeptical.

B.2.2.6.2.1 Conservation of the structure in a state of ruins

In this approach (described as *conservative restoration* in the National Heritage guidelines [31,34]), only the interventions necessary to preserve the structure from further deterioration should be undertaken (Figure B.2-30). Interventions that interfere with the current visual aspect should be minimal. The signs of ageing (historical patinas that do not support damage propagation) must be preserved as much as possible. The remnants of the original coatings should also be preserved and maintained; later-added paints (recent graffiti) may be removed.

Figure B.2-30. Conservation of the diving tower in the state of ruins: the surface should be cleaned from soiling, rust, and graffiti. The remnants of the original paint should be preserved, and the exposed concrete surfaces should be cleaned and preserved uncoated. The exposed reinforcement may be conserved uncovered or covered with a reprofiling mortar without remodeling the original shapes (edges).

According to the opinion of the restorer, the "conservation of the ruin" may consider the conservation of the exposed reinforcement without re-covering it: this entails removing the rust from the reinforcement and protecting it with a transparent coating. Another option is to cover the exposed reinforcement with a reprofiling mortar after cleaning the rust, but this intervention should not remodel the original shape (e.g., the edges). The cantilevered stairs, the most damaged and vulnerable elements of the structure, should be protected; the rust on the metallic exposed parts should be cleaned and covered with mortar. The original geometry of the stairs should not be restored, and the missing stairs should not be remade. The structural aspects of such an intervention must be assessed, as they are a crucial safety demand and will eventually determine the acceptance of such an approach.

B.2.2.6.2.2 Restoration of the original state

After decades of abandonment, the structure of the diving tower has lost elements that are significant for its architectural expression: the handrail, the flagpole, and the first 10 stair steps (Figure B.2-31). The restoration of the original state of the diving tower (*restitutive restoration* according to [34]), or at least of its original form, may be considered (Figure B.2-32). The swimming stadium complex is in a state of ruins; in particular, the pool area has minimal chance of being renovated to recover its original state. If the whole complex does not undergo a radical transformation, the intervention to return the original state of the diving tower brings controversy. Such intervention, including applying new coatings on the concrete structure and reinstallation of steel elements (handrail and flag pole), can hardly be accepted if the rest of the complex is preserved in a state of ruins.

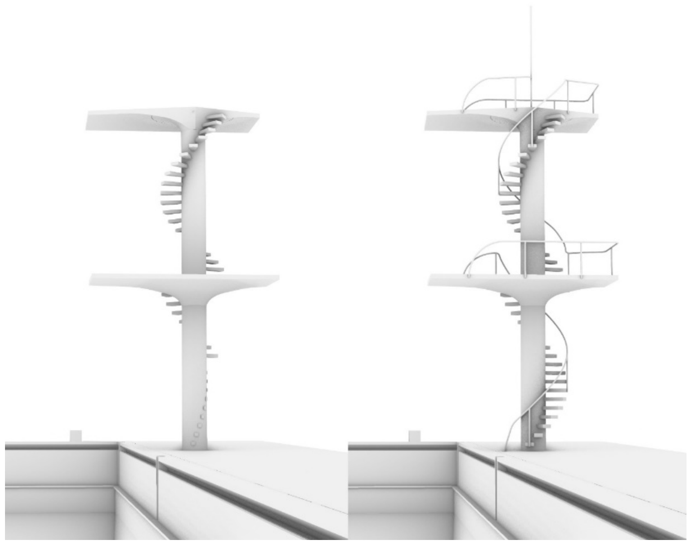


Figure B.2-31. Model of the current state (left) and reconstruction of the original state (right).

Figure B.2-32. Restoration of the original state: the edges of the platforms and the steps of the stairs are remodeled to their original shape. The handrail and flagpole are reinstalled. The surfaces are entirely coated with finishing coats with a similar composition to the original ones.

The analyses of the coating layers identified components present in the original coatings. Also, the historical photos show the original finishing of the concrete surfaces: the marks of wooden formworks are visible on the pillar; this indicates that a very thin surface finishing was applied.

The shape of the handrail and the flagpole can be partly visualized from the original drawings (the anchoring points of the handrail columns); the rest of the geometry can be derived from historical photos (Figure B.2-33). The handrail has been removed, but the same material may still be present in the anchoring points of the platforms. The material specification (e.g., steel pipe D42 mm for the handrails) can be found in the proposed budget plan. Other metallic elements were produced with this material, as can be observed in the remnants of the pool ladders.

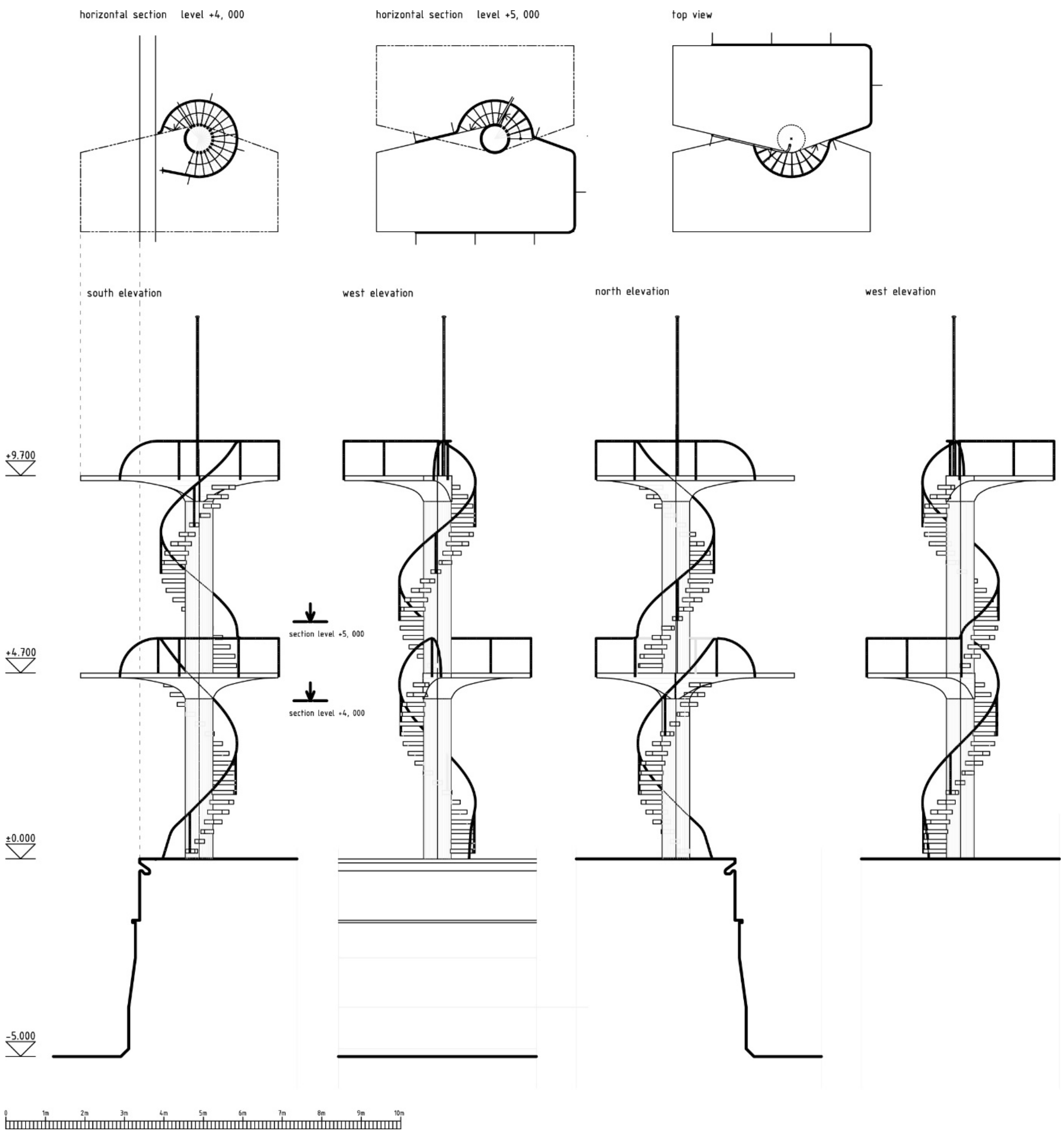


Figure B.2-33. Drawing of the reconstruction of the original state of the diving tower.

Other steel elements have disappeared: the tightening mechanisms of the coconut matting on the platforms. These elements were not a direct part of the structure, as they were clamped to the slabs of the platforms. The restitution of these elements goes hand in hand with the restitution of the original floor cover of the platforms: the coconut-fibre matting (Figure B.2-34).

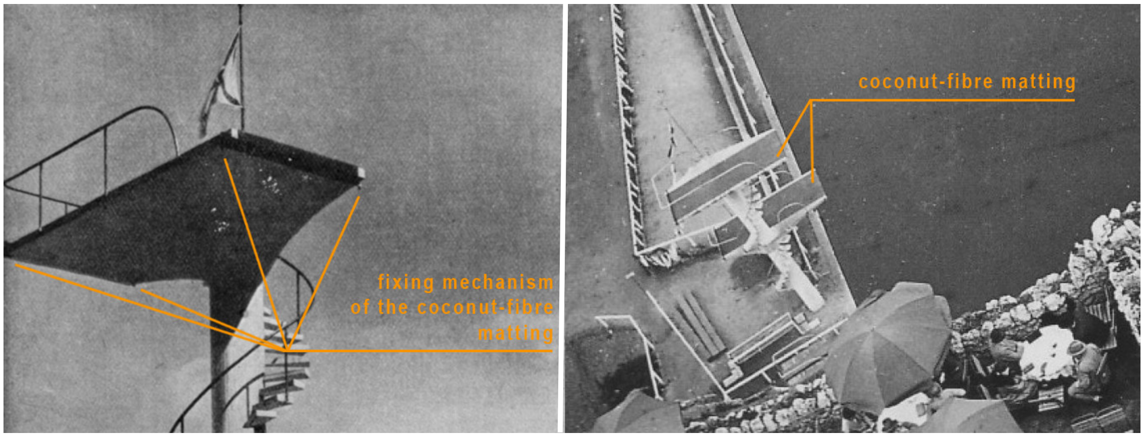


Figure B.2-34. Fixing elements of the coconut-fibre matting cover to the platforms.

The surface finishing of the steel elements is described in the proposed budget as a "double varnish paint." The color of the paint remains unclear. The composition of the original coats seems hard to find, but analyzing the coats of the remnants of the steel pipe ladder of the pool may provide helpful data.

B.2.2.6.2.3 Alternative restoration of the original form

As mentioned, the proposed restoration concept should be related to the plan for the entire site. When trying to imagine the possible plans for the complex, a more realistic scenario (instead of its complete restoration) is the transformation of the site into a green area with the conserved ruins of the original structures (swimming pool, diving tower and fountain) surrounded and partially covered by vegetation (tribunes). The latter should be maintained to avoid further damage to the structures.

Besides the conservation of the tower in the state of ruins, another restoration concept seems relevant in this context. Completion of the original shape of the diving tower, including the installation of the missing handrail, does not necessarily mean the complete restitution of its original appearance, as it is known from the 1930s photos. Such a conversion plan of the site should be reflected in the restoration concept of the tower.

The intervention may exclude the application of a concrete surface finishing mimicking the original one. The exposed concrete surfaces may be left uncoated, eventually with the ageing marks, and the original finishing coats can be preserved in selected areas. Missing and highly damaged elements (stairs) can be reintroduced and replaced, when necessary, e.g., using cast concrete with a slightly different texture/colour. The replacing elements should be distinguishable from the original ones, as indicated in the Venice Charter, Art.12. The coatings of the handrail remain in question; the concept of presenting the structure in a "rough state" can be regarded analogous to the treatment of the concrete surface (Figure B.2-35).

The proposed alternative restoration intervention aims to complete the shape of the structure and present the original shape as its principal architectural value. Keeping the structure in a "rough state" can help perceive the qualities of its forms and, at the same time, grasp the authenticity of the original material and construction technology. For the presentation of the uncovered concrete surfaces, different requirements are needed for the treatment of the original material (cleaning) and for the quality, texture, and colour of the reprofiling materials.

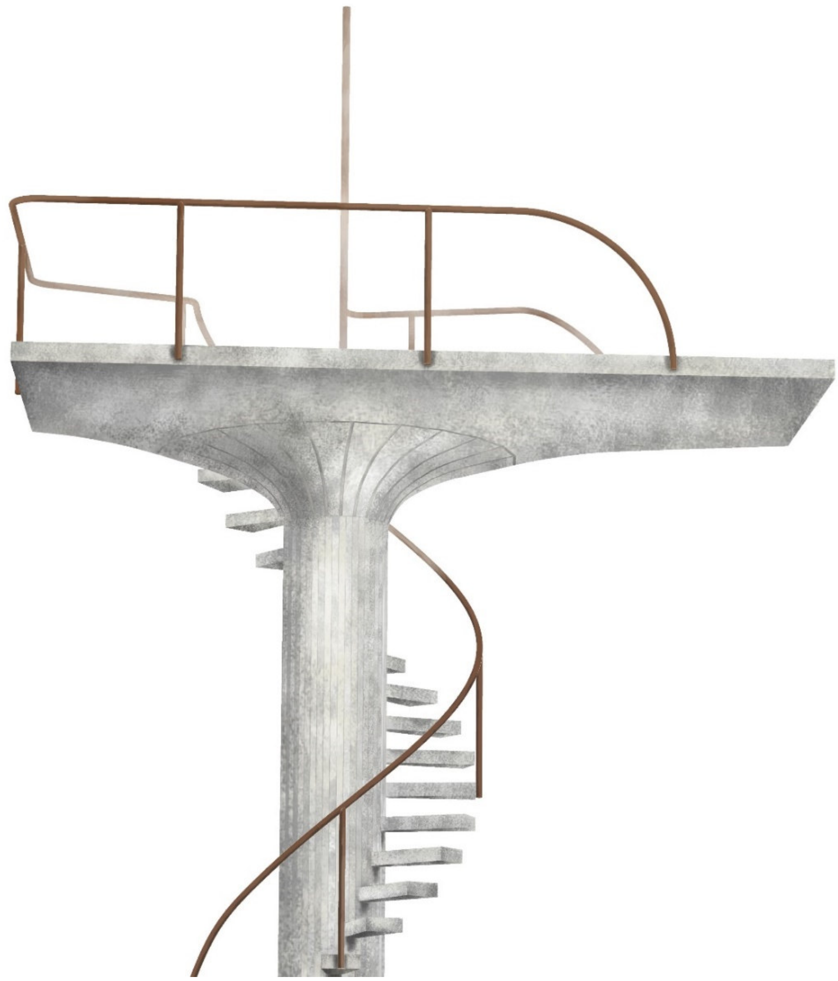


Figure B.2-35. Alternative restoration approach: reconstruction of the original shape without the restitution of the original finishing coats. The missing elements of the structure should be remodelled and reinstalled. The exposed surfaces of the construction material should be kept uncovered. The ageing marks should be preserved.

B.2.2.6.3 Structural aspects

A structural assessment of the tower is crucial to find out the potential restoration possibilities. Further tests and analyses have to be planned to get sufficient knowledge about the state of the concrete and of the reinforcement [32,35]. The level of degradation must be analysed in various parts of the structure (e.g., carbonation depth). The position and dimensions of the reinforcement must be identified, as well as the level of its corrosion. The strength of the concrete should also be measured.

The intervention proposal must consider the stability and load-bearing capacity of the structure. The restoration of the visual qualities should be planned after assessing the state of the structure. Therefore, this work proposes conservation methods and approaches that are dependent on the structural assessment.

B.2.2.6.3.1 Reprofiling and local repairs

Several damages have been registered on the edges and bottom sides of the platforms, namely areas with detached concrete cover and exposed reinforcement. Patch repairs using a reprofiling cement-based mortar can be considered for remodeling the lacunae on the pillar and platforms, namely the areas around the exposed reinforcement [32]. The rust on the reinforcement must be cleaned and the deteriorated concrete removed. The concrete surfaces must be treated with an adhesion primer to receive the reprofiling material, which must accomplish both structural and visual (heritage protection) demands. Additional steel reinforcement may be added when necessary to improve the adherence of the old to the new material.

Structural assessment of the anchoring system is necessary for developing the design. The original fixing points of the handrail must be cleaned, the original anchoring elements assessed, and the detail of the anchoring specified. Fixing the new element to the original anchoring element can also be considered.

B.2.2.6.3.2 Restoration of the cantilevered stairs

The remodeling of the damaged cantilevered stairs and the restitution of the missing ones are two particular structural issues. The majority of existing stairs are severely deteriorated; most of the concrete cover has crumbled, exposing the reinforcement – two L-profiles and a steel wire (Figure B.2-8). The concrete between these two load-bearing L-profiles survives in most of the steps, but its adherence to the partially exposed and corroded steel profiles is unknown.

The remaining load-bearing capacity of the L-profiles must be assessed, as these may have lost a significant part of their original thickness due to corrosion. The insertion of additional reinforcement or the complete substitution of the existing one should be considered.

If the existing reinforcement remains satisfactory, the profiles should be cleaned from corrosion and an anti-corrosion coating should be applied. This treatment may affect the adhesion of the remaining concrete mass between the profiles, so care should be taken to ensure that it remains adherent to the steel. In case the adherence of original concrete to the L- profiles is not sufficient after cleaning, additional reinforcement (stainless steel mesh) should be added to fix the new reprofiling mortar.

Another option is to clean the rust of the L-profiles and remove the concrete. Afterwards, additional reinforcement should be installed and the stair steps should be cast with a new reprofiling concrete mortar. Additional reinforcement will also be necessary to fix the handrail poles to 6 of the steps of the stair.

If the reinforcement is too weak, complete removal of the old stair steps, insertion of new reinforcement and casting of new steps may be necessary. The same applies in the case of missing steps (i.e., the first 10 steps). The new reinforcement should be fixed separately into the concrete pillar; it may also be necessary to assess the possibility of welding the new reinforcement to part of the original L-profile embedded in the pillar.

B.2.2.6.3.3 Consolidation of the surface

The superficial cement binder has been washed away and the aggregates have been partially exposed on the top of the platforms. The main reinforcements of the cantilevered platforms are located at the lower part of the platforms and their structural state should be assessed. Consolidation of the concrete surface is considered essential.

B.2.2.6.3.4 Restitution of steel elements

The restitution of the missing handrail and flagpole requires special assessment of the fixing points (6 on the stairs, 7+7+1 on the sides of the platforms) and design of the fixation of the poles. Additionally, the structural stability of the new handrail has to be assessed. The shape and stability of the handrails, as well as the load bearing capacity of the entire structure, must also be considered.

B.2.2.6.4 Technical and aesthetical aspects of the restoration

The restoration of a historical concrete structure has both technical and aesthetical aspects. The suggested preliminary methods for intervention on the surfaces and particular elements are listed below [36].

B.2.2.6.4.1 Consolidation of concrete

Before cleaning, the most damaged concrete surfaces must be locally consolidated with a consolidant (based on silicic acid ester). If necessary, the same procedure can be repeated after cleaning.

B.2.2.6.4.2 Cleaning of the concrete surfaces

The original coatings survive only in certain areas of the structure. The most well-preserved parts are at the bottom side of the platforms and at certain areas of the pillar. The concrete surfaces are partially exposed and others are covered with more recent paints (graffiti). The exposed metallic elements (uncovered reinforcement, remnants of the handrail anchoring elements, damaged and cut out step stairs) show corrosion. The leached rust from the corroded metallic elements contaminates some of the concrete surfaces. Soiling and pollution aerosols are other sources of contamination of the surfaces. Biological colonization (e.g., lichens, cyanobacteria, mosses) affects mostly the upper side of the platforms and stair steps.

The soiling deposits should be cleaned with steam or water jet with controlled pressure and temperature. Before washing, the surfaces should be dampened with a detergent solution. A biocide product (e.g., based on quaternary ammonium salts) should be applied with a sprayer on moist concrete surfaces to remove biological colonization. Afterwards, the surfaces should be washed with water. The leached rust from the corroded metallic elements and silicate deposits can be removed using low-pressure micro-jet washer (using corundum, garnet or dolomite as abrasive material, with an approximate working pressure of 4 bar).

If it is decided to remove the remnants of the coatings or the more recently applied layers that differ from the original ones, a mechanical (hand) technique should be used, e.g., using a hammer, micro-chisels and lancets. In general, mechanical cleaning is preferred to chemical. Low pressure jet washing can be applied (details mentioned above), mainly on oil-based paints and graffiti. The use of solvent pastes (e.g., ammonium hydrogen fluoride gels) should be carefully considered and tested before application.

B.2.2.6.4.3 Removal of damaged parts

Severely damaged concrete should be removed with stonemasonry tools; low vibration tools are preferred (e.g., hammers and chisels, angle grinder).

B.2.2.6.4.4 Treatment of the exposed steel reinforcement

The corrosion products should be jet-washed from the surface of the reinforcement using a non-ferrous abrasive. Afterwards, the surface should be coated with a corrosion inhibitor product. A suitable adhesion primer should be applied, if reprofiling with new mortars is intended.

B.2.2.6.4.5 Grouting

Injection of a re-alkalising agent (lime-based) should be applied into the concrete via the cracks along the remaining steel reinforcement. Mechanically strained cracks can be treated by injection with epoxy resin. Subsequently, the cracks should be filled with a coloured cement-based paste.

B.2.2.6.4.6 Remodeling/Restitution of missing parts

Small plastic defects (e.g., the crumbled edges of the platforms, lacunae caused by corrosion of the reinforcement) can be reprofiled with new concrete, coloured in mass with pigments to match the colour of the old concrete.

The retouching of the newly inserted material shall be chosen according to the preferred restoration concept; the texture of the new materials can be left untouched or adjusted to the aspect of the old concrete surfaces (e.g., with exposed aggregate).

The reprofiling material can be an available commercial product (e.g., Betofix RM by Remmers) modified to the required appearance. Alternatively, the reprofiling material can be designed in the laboratory to reproduce the composition of the original concrete.

The size of the aggregate components is a crucial point regarding both the size of the elements to be remodeled and the required physical properties. The maximum grain size of the gravel used in the original concrete cannot be used. The parts requiring reprofiling are of small size and have complex shapes; therefore, the largest original grain size could be hardly used.

In the case of restoration of the original state, and the particular case of the stair steps, the remnants of concrete with lack of cohesion must be removed and the reinforcement should be cleaned from rust and treated with a corrosion inhibitor, as mentioned above. Additional reinforcement is probably needed and should follow the guides of the structural assessment. The use of stainless-steel reinforcement should be preferred; formwork should be installed and the steps should be cast with appropriate concrete.

In the case of the ten missing stair steps, a completely new structure should be inserted in the lowest part of the column. The design of the reinforcement should follow the current demands of concrete cover thickness. The steps can be cast in a similar way to the restored ones. The use of precast elements may be considered.

B.2.2.6.4.7 Fixation of the fragments of the original coats

The remnants of the original coating layers can be fixed with the application of a consolidant, possibly with underlay injecting.

B.2.2.6.4.8 Local colour retouches

The newly remodeled parts can be colour-retouched to match the old concrete; a slight difference in texture and colour may be relevant.

B.2.2.6.4.9 Surface finishing

The concrete surfaces may be colour-retouched locally, depending on the restoration concept. Afterwards, an overall semi-transparent protective coat can be applied; a lime-based paint should be preferred, but a silicate-based product may also be suitable – the reversibility of such an intervention must be taken into account. On the surfaces directly exposed to rain, a higher number of coats may be applied.

B.2.2.6.4.10 Application of water-repellent

A water-repellent agent (based on silane or siloxane) should be sprayed on all the surfaces after the curing period of the reprofiling materials.

Depending on the chosen restoration concept, the materials' specification of the handrail and flagpole can benefit from analysing the remnants of the metallic elements preserved in the pool (e.g., ladder fragments).

B.2.2.6.5 Accessibility of the diving tower and limitations for future use

The accessibility to the diving tower depends on the restoration concept and the structural assessment. However, considering the current state of the structure and the safety demands, the accessibility to the diving tower must be limited. The tower's preservation as an inaccessible architectural object inside a partially accessible site seems to be the most realistic alternative. Access to the tower can be considered in the context of guided visits.

The selection of measures to ensure safety restrictions depends on the restoration concept and, most of all, on the type of conversion of the entire site. If the site is operated as a closed area with limited access (e.g., with security personnel and camera surveillance), the measures to avoid access to the diving tower may be simple (e.g., an informative poster and an electronic alarm device). In the case of a freely accessible site, the plan should be more robust and designed to avoid vandalism. Nevertheless, it is almost impossible to prevent unauthorised access, if the aim is to present the structure to the public as an architectural landmark.

B.3 UCY: Melkonian Educational Complex

B.3.1 Introduction

The architectural, technological and social aspects of Melkonian Educational Complex are part of the building's great aesthetic value and uniqueness, from the period of its construction until today. The Melkonian brothers, wanting to create a grandiose project, with the help of the Armenian architect Garo Balian, introduced a novelty for the standards of Cyprus. The original material and morphological essence of the monument emphasizes its historical value and authenticity. Even the subsequent additions are part of its history, presenting a continuum over the years. According to Article 4 of the Charter of Venice, it is deemed necessary to maintain and continuously care for the monument, in order to ensure its preservation. The contribution of the complex, particularly to the Armenian community, should be considered significant, and in accordance with Article 5 of the Charter of Venice, necessitates the maintenance and restoration of the monument. The mansion for 63 years served the function for which it was built, in accordance with Article 7.2 of Burra Charter, which refers to the avoidance of change of use. At the end of the school's use period, the headmaster's mansion was abandoned. According to Article 16 of the Charter of Venice, any maintenance work and rehabilitation that may take place should be fully documented. Each piece is part of the history of the monument and, therefore, it is deemed necessary to capture and record in detail all data and tasks to be accomplished. Still, it is important that any additions and operations made to it, for reasons of reuse, differ in materiality and architecture, thus separating the old from the new. In accordance with Article 9 of the Charter of Venice, there must be respect for the original status and authentic elements of the building, as well as recognizability and autonomy of the new intervention. The solutions and changes suggested for reuse of the building, according to the Burra Charter, should be based on the principle of reversibility and respect for traditional materials. In addition, according to the Amsterdam Declaration, maintenance should aim at extending the life of the building and ensuring, as long as possible, durability of its tangible and intangible values.

In accordance with the legislation of Cyprus, regarding the maintenance and repair of traditional/listed buildings, the maintenance of all elements, building related materials, construction details, decorative elements and of the surroundings, is necessary. Therefore, any alteration that could change the relationships of the building's volumes, shape, materials and colors is ruled out. Still, new additions, should respect the original status of the building, the balance of its composition, its relations with the surrounding space, as well as its original parts and features. In terms of repair, this should be done where necessary, showing compatibility with the traditional materials. Finally, according to the Cypriot legislation, listed buildings can be assigned all permitted uses, provided these show respect for the particular character of the buildings (typology and morphology).

Figure B.3-1 Reinforced Concrete columns, beams, porch slabs in the Melkonian Headmaster's House

Yet, the retaining and repairing, rather than replacing, poses a challenge when historic reinforced concrete elements are concerned. While in regions without earthquakes, preventive techniques (such as the use of water-repellent materials, or the adoption of electrochemical methods, such as re-alkalization of concrete, or cathodic protection of reinforcement [37]) may be adopted, in the case of structures under-designed for lateral loads, more active measures have to be undertaken. This is especially true in cases where, in addition to seismic actions, the building materials have been significantly weathered. Furthermore, repair materials should have lower modulus of elasticity, compared to the original concrete, in order to reduce the risk of damage to the latter (ACI Committee 546, 2006 [38]).

Historic concrete, in its earliest forms, and in particular in the case of the Melkonian Complex, was produced and designed by patented systems, such as the Hennebique [39], which are now considered obsolete. Reproducing the same materials and techniques is, thus, not an option, since both the raw material (cement, aggregates, steel) properties and the structural members geometry and detailing have changed. In this case, the conservation approach should aim at *retreatability* (i.e., the repair material should not preclude or impede further treatment in the future) [40,41]. Retreatability replaces the previously used term *reversibility*, which originated from art conservation and was deemed unsuitable for building conservation [41,42].

The retrofit proposal hereby presented assesses the use of ECC jacketing on historic low strength concrete, through cover replacement. The historic case study structure of the Melkonian Headquarters Mansion (Fig. B3-1) built in accordance with the Hennebique patented system in Cyprus, with reinforced concrete structural members and load-bearing masonry walls, was investigated and assessed under seismic loading. The seismic assessment revealed the structural deficiencies of the case study building's structural members. The concrete properties and detailing, the raw materials and the mix design are not in agreement with today's practice included in current Design Codes: the diameter and shape of the natural aggregates, the low strength of the cement used at the time, the mild steel rebars without ribs, the lack of stirrups and the small dimensions of the cross-section are all against current seismic design provisions and concrete standards. These render any attempts to reproduce exactly the original concrete material and members not feasible. Furthermore, the structural assessment of the existing column members showed that, in the event of an earthquake, these will fail in a brittle shear manner, compromising the stability of the porches they support.

The properties of the original concrete material have been used to define a new, equivalent low-strength concrete to be subjected to repair. A Strain Hardening Fiber Reinforced Cementitious Composite (SHFRCC) or ECC material was prepared by testing Polyethylene (PE) fibers of different lengths; this was used for the repair jacketing of the low-strength concrete. The experimental program consisted of a series of tests (compression, tension, split, bending) for the characterization of the materials designed and produced in the lab, and two types of repaired cores under compression, one to define the confinement effect of the jacket and the second to determine the axial load of the final retrofit practice.

B.3.2 Design of reference low-strength concrete (LSC)

Even though reproducing exactly the same concrete mixture as the original one was not feasible, due to the different properties of the raw materials available today, a mix design (LSC) with similar compressive strength and density to the original concrete found in the structure under study was prepared: i.e., target cube compressive strength 15 MPa and target density ρ=2192 kg/m^3. This ensured the "compatibility" of the two mixtures. To achieve this, EN 1766 [43] was used, along with the American *Concrete* Institute (ACI) *mix design* proportioning method [44]. According to EN 1766, Concrete Type MC (0.9) was chosen, with a mean compressive strength at 28 days of 15±5 MPa for cubes and 12±5 MPa for cylinders. This mix should contain 195 kg/m^3 of cement, 10 mm maximum aggregate size and a water:cement ratio of 0.9±0.05. The mix proportions for the sand and coarse aggregate were calculated with the ACI method, but the cement (Ordinary Portland Cement, OPC 32.5) to sand ratio was set at 1:3, in order to replicate the mix proportioning used at the time of the construction of the case study building, that varied between 1:2:4 to 1:3:6 (cement:sand:coarse aggregate) [45]. The final mix proportions are summarized in Table B3-1.

*Table **B3-**1. Mix designs for Low Strength Concrete (LSC) and ECC repair material*

Sample	Cement	Water	Coarse aggregates	Sand A	Sand B	Silica fume	Fibers
LSC	1	0.9	7.75	1.55	1.55	-	-
ECC	1	0.375	-	0.395		0.083	2%

B.3.3 Strain Hardening Fiber Reinforced Cementitious Composite

A type of Strain Hardening Fiber Reinforced Cementitious Composite (SHFRCC) or ECC was chosen to be used as repair material for the historic case study building concrete columns that show cover delamination, corrosion of reinforcement and lack of stirrups/confinement. ECCs have the ability to arrest cracking through the action of the fibers bridging the cracks. High Tenacity Polyethylene (PE) fibers of 12 mm length were used; these were provided coated by the supplier. The length and surface characteristics of the fibers play an important role in the tensile strength, crack-bridging effect and ductility in tension of the end-composite [46]. PE fibers have a hydrophobic surface, thus a very low bond strength is exerted between the fiber and the surrounding matrix. In this case, pull-out may lead to strain softening effects. In order to increase the bond, the provider of the fibers adopted in this study used a proprietary coating. The peak strain of the 12 mm High Tenacity Polyethylene fibers hereby used is 2.6%; their density and diameter are 970 kg/m^3 and 17.9 μm, respectively, their breaking strength is at 3000 MPa and their modulus of elasticity is 114 GPa.

Besides the fibers, the ECC mix design consisted of Ordinary Portland Cement (OPC) 52.5, silica sand with maximum grain size of 300 μm, and silica fume. The silica fume Grade 920 was provided by ELKEM Microsilica Cyprus. Silica fume is a recovered mineral component (RMC), the use of which has a high sustainability impact [47]. It can fill the gaps between cement grains and give mobility to the mix by allowing concrete to flow more easily when energy is applied to it, thus reducing segregation [48]. Furthermore, since silica fume has pozzolanic properties, it increases the strength and reduces the permeability of the final product [49]. The ECC mix design is shown in Table B.3-1. PE fibers were added at a quantity of 2% by volume. The mixing order was as follows: (i) the dry materials (sand, silica fume, cement) were mixed together for more than 10 min, (ii) 90% of the water was added to the mix, which achieved self-compacting properties, (iii) fibers were added slowly to the mix in order to achieve proper dispersion, (iv) the rest of the water was added, along with a High Range Water Reducer (HRWR).

B.3.4 Mixing, casting and preparation of specimens

The technique of replacing the cover of low strength reinforced concrete members with ECC materials has not yet been studied extensively, and the effectiveness of the confinement provided by the ECC has not yet been quantified. Another gap in the literature is the estimation of the final compressive strength of the jacketed member, which is related to the increase of the capacity of the original low-strength concrete due to the confinement effect. In order to explore this subject, small cylindrical specimens of 100 mm diameter were prepared, confined with 25 mm cover of the ECC material (Table B.3-2). The specimens were tested under uniaxial compression. Two sets of experiments were performed (Fig. B.3-2): (a) one with compression only on the internal diameter low strength concrete core, to assist in defining the new confined strength and confinement provided by the ECC, and (b) one on the full final cross section of the jacketed cylinder. Low-strength concrete specimens of the same size were used as reference. Three specimens were tested for each type of setup.

Table B.3-2. Specimen dimensions before and after jacketing. Samples C-100/150 refer to the as cast non-repaired (reference) concrete samples, while samples R-C-100/150 refer to the repaired cylinders with final diameter of 100/150 mm; COMP. D_o refers to compression applied only to the internal core, while COMP. D_{col} refers to the samples where the load was applied to the full cross section of the member; D is the diameter and H is the height of the specimens before and after the repair

Sample	Type of loading	Material	Dim. before repair		Repair	Dim. after repair	
			D (mm)	H (mm)		D (mm)	H (mm)
C-100	COMP. D_o	C12	100	200	-	-	-
C-150	COMP. D_{col}	C12	150	300	-	-	-
R-C-100	COMP. D_o	C12/FRC	100	200	YES	150	200
R-C-150	COMP. D_{col}	C12/FRC	100	300	YES	150	300

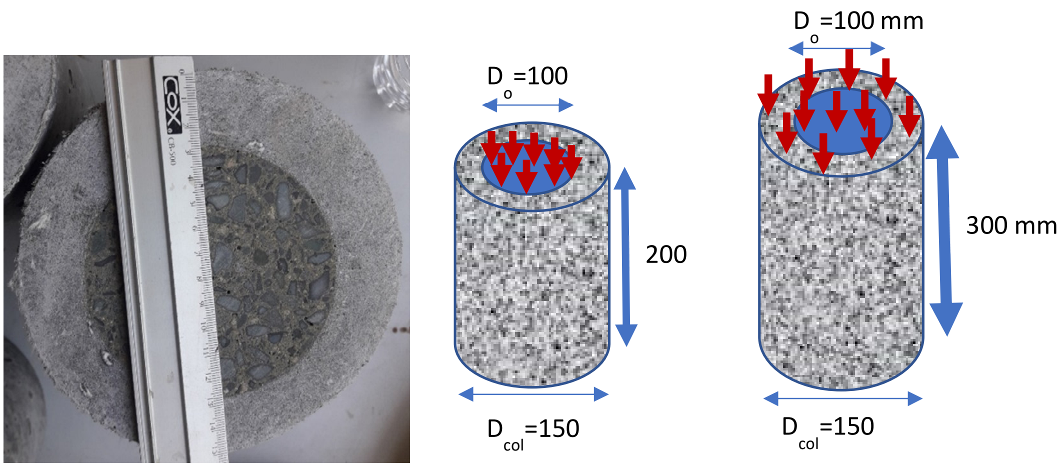


Figure B.3-2. Left: Photo of a low strength concrete core confined with ECC. Middle: Setup A for confinement. Right: Setup B for jacketed member compressive strength.

In order to prepare the specimens, the low strength parts were first prepared with the use of cylindrical moulds. After casting, the specimens were left to dry for 24 hours and they were then placed in a sealed container, covered with a wet burlap. One week later, the low strength cylinders were placed in the bigger diameter moulds and the ECC was cast around them; compaction of the ECC was carried out with the use of a rod. As with the original cylinders, 24 hours after casting, the new specimens were wrapped in wet burlap and placed in a sealed container until the repair material reached a curing age of 28 days.

B.3.5 Experimental Results

B.3.5.1 Part A: Tests for the characterization of the materials

B.3.5.1.1 Low-strength concrete.

Tests were conducted on the LSC in order to acquire the compressive strength and indirect tensile strength of the material. The compressive strength and strain at maximum compressive stress, the split cylinder tensile strength, and the flexural strength under four-point bending are recorded in Table B.3-3, together with the average values and standard deviations of the results. The stress-strain, both axial and lateral, under uniaxial compression, and the failure patterns are depicted in Fig. B.3-3.

*Table **B.3**-3. Strength of LSC under compression (C), split (S) and flexure (B) tests*

Specimen	f_{cmax} (MPa)	ε_o	Specimen	$f_{t,sp}$ (MPa)	Specimen	f_{fl} (MPa)
L1-C1	9.69	0.00445	L1-S1	1.195	L1-B1	2.101
L1-C2	9.32	0.00749	L1-S2	1.437	L1-B2	2.349
L1-C3	11.64	0.00460	L1-S3	1.569	L1-B3	2.200
Average	10.22	0.0055		1.40		2.22
Stand. Dev.	1.64	0.0020		0.09		0.11

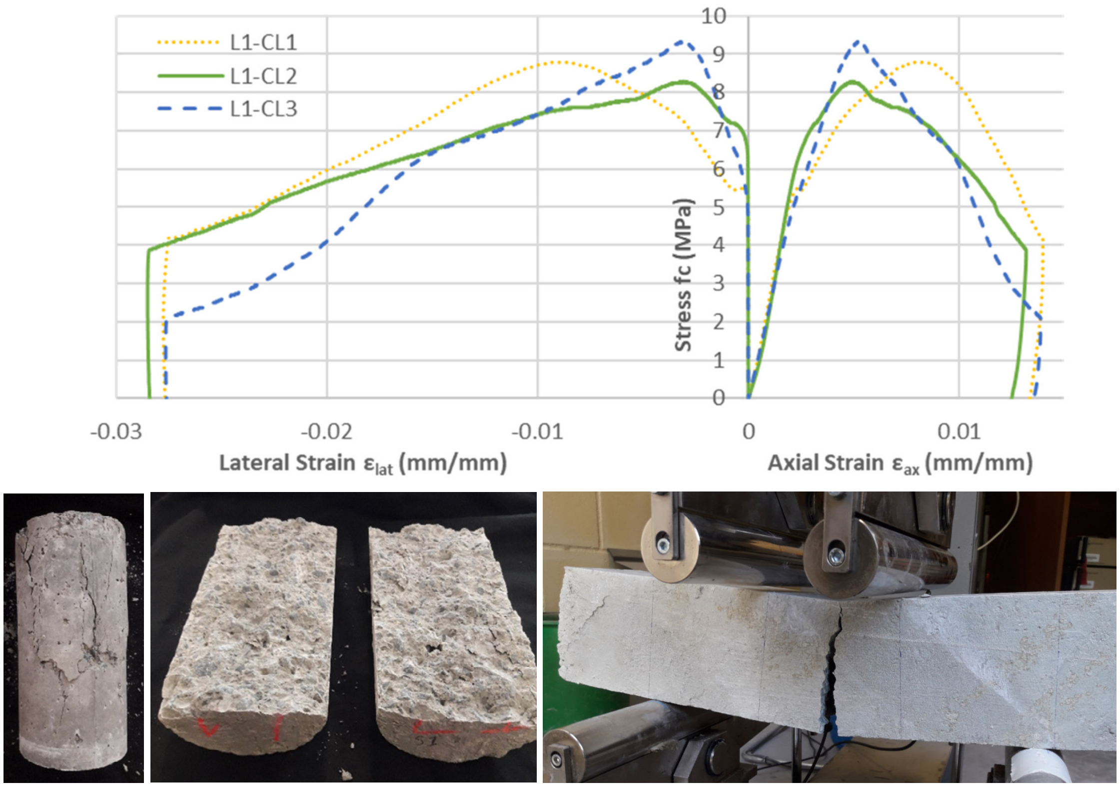


Figure B.3-3. Top: Compressive stress-axial strain-lateral strain of LSC specimens. Bottom: Failure patterns under uniaxial compression (left), split cylinder (middle) and four-point bending (right) tests.

B.3.5.1.2 ECC jacket for repair.

For the characterization of the behavior of the ECC jacket material, uniaxial compression, tension, split cylinder and four-point bending tests were performed, resulting in the stress-strain curves of Fig. B.3-4. The ECC material exhibited strain hardening behavior, with an ultimate tensile strain prior to crack localization in the order of 1%. The uniaxial tensile stress obtained was ca. 2.5 MPa. The strain hardening behavior was extrapolated to the indirect tensile tests of split cylinder and four-point bending that also exhibited multiple cracking, large deformation capacity, increase of strength after first cracking and high energy dissipation. Additionally, in the uniaxial compression tests, failure was delayed with a shift of strain at peak load, and low lateral deformations, due to the confinement action of the fibers bridging vertical cracks; this is typical of strain hardening fiber reinforced cementitious composites [50].

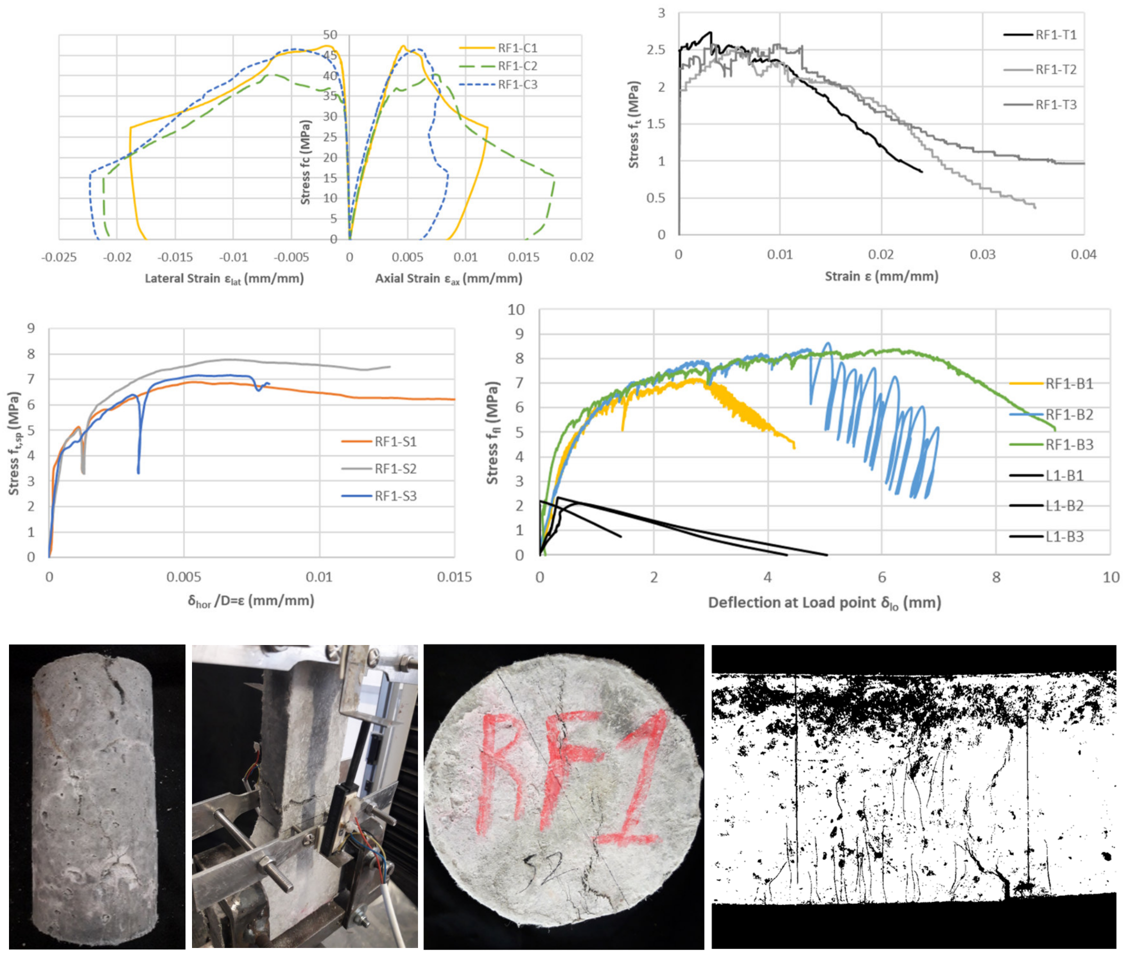


Figure B.3-4. Top row: Compressive stress-axial strain-lateral strain (left) and uniaxial tension stress-strain curve (right) of ECC specimens. Middle row: Split cylinder stress-horizontal strain (left) and four-point bending stress-load point deflection (right) of ECC specimens. Bottom row: Failure patterns of ECC specimens.

B.3.5.2 Part B: Evaluation of the effect of confinement on the compressive strength of historic concrete

The confinement effectiveness on the compressive strength of the LSC was verified by comparing the results of similar cylindrical specimens (100x200 mm), with and without confinement, as shown in Fig. B.3-5. The confined LSC compressive strength (f_{cc}) was double the relevant unconfined compressive strength (f_c) due to the restriction in lateral expansion provided by the ECC material. The strength of the confined concrete was calculated using the lateral stress (σ_{lat}), based on the Richart model for confined concrete [51]. The lateral stress imparted by the ECC, σ_{lat}, is related to the tensile split first cracking strength, $f_{t,sp,y}$, and the cover to internal core ratio, c/d_o:

$$f_{cc} = f_c + 4.1 \cdot \sigma_{lat}. \quad (1)$$

$$\sigma_{lat.} = 2 \cdot f_{t,sp,y} \cdot (c/d_o) \quad (2)$$

where $\sigma_{lat.}$=2.26 MPa, f_c=10.22 MPa, f_{cc}=19.49 MPa.

Therefore, the confined concrete strength may be calculated by Eq. 3:

$$f_{cc} = f_c + 8.2 \cdot f_{t,sp,y} \cdot (c/d_o) \quad (3)$$

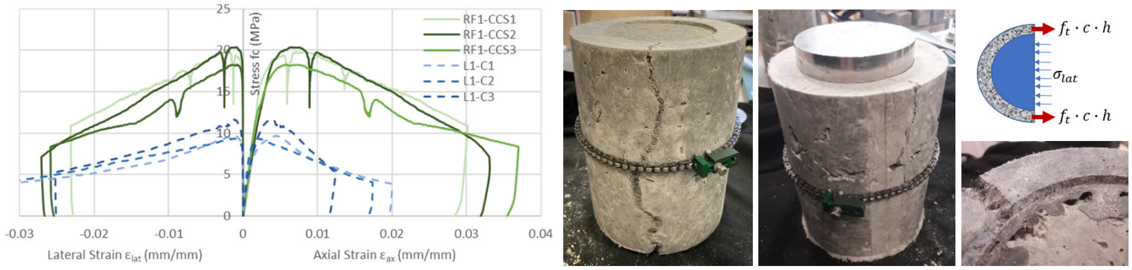


Figure B.3-5. Compressive stress-axial strain-lateral strain of LSC confined with ECC (left) and failure patterns (right).

B.3.5.3 Part C: Evaluation of the compressive strength of jacketed historic concrete columns

Cylinders measuring 150x300 mm, consisting of an internal core of LSC with dimensions 100x300 mm and 25 mm ECC cover, were tested under displacement-controlled compression, with the load applied on the entire cross section. The compressive strengths of the confined specimens ($f_{col,jac}$) were equal to 3 times that of identical 150x300 mm cylinders of LSC (f_c). The stress-axial strain-lateral strain of the members is recorded in Fig. B.3-6. The average values of compressive strength from the tests were used to calibrate an equation that can be used to compute the compressive strength of the ECC jacketed LSC members. The analysis used equilibrium of forces, as well as Eq. 3 for the confined LSC core strength (f_{cc}).

$$N_j = A_{cov} \cdot f_{c,ecc} + A_o f_{cc} = (A_{col} - A_o) f_{c,ecc} + A_o f_{cc} = \frac{\pi}{4}(D_{col}^2 - D_o^2) \cdot f_{c,ecc} + \frac{\pi}{4} D_o^2 \cdot f_{cc} \quad (4)$$

$$f_{col,jac} = \left(f_c + 8.2 \cdot \left(\frac{D_{col} - D_o}{D_o}\right) \cdot f_{t,sp,y}\right) \cdot \left(\frac{D_o}{D_{col}}\right)^2 + f_{c,ecc} \cdot \left(1 - \left(\frac{D_o}{D_{col}}\right)^2\right) \quad (5)$$

Where N_j is the ultimate axial load obtained during the test, A_{cov} is the area of the ECC confinement, $f_{c,ecc}$ is the compressive strength of the repair material, A_o is the area of the internal LSC core, f_{cc} is the strength of the confined LSC core, A_{col} is the total area of the member's cross section, D_{col} is the total diameter of the member's cross section, D_o is the internal diameter of the LSC.

As seen in Eqs. 4 and 5, the compressive strength of the jacketed column is related to (a) the split tensile strength at the initiation of cracking, $f_{t,sp,y}$, and the compressive strength, $f_{c,ecc}$, of the ECC repair material, and (b) the ratio between the internal diameter and the jacketed column total diameter, D_o/D_{col}.

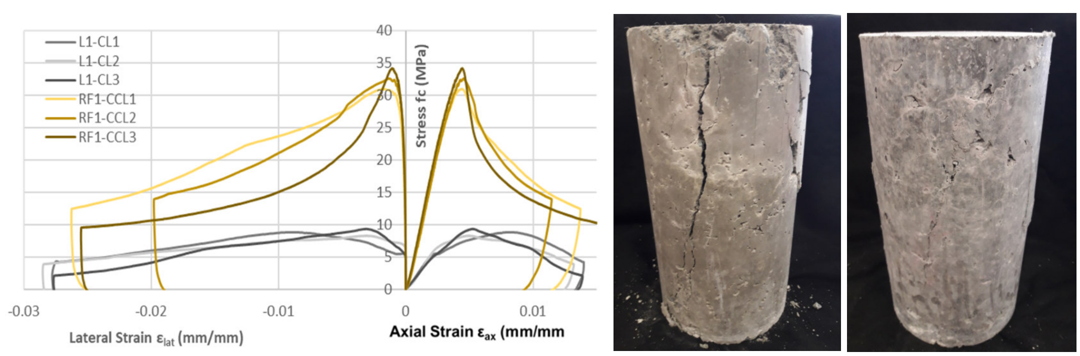


Figure B.3-6. Compressive stress-axial strain-lateral strain of jacketed LSC member with 25 mm ECC (left) and failure patterns of LSC (middle) and jacketed (right) members.

Design of the jacket repair

The design of the repair of LSC members using ECC jacketing may benefit from the use of diagrams that relate the original member's compressive strength, the ratio of the jacket thickness to the jacketed column's final diameter and the resulting/required compressive strength of the repaired member. These three parameters may be plotted in diagrams for different LSC compressive strengths, as shown in Fig. B.3-7 for the specific repair ECC material. The equation relating these properties is extrapolated by Eq. 6:

$$f_{col,jac} = f_{c,ecc} + 4.1 \cdot f_{t,sp,y} \cdot \left(\frac{D_O}{D_{col}}\right) + \left(f_c - f_{c,ecc} - 4.1 \cdot f_{t,sp,y}\right) \cdot \left(\frac{D_O}{D_{col}}\right)^2 \quad (6)$$

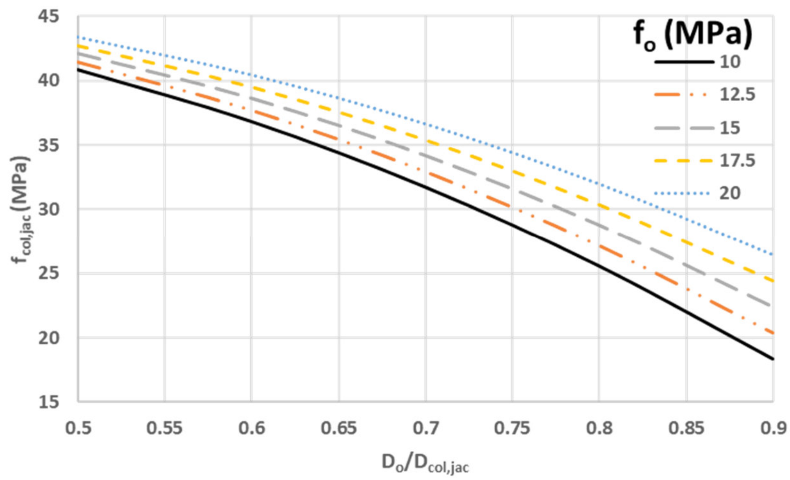


Figure B.3-7. Simple diagrams for the calculation of the necessary $D_o/D_{col,jac}$ ratio in relation to the required compressive strength of the repaired concrete ($f_{col,jac}$) and the compressive strength of the original concrete (f_o).

B.3.6 Conclusions

Historic concrete structures are prone to deterioration and damage due to their intrinsic characteristics, which relate to the properties of the raw materials, the geometry of the members and the detailing of the reinforcement. Restrictions on the possible retrofit solutions require that the structural members' dimensions, and thus the original architectural form, should not be altered, while safety provisions, especially under seismic loading, require drastic increase in strength and ductility. In this context for the determination of a possible solution for the retrofit of the Melkonian Headmaster's Mansion's columns, the effect of jacketing low-strength historic concrete, by replacing the concrete cover with strain hardening fiber reinforced cementitious composites, was explored. This strengthening practice for low-strength historic concrete appears to result in very effective confinement, even with small covers. The confinement effect, according to the experimental results, is related to the split tensile strength of the ECC material. Additionally, the compressive strength of the jacketed member is related to the properties of the ECC in tension and compression, and to the $D_o/D_{col,jac}$ ratio. Finally, simple equations and diagrams have been provided to enable the design for the retrofit of low-strength historic concrete with ECC jacketing for general purposes.

B.4 UNIGE: Hennebique grain silos, port of Genova

Figure B.4-1 Historical view of the south facade. Ex magazzini granari Hennebique, Genova 1901

B.4.1 Construction and modifications in time

The first project of the Silos of the port of Genoa dates back to 1899 (Fig. B.4-1). The complex is considered one of the first and most relevant works in reinforced concrete built in the early part of the twentieth century. The Silos were designed by Milanese engineers A. Carissimo, G. Crotti and G.B. Cristoforis who, at the time, contributed "*to dissolve the doubts that still existed about the construction system adopted*". The building belongs to a period in which the construction technique of reinforced cement conglomerate was still in a pioneering phase characterized by some patents that reflected both studies on theories and calculation methods and relevant legislation.

The construction was planned in two successive phases (Fig. B.4-2), according to a project that already included, at the functional level, an expansion [52]. The first lot (of the two planned) was built between 1900 and 1901 by the company Porcheddu of Turin, Agent and General Dealer of the "Hennebique System" for Upper Italy. Along with the silos, an iron pier for docking ships was also built. The second lot is documented to have begun in 1906, the year in which the plans were introduced to the harbor administration. The company that carried out the works of the expansion was the Ferrobeton of Milan holder of the Monier patent for reinforced concrete structures [53]. The building on this occasion was extended westward, bringing its length from 145 to 212 meters today.

Further extensions were made by Ferrobeton between 1924 and 1929 (Fig. B.4-2). The extensions mainly concern the part towards the sea, with the raising of the storage cells of the grains, the construction of a new series of cells, the general roof of the summit terrace with the arrangement of the offices and the reinforcement of 68 pillars. The maximum capacity reached by the silos was 65000 ton of grains that could be stored and moved, with a discharge potential of 8000 ton/day [54].

In 1941, the building was bombed and its central front was destroyed. In 1945, the reconstruction of the central tower, the floors of the pump room, the ribbons room, the sea side and the offices took place (Fig. B.4-2). After the war, new additions were made to the façade (Fig. B.4-2) and some secondary bodies were built to connect the complex with the granary silos of the nearby Parodi bridge, designed in 1926 but built after the World War and demolished in 1999.

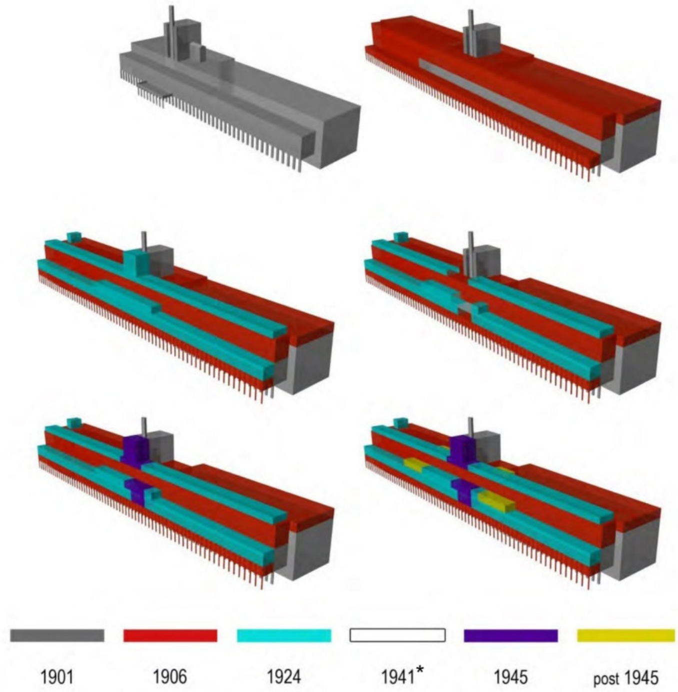


Figure B.4-2 Collapse following the bombing of Genoa by the Royal Navy during the Second World War

B.4.1.1 Scheme from Relazione Strutturale ing. S. Podestà - 2011

The different phases of construction and expansion of reinforced concrete structures are often characterized by absence of continuity characterized by elements built adjacent to each other. In addition, the construction of elevations in part of the building required the adaptation of existing structures, carried out according to the knowledge and culture of the time, which was sometimes insufficient to meet these needs.

B.4.1.2 Actual state

The complex has been abandoned since the 1980s and is currently in a state of total abandonment (Fig. B.4-3). The neglect and lack of the most basic maintenance and protection works have favored the progress of degradation processes, which are now in many parts irrecoverable, and compromise the stability of some structural elements, such as floors, pillars, beams, especially in some portions of the building which are often exposed to stormwater leaching and other aggressive environmental and atmospheric agents [53].

The granary silos were built at a time when the construction techniques of reinforced concrete were not yet developed and it was not possible to share previous experiences. For this reason, the concrete packaging methods were not completely reliable. The mixtures used contained round and large aggregates that induce to the material physical characteristics that promote degradation phenomena.

In addition, the natural environment favors the advancement of decay, as rainwater and the marine ecosystem are particularly aggressive [55]. The decay phenomena found on the structure are of both physical and chemical nature and mainly include carbonation of concrete, presence of sulfates and chlorides, corrosion of reinforcement, expulsion of re-bar cover, presence of lower and upper vegetation, attack of mold and fungi, accumulation of guano. The most serious forms of decay affect the parts of the complex that are most exposed to the external environment, and which have sometimes reached criticalities that cannot be recovered (to the extent that is necessary to proceed to total demolition and possible reconstruction) [55].

The comparison of the data collected during the studies carried out between 2013 and 2018 testifies to the progressive worsening of the conditions of decay of beams and slabs, both of the roofing and internally to the front body of the factory, and in the lateral portions of the east and west. This situation requires immediate careful and extensive monitoring, especially of the elements that could reach collapse, compromising the structural stability of the building [55].

Figure B.4-3 The southern facade of the complex

B.4.2 Approach to the restoration project

In 2018, the Autorità di Sistema Portuale of the Western Ligurian Sea, that has the concession from the Demanio Marittimo dello Stato, activated an agreement with Regione Liguria, Comune di Genova, Soprintendenza Archeologia, Belle Arti e Paesaggio della Liguria and Dipartimento dAD-Architettura e Design of the University of Genova to start new studies on the Hennebique Silos aiming at their restoration and reuse. The Dipartimento dAD then drew up, on behalf of the Entities involved, the Technical Data Sheet that Italian legislation foresees for interventions on any public property listed for its cultural interest, as an indispensable element for the Technical-Economic Feasibility Project of each intervention.

The following pre-project guidelines are therefore a summary of those provided by the Technical Data Sheet approved by the Soprintendenza Archeologia Belle Arti e Paesaggio territorially competent, to which any future project on Hennebique Silos will have to comply. These guidelines are for the valorisation, conservation and reuse of the building to realize an effective and correct restoration, both culturally and technically. The general principle that the restoration must follow is, first, the material preservation of the building and its constructive stratifications. In particular, it is necessary to ensure the strict preservation of its volumetric consistency and configuration and of its fundamental architectural, spatial, technological and constructive characteristics, as evidence of the 'material culture' of a pioneering era for the construction of reinforced concrete structures.

The restoration must also ensure the preservation of a significant portion of the granary cells, as evidence of the original function of the building, together with the elements that are representative of its functionality as "an industrial machine for grain handling". These include the in-situ enhancement of the machineries, plants and technical elements still surviving and recoverable, also protected by the State under the Code of Cultural Heritage and Landscape. In the same way, the intervention to realize the historical-cultural enhancement of the building and of the site, must be aimed at future public fruition of a significant part of the complex. The static structural aspect is a fundamental element of the complex, and of its historical value, and contributes to determining its material and cultural identity.

The restoration project should ensure:

- the maintenance of the original structural design of the complex, compatible with the necessary structural improvements;
- the compatibility of the materials used for the requalification with the original ones, so as not to cause damage to the existing structures;
- the durability of the materials and technologies used, which must be such as to ensure subsequent ordinary or extraordinary maintenance, easy and sustainable, without this leading to significant and irreversible alterations of the architectural complex.

It is necessary that the restoration intervention provides for the preservation of the external facades of the complex in their consistency, for their remarkable compositional and technological quality. Therefore, the intervention project shall preserve:

- the volumetric consistency of the building, with the possibility of modifications of the most recent additions and in a precarious state of preservation, taking care to ensure the substantial quantitative/volumetric correspondence between demolished parts and reconstructed ones;
- the central body with its emerging part and the chimney (Fig. B.4-4);
- the spatial unity of the full-height room on the ground floor and the spaces connected to it, between the two stairwells of the central body;
- the practicable terrace of the roof;
- the sea-side façade (Fig. B.4-5), with the possible exclusion of the extensions realized after 1941;
- the lateral elevations, with the possibility of creating limited openings and connections with the outdoor spaces respecting the formal composition;
- the string courses, frames and other moulded elements, in the parts of the building to be preserved;
- the preservation of the built matter, choosing plant solutions external to the preserved parts in reinforced concrete;
- the imitation of ashlar finish of the facades in the parts to be preserved;
- the most significant external writings;
- the Liberty railings still present.

Figure B.4-4 External front [57]

Figure B.4-5 View of the exterior [56]

Regarding the functional and distribution system, the following components must be preserved and properly exploited, as archaeological evidence of the production and architectural history of the complex:

- part of the granary cells of the first phase (Hennebique patent) and of the second phase (Monier patent), with the possibility of functional changes to the internal and external connections;
- an illustrative section of the grain handling system, including the characteristic and still preserved in situ accessory elements (Fig. B.4-6);
- some driveways on the ground floor, in part accessible by the public, and maintaining in part the difference in level existing between the rails and platform;
- the direct view of the sea;
- the floor with openings for filling the grain cells on the top floor (corresponding to those to be preserved);
- grain handling machines, originally placed on the floating pier and subject to a measure of declaration of cultural interest, with their adequate and significant relocation in the complex;
- the more meaningful signages, writings and internal panels related to the functions of the building, in its various phases of life and the port activity in kind.

Figure B.4-6 Internal rooms for the grain handling

To ensure the historical and cultural enhancement of a significant part of the complex, possible public use of the following is suggested:

- the granary cells preserved for memorial purposes, near the central body and the western and eastern heads of the complex;
- parts of the basement, ground floor, first floor affected by the in-situ conservation of an exemplary section of the grain handling system
- the large full-height space of the central body and the rooms connected to it, where significant finds from the history and original function of the building will be exhibited (Fig. B.4-7);
- a significant part of the summit terraces (Fig. B.4-7).

Figure B.4-7 External summit terraces (left) and internal pump room at full height (right)

B.4.3 Specific measures on reinforced concrete elements

The restoration of the structures and parts of the complex made of reinforced concrete cannot be established in a generalized way. This must be targeted, punctual and made with specific techniques, case by case, based on the state of conservation of the different areas of the artifact at the time of intervention, the structural function of the object of restoration and its cultural-historical value.

It is, therefore, necessary to assess, from different multidisciplinary points of view, the feasibility of:

- use of fabrics/nets or foils/preformed angular carbon fiber for the reinforcement of beams and pillars in areas where consolidation/restoration of the load-bearing capacity of the elements is necessary;
- re-alkalizing treatments of reinforcement and the use of mortar to restore the integrity of the re-bar cover in areas where this is missing or heavily degraded;
- restoration of the alkalinity of the concrete in areas where it is possible to maintain;
- conservation measures on surfaces, including cleaning and consolidation, after having carried out further investigations of the state of the matter and materials, especially for the surfaces of the outer envelope, such as the string course bands, frames, faux embossed finish and other moulded elements.

Part C: CONCLUSIONS

Historic concrete structures played an important role in the modernization of the construction sector in Europe. Though some initial steps have been taken for the recognition of such buildings as part of Europe's cultural and architectural heritage, decisive steps still need to be taken by the competent authorities in each member-state for these buildings to be preserved and restored, ensuring their unique characteristics are not lost. Due to the lack of an agreed uniform regulatory framework, and in the absence of Europe-wide experience in restoring listed concrete heritage buildings, their restoration follows different paths in different member-states, but also within member-states themselves, with some cases being more successful than others when attempting to balance issues around the preservation of the building's architectural characteristics, its seismic resistance, requirements arising from its re-use etc.

Concrete, as a widespread material used in the past 200 years, has contributed to the construction of complex structures that could have not even been imagined before. While practices change over time, architects and engineers involved in the preservation of concrete structures need to first understand the particularities of the material and of the design principles of the time concrete was introduced. Even though practices for the repair of standard concrete structures exist and are regulatory specified, historic concrete poses special challenges, and restoring such structures following the current health and safety requirements can bring changes to culturally and architecturally significant building elements.

This report is a first attempt to list examples of restoration proposals for the repair or retrofit of specific historic concrete structures. The case-specific examples from Cyprus, Italy, the Czech Republic and the Netherlands, deal with different issues arising from the local environmental conditions and specific needs, the characteristics of the materials, the architectural concept, the seismic stability etc. These restoration proposals, despite referring to specific case-studies, they may nevertheless serve as generalised examples for practitioners in different parts of Europe.

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