POLITECNICO DI TORINO

Department of Structural, Building and Geotechnical Engineering
Master Course in Civil Engineering

Master's Course Thesis

Analysis of conservation state of ferrocement structures of Pier Luigi Nervi: experimental analysis

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1 ABSTRACT

Reinforced concrete is the most present material in the Italian building environment and most of the reinforced concrete structures in Italy comes from the economic Boom period.

This period is characterized by a great experimentation work on this and other materials, one of them is ferrocement. New challenging shapes where researched and building records achieved, giving birth to architectural landmarks and masterpieces.

By the way, the experimentations considered reinforced concrete and ferrocement as eternal materials and didn’t face the durability problems which come out with time. So nowadays, especially the structures which where the most innovative in that period, presents various durability and conservation issues.

Those structures represent an important part of the Italian history and building engineering culture, they must be conserved and protected from degradation issues.

This work is focused on the Torino Exposition Hall B (To-Expo), designed by the Italian engineer Pier Luigi Nervi, a unique and a pioneer structure for reinforced concrete use and the ferrocement introduction, with the goal of define the conservation state of the structure and experiment new conservation possibilities for the material. The thesis work is part of a project supported by the Getty Keeping It Modern Initiative to develop a Conservation Plan for the rehabilitation of this masterpiece.

2 INTRO

In 1936 Ettore Sottsass designed the first building of the To-expo: the fashion building. This building is realized to host events for the city, it is located in a central area of Torino, inside the Valentino Park.

After the war, in 1947, a new project is commissioned by FIAT with the goal of to restoring the fashion building and create a new hall for the international automobile exposition of 1948, the hall B is so be designed and realized by Pier Luigi Nervi by the large use of ferrocement and prefabrication. In 1949 a new hall is committed to Nervi, the hall C and n 1954 the hall B has been enlarged. Both the buildings were celebrated as masterpieces of the engineering and great examples of structural possibilities.

In the next years the Hall B is hosting the international automobile exposition, but also in 54' the second exposition of the health arts. The expositions are moved to the Lingotto exposition centre some years later, so since then the hall B is only occasionally used for events, as for example in 2006 with the winter Olympics games is used for ice skating.

The halls B and C of To-expo are a famous example of ferrocement shell and P.L. Nervi architecture. Nowadays the Halls are in a state of partial abandon, used only for rare exhibitions and events. Getty foundation proposes the realization of a conservation plan "CP" for the two halls designed by Nervi.

The work of this thesis regards the materials and durability team [1], by working on the following activities:

- On-site investigations of the building
- Experimental investigations on materials and mock-ups

On-site inspections are carried out using non-invasive, partially destructive, or destructive inspections on the structural elements to check the presence of cracking, corrosion process acting or other important issues that can compromise the structural behaviour of the building.

The experimental investigations on material and mock-up are concerning:

- Determine material's properties by testing samples extracted on-site.
- Realizing ferrocement and cement samples with the same characteristics of the one used in the halls and carry out different tests to define the material's properties.
- Test different solutions for the material's conservation.

3 REINFORCED CONCRETE DEGRADATION

Reinforced concrete degradation is a challenging topic that's of fundamental importance to guarantee a good conservation of the structures with consequently a good use of the building heritage. This study subject for reinforced concrete structures is still subject of research as it is a relatively new field. The deeper investigation of the corrosion mechanisms in concrete can lead to a longer and safer usage of reinforced concrete structures.

3.1 REINFORCED CONCRETE

Reinforced concrete is the synergy between two materials: steel and concrete. Concrete is an elastic-plastic material, very good in compression, but with limited tensile property. Balancing the concrete weaknesses, steel behave in a good way in tension. Concrete PH is naturally higher than 13. This allows the protection of steel from environmental corrosion agents. In addition, the two materials have similar thermal expansion coefficient, which allows them to work together. Reinforced concrete comes out to be cheap and resistant enough to become the most used material in the world.

3.1.1 Concrete

Concrete is a heterogeneous material and is important to notice that its physical and chemical characteristics are heavily dependent by its components and by the ratios between its components, such as the ratio of water and cement which heavily influences the porosity and the mechanical property of the material.

Concrete is a mix of materials, composed as follows:

- **Water**: is the main ingredient which influence the workability of the cement paste during pouring, the concrete voids ratio, shrinkage and consequently the concrete maximum resistance. Is better to keep the water/cement (w/c) ratio under 0.5; if lower difficulties in workability comes out but this issue can be solved using additives.

- **Cement**: is obtained by grinding of clinker (that's obtained in rotating ovens at a temperature about 1300 - 1450 °C), cement powder is obtained. Cement's main components are the following.
    - tricalcium silicate $\mathbf{C_3S}$ is a component that contributes to the strength of the material but is developing its contribution to it in a real long time, it needs years to develop entirely.
    - dicalcium silicate $\mathbf{C_2S}$ will mainly develop its contribution to the concrete's resistance in months, giving to concrete enough resistance to be used instantly
    - tricalcium aluminate $\mathbf{C_3A}$, is a component that will react in some days to give a first low resistance to the concrete in a short time.
    - Ferric phase $\mathbf{C_4AF}$, which is also a fast hardening and low resistance component.

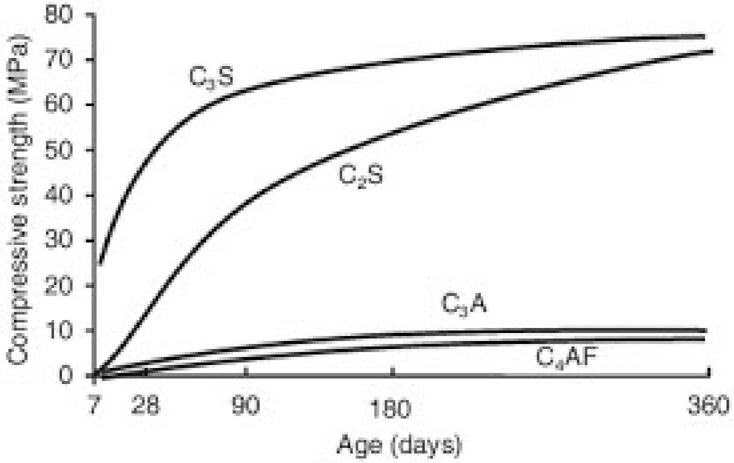

Figure 1 elements compressive strength development vs time [2]

- **Aggregates** have different sizes, the good balance between them is necessary to ensure the capability of the volume to be fulfilled. The aggregates are divided by size as:
    - Large Aggregate: Gravels, with diameter ϕ> 2 mm
    - Fine Aggregate: Sands, with diameter 0.25 mm<ϕ< 2 mm
    - Thin sands, with a diameter ϕ< 0.25 mm

  A good grading of the aggregates is provided in the Fuller curve, this proportion guarantees a good mix.

- **Additives** are becoming an important part of the concrete produced today. Additives facilitates workability of the material during pour and reduce the shrinkage of the material during curing. There are several different types of additives available in the market today [3]:

    - **Fluidifying additives**, are the most used additives. They allow to modify the concrete workability to facilitate during pouring.
    - **Super fluidifying additives**, is a common additive which allows to increase in a very important way the concrete's workability, it can be important to be used in case of highly reinforced beams.
    - **Setting accelerating** are additives that decreases the time necessary for passing from the plastic to the rigid state.
    - **Hardening accelerating** additives decreases the time necessary for the developing of the initial mechanical resistance of the concrete.
    - **Setting slowing additives** increases the time necessary for passing from the plastic to the rigid state.
    - **Setting slowing / fluidifying additives** are additives which acts by fluidifying the concrete paste and, as a secondary effect, slows the setting of the paste.
    - **Setting slowing / super fluidifying additives** works as the setting slowing / fluidifying additives, but with high fluidifying performance.
    - **Setting accelerating / fluidifying additives** have the effect of increasing the cement paste workability and as a secondary effect accelerates the setting.

- **Aerating additives** allows to insert in the concrete a pre-defined quantity of air micro bubbles.

The choice of the materials mix be used to realize concrete is of fundamental importance, because they must guarantee that the concrete is able to develop the chemical reactions which generates the microstructure of the material, and consequently its resistance. On the other hand, the materials forming concrete has also to be pure from any pollutant that may develop chemical reaction able to compromise the concrete's structural resistance.

3.1.2 Steel

Steel is a very homogeneous material, with an elastic-plastic behaviour and a high resistance.

Basic steel is composed by a mix of iron and carbon (up to 2%). Steel is both a good electric conductor and a good thermal conductor, that's due to the material's structure. In fact, the steel is made up of free electrons which can move inside the material and so easily transport heat and electric charges.

Iron, if not mixed with carbon, presents low mechanical resistances but the mix gains an increase of the resistance, with a consequent lowering of ductility. Generally, the carbon quantity and effects can be analysed in the Fe-C graph.

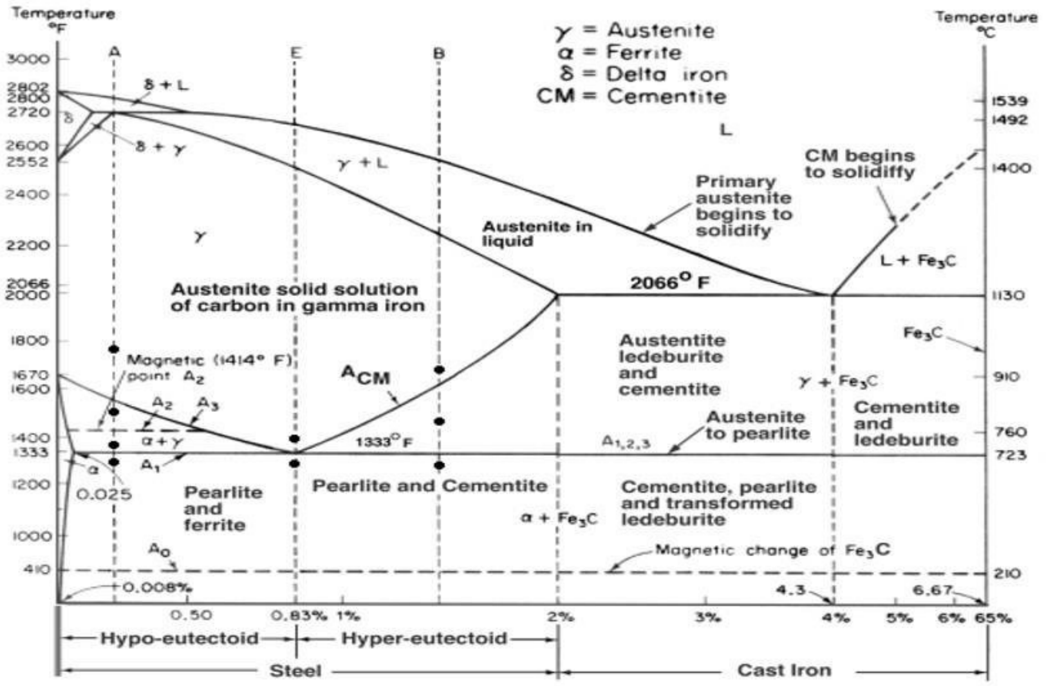

Figure 2 Fe-c phase diagram

We can distinguish in this graph different steel's solid solution:

- **Ferrite α**, which has got a maximum carbonium solubility of 0.02-0.03%, in the body centred cubic (BCC) configuration
- **Austenite γ**, which carbonium solubility is of 1.98 – 2% at 1130 °C in face centred cubic (FCC) configuration
- **Ferrite δ**, where carbonium maximum solubility is about 0.1%, and 1492 °C in BCC configuration.

Adding different types of elements, can lead to modify this graph by increasing or decreasing the austenitic field.

Austenitic field is increased by the following elements:

- Carbon
- Nickel
- Manganese
- Azote

Different cooling ratios are cause of different structures in the steel form. Typically, the steel is subjected to elevated temperatures and then cooled to reach its final form. In this process, grains are growing defining the microstructure of the material, the cooling ratio may lead to the formation of bigger grains in case of slow cooling, or to little grains in case of fast cooling. The mechanical behaviour of the steel changes with its internal microstructure, fast cooling will generate little grains which will cause higher resistance and lower ductility, while the opposite is achieved if the microstructure grains grow up bigger.

Steel for construction can be divided in three categories depending on the application in the field:

- **Reinforced concrete steel** is a steel which present good mechanical properties, and high ductility. Ductility is a fundamental property of steel when safety conditions are considered, that's because the ductile behaviour of the steel allows to absorb a large amount of energy for example during earthquakes events.
- **Pre compressed reinforced concrete steel**, this type of steel is made up to have a higher maximum resistance, which can reach values of 1800 MPa in maximum cases, but with reduced ductility.
- **Steel for metallic structures,** this steel needs to be carefully protected from environmental agents[1] (so paintings will be fundamental), and generally has good resistance against corrosion.

3.2 CORROSION IN REINFORCED CONCRETE

Concrete mechanical properties allow an optimum and safe structural solution for buildings, but several degradation mechanisms can affect the material, all those degradation mechanisms need to be understood and analysed to properly develop repair programs and interventions in reinforced concrete structures.

In reinforced concrete structures, corrosion is the most common deterioration mechanism. Corrosion is an electrochemical reaction between two elements: moisture and oxygen. When a corrosion mechanism starts, two areas are created and involved: anode and cathode. Anode is the area where oxidation occurs, and rust forms, cathode is the area where oxygen is consumed.

Corrosion is developed on steel bars when the concrete's PH gets lower than 9. The strongly basic chemical environment normally protects the steel, but during corrosion process the environment loses its basic properties and consequently, corrosion is developing in steel, rust forms from steel and the volume of the reinforcement bars increases about six times. This increase of volume

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[1] In reinforced concrete structures the concrete's PH, naturally highly basic, is protecting the steel from corrosion, which happens in acid environments.

causes the blowing out of the concrete near to the steel bars. Typically, two phases can be noticed in the corrosion process:

- An incubation period in which the concrete's PH is lowering, but corrosion still didn't start in steel.
- A propagation period in which the PH lowering of the concrete causes rust formation, concrete starts cracking where rust causes volume expansion of the reinforcement.

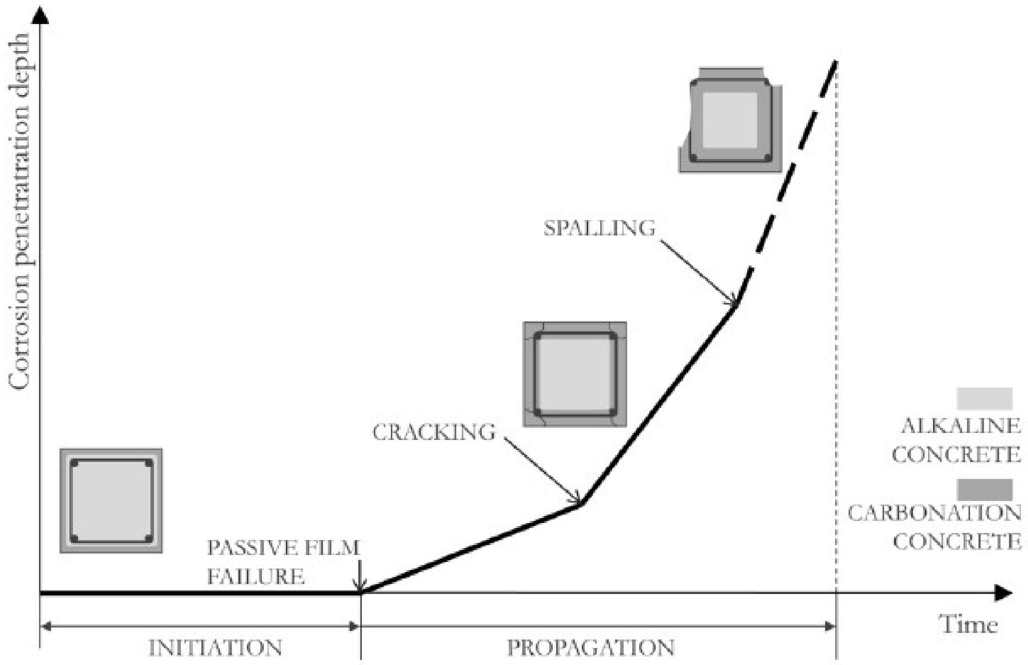

Figure 3 Corrosion development in reinforced concrete

Due to this phenomenon, the available section of the structure useful to resist to the loads is reduced in a significant way, this can obviously lead to big structural problems, which starts from difficulty of use for some type of structure and, in the worst cases, can cause the structure collapse.

The main corrosion causes in reinforced concrete can be resumed as [4]:

Chemical or electro-chemical corrosion causes

- Chloride's exposition
- Sulphates and sulphite action
- Freeze-thaw damage
- C02 exposure
- Concrete washout
- Carbonation
- Alkali – aggregates reaction

Physical corrosion causes

- Stress corrosion cracking
- Load cracking
- Shrinkage cracking

- Creep cracking
- Thermal variation cracking
- High temperature exposition

There are some concrete types which is better to avoid using in specific situations, for example [5]:

- In marine environment (XS) or in environments in contact with de-icing saults (XD) it can't be used Portland cement (CEM I) or Portland cement mix (CEM II)
- In buildings exposed to CO_2 corrosion (XC) it must be avoided the use of Pozzolanic cements (CEM III), blast furnace cements (CEM IV) and Composite cements (CEM V)
- In buildings in contact with selentic soils or selentic water must be avoided the use of Portland cement mix (CEM II)
- In concretes where potentially alkali-reactive aggregates are present, must be avoided the use of Portland cement (CEM I) or Portland cement mix (CEM II)

Concrete's degradation is not usually directly attributable to the concrete type or class, but this can have an important effect on the concrete conservation or deterioration. As an example, the starting phase of the corrosion process (the incubation period), can be postponed using specific types of cement paste or aggregates, or using a minimum concrete cover.

Also, the additives in the concrete mix can have some deterioration effects. Mainly those effects are constituted by superficial defects in the form of little voids of variable dimensions (from some millimetres up to few centimetres), mainly due to superplasticizers additives based on polymers. Low w/c ratio increases the entity of those effects, cause of the higher viscosity of the mix.

Water is one of the most important degrading agents for concrete, that's because without water polluting substances wouldn't be able to get inside the concrete and even electrochemical processes cannot develop in dry concrete. Low voids ratio can help in reducing the concrete deterioration probabilities. w/c ratio is highly connected to the void's ratio, lowering the w/c ratio will lead to low permeability concrete.

The penetration of pollutant agents is usually due to fluids penetration in concrete, mainly by three mechanisms [3]:

- **Permeation**, a mechanism for which a strong pressure gradient is causing the external pollutant aging penetration
- **Diffusion**, which is a mechanism where the penetration of the pollutant agent is mainly governed by the concentration gradient
- **Capillary suction**, which is generated from the superficial adhesion forces between liquid and soil

All those processes are usually present at the same time in structures.

3.3 CHEMICAL OR ELECTROCHEMICAL CORROSION CAUSES

This type of corrosion is involving mainly chemical reactions or electrochemical processes between aggressive agents coming from the external environment or from the concrete's aggregates and the concrete itself. Structures in contact with water or underground in constant contact with soil are more subjected to this type of corrosion, because in water and soil substances cause of chemical degrade for concrete may be found.

3.3.1 Chloride exposition

Chloride exposition corrosion is one of the most severe corrosion. Chlorides are naturally present in sea water and in marine environments, but they are also present in de-icing salts.

Chlorides migrates in the concrete by electric field and in water flow, and the rate of diffusion can be described by a diffusion coefficient [6]. The capability of transport of chlorides is affected by the pore structure, the more pores are connected and the more easily chlorides will migrate in the structure.

Chlorides action on concrete

Structures where the use of de-icing salts is abundant are highly subjected to chlorides deterioration action, but those can also be introduced by error in water used for casting concrete, also structures in contact with water that contains chlorides are highly affected. This kind of deterioration can drastically reduce the service life of a structure.

Chlorides can act in two ways [4]:

The first one involves calcium chloride ($3CaCl$), used as de-icing saults, largely used in cold environment's structures and roads. Its main effect is the disintegration of cement paste around the aggregates. The reaction of the disintegration mechanism is:

$$3CaCl + Ca(OH)_2 + 14H_2O \rightarrow 3CaO * CaCl_2 * 15H_2O$$

Calcium chloride ($3CaCl$) penetrating in concrete reacts with the lime in form of calcium hydroxide ($Ca(OH)_2$) and forms the hydrated calcium oxychloride ($3CaO * CaCl_2 * 15H_2O$).

In the second one sodium chloride (NaCl), that's also a de-icing sault, can react with the aggregates of concrete. Sodium and potassium present in concrete and amorphous silica present in aggregates reacts.

The velocity of penetration of the chlorides is strongly dependent by the factors which determines the void ratio in concrete and the depth of penetration will be dependent by the concentration of chlorides in the liquid in contact with the surface (mainly the pollutant substances are entering in the concrete in a liquid form).

Chlorides action on steel

Steels are protected by a stable passive film, which is thermodynamically stable in an alkaline environment, even if chlorides are present [7].The stability of the protective layer on the reinforcement bars can be attacked by a high presence of chlorides. In this condition steel will transform into iron hydroxide, forming rust.

In this corrosion phenomena during the incubation period, the depassivation of the protective layer develops, and later rust is generated, consequently the section of steel bars is reduced. However, "The incubation period is associated with a critical chloride concentration cumulated on the reinforcing steel surface" [8]. During the incubation period no physical damage occurs [6] on the steel.

A study carried out by Olivier Poupard, Abdelkarim Aït-Mokhtar, Paul Dumargue [8] shows that the chloride threshold level increases with the decrease of the w/c ratio, this means there is a correlation between the capability of the chlorides to migrate in a porous material and their capacity to attack the steel. Concretes with a low voids quantity may result to be more resistance to chlorides attack.

This type of corrosion is referred to as pitting corrosion. Localized and diffused corrosion can also co-exist due to the environmental conditions. If a first point of the steel surface is interested by pitting corrosion[2], the area of acting of corrosion behaves as an anode and the surrounding steel protected by the passive layer behaves as a cathode, creating a micro corrosion cell and corrosion area grows. The pitting nucleation, as widely recognized, is usually followed by repassivation [6], but a local fall in the PH combined with an increase of the chlorides content may prevent this phenomenon

3.3.2 Sulphate and sulphides action

Sulphate Ion SO_4^- can attack the concrete from outside and inside. Sulphates can be present in water or in soil, possibly from natural, biological, or anthropic origin. Sulphate is naturally present is soils due to the evaporation of sea water caused gypsum deposit, even if generally in low quantities, but some areas can have high sulphate concentration that can be dangerous for concrete. Sulphates can also come from the decomposition of biological substances in aerobic conditions. Sewage systems are interested by the presence of sulphates from water passing through them. From inside the sulphates can attack the concrete mix if present in the aggregate used in the mix.

Sulphate can reacts with $Ca(OH)_2$ and hydrated calcium silicate generating some an increase in volume of the material.

Gypsum is melted and then crystallized in the concrete's voids, without volume variation:

$$\mathrm{Ca(OH)_2} + \mathrm{SO_4^{2-}} + 2H_2\mathrm{O} \rightarrow CaSO_4 \cdot 2H_2O + 2OH^-$$

Then it can be that C_3A residues are involved in the reaction as:

$$C_3A + CaSO_4 \cdot 2H_2\mathrm{O} + 24 - 26H_2\mathrm{O} \rightarrow C_3A \cdot 3CaSO_4 \cdot \mathrm{H}_{30-32}$$

Or is more common that hydration products of tricalcium aluminate (C-A-H) as:

$$C_3AH_6 + 3(CaSO_4 \cdot 2H_2\mathrm{O}) + 24 - 26H_2\mathrm{O} \rightarrow C_3A \cdot 3CaSO_4 \cdot \mathrm{H}_{30-32}$$

Secondary ettringite develops, which is particularly dangerous for concrete because it causes the swelling in the concrete up to the breaking of the material and the detachment of some material parts.

To avoid this type of deterioration, a range of maximum percentage in weight is determined for the sulphates as the 0.8% for fine fractions and 0.2% for gross fractions [5].

Sulphide ion is not directly dangerous for the concrete, but due to its presence acid substances (ferrous sulphate) will develop which can decompose and attack the concrete. Expansive phenomena called pop out will be generated and damages provoked. It can be dangerous in:

- Clay soils with a high amount of FeS_2 (that can be found in soils with pyrite presence), cause sulphuric acid (H_2SO_4) and carbon dioxide (CO_2) will be generated.
- Sewers waters with a high amount of hydrogen sulphite (H_2S), this sulphite if in contact with air is transformed in hydrogen sulphide, that will damage the concrete where water is not present

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[2] This phenomenon is called pitting nucleation

3.3.3 C02 exposure

When CO_2 reacts with reinforced concrete, it neutralizes its alkaline components and lowers the PH value under critical values that generates an environment favourable for corrosion to initiate[3]. This process is called Carbonation.

CO_2 can be found both in water and air in different percentage depending by the environmental pollution conditions. In normal conditions, in absence of macro defects, the corrosion rate is very low (<µm/year) and can be considered null in practical aspects. In these conditions the steel inside the concrete is protected by a thin oxide layer (<2nm) that forms rapidly in the first phases of concrete's hydration. The stability of this protective film can be broken by the CO_2 presence.

3.3.4 Washout of concrete

If concrete structures are in contact with water rich of CO_2 washout of concrete can be developed. CO_2 in water reacts with calcium hydroxide present in the cement paste, and creates calcium carbonate:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

which will then react with carbonic acid creating calcium bicarbonate, that can be washed out from the cement paste due to an elevate solubility, causing concrete structures degrade.

$$H_2CO_3 + CaCO_3 \leftrightarrow Ca(HCO_3)_2$$

We distinguish the case of water with a high or low presence of CO_2 .

A high concentration of CO_2 leads to washout and so ,in the last equation, the equilibrium will tend to the right side, with a consequent loss of material. So if CO_2 aggressive water is present, the concrete paste will get a loss of material and mechanical resistance.

Low CO_2 presence water don't have any washout effect, on the opposite it leaves limestone on the material.

3.3.5 Carbonation

Carbonation does not produce directly damages, but lowering the PH results in the de-passivation of the steel bars, preparing an environment favourable for corrosion to initiate. The reaction is the following:

$CO_2 + Ca(OH)_2 \text{->} Ca\ CO_3 + H_2O$

The speed of the carbonation process is influenced by the CO_2 penetration rate, which depends by:

- The mechanical resistance of the concrete, the higher then the lower is the penetration rate.
- The relative humidity of the environment, in moderate humidity environments the penetration is favoured, if the concrete is exposed to rain the process is slower, because this stop temporary the CO_2 penetration.

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[3] Typical values that cause corrosion developing in concrete are PH<9, with consequent de-passivation of reinforcement.

- The hardening process: if it is carried in humid environment, the CO_2 penetration rate is lowered.

If the carbonation reaches the reinforcements, the protective film is damaged and if water and oxygen are present corrosion can initiate.

To contrast this, it is possible to:

- Reduce the concrete void ratio, to slow down the CO2 diffusion process using low w/c ratio in concrete.
- Increase the concrete cover thickness

3.4 PHYSICAL CORROSION CAUSES

Those processes mainly involve processes of temperature variation, humidity gradients and static or dynamic loads applied on the structure. Physical corrosion causes can be predicted during the design of the building, and so consequently safety solutions can be adopted to counter the degradation that may occur.

3.4.1 Cracks opening causes

The crack opening represents a big issue in concrete structures, they can be due also to the presence of high stresses concentration in some parts of the structure, due to loads or shrinkage process.

This kind of cracks is not always developing severe reduction of the structure resistances in short times, but regarding long times they can become dangerous. In bridges, or in general in pre-compressed structures, a goal for the maintenance is to avoid the formation of cracks, so deterioration of the material is not favourited.

Cause of this risk, an analysis of the crack opening is fundamental to avoid developing of dangerous situations in concrete structures (related to the durability of the material). Of course, for each type of crack there will be a physical meaning and by understanding the structural concept of the building is possible to get back to the causes of a crack, and so fix it.

The most probable reason for the opening of some cracks is the presence of high loads and stresses concentration in some points. Cracks and defects need to be analysed both in the main structure of the building and in secondary elements, this can lead to a better understanding of the causes of the develop of the cracks. An important thing to consider is that in concrete the crack opening is always perpendicular to the direction of the tensile stresses.

Compression cracking. The first kind of cracking that can be analysed is the compression cracking. This kind of cracking is typical because concrete structures usually work in compression, due to the low traction resistance of the concrete and all the durability and stability problem that could be developed consequently. A typical behaviour of a pillar or a wall in compression state is the tendency to throw-out and the developing of cracks in direction following the compression lines, and in particular the cracks can be focused on the steel reinforcement rebars position.

Flexural cracking. This kind of cracking is also very common in reinforced concrete beams. If a beam is subjected to flexural stresses, one part of the fibres of the beam, which are usually the upper ones, is subjected to compressive stresses, and the other one will be tensioned with opening of some cracks that follows the section height due to the low resistance in tensional stresses in concrete.

Shear cracking, flexural-shear cracking. Shear cracking is one of the most dangerous failure mechanisms in concrete buildings because the type of failure associated with this type of mechanism is brittle. Is common that the failure mechanism is usually a combined flexural-shear failure mechanism, as the result of different types of components in concrete. In a beam subjected to mainly shear stresses, the crack opening tends to follow a 45° straight line. The presence of flexural stresses in the beam leads to cracks of 45° in the middle of the beam and orthogonal cracks closer to its sides.

Torsional cracking. The shape of the cracks generated by a torsional stress is very similar to the one due to flexural-shear cracking. That's because the stress mechanism developed on the beam's face is practically the same. The difference is in the orientation of the cracks on two opposite faces of the beam, that in this case will be opposite as well.

Traction cracking. Having traction cracking is rare in reinforced concrete structures, cause since the concrete is working in a good way only in compression, its elements are usually only designed as compressive elements. By the way due to shrinkage, it can be developed.

Table 1 crack opening types

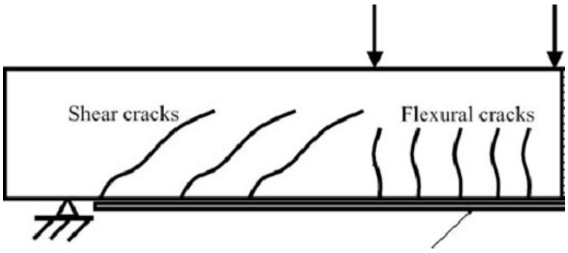


Figure 4 shear and flexural cracks shape [9]

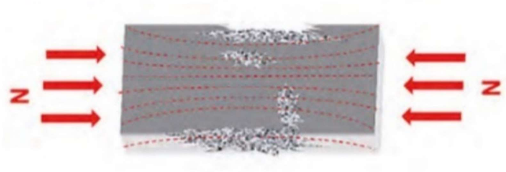


Figure 5 compression crack lines [4]

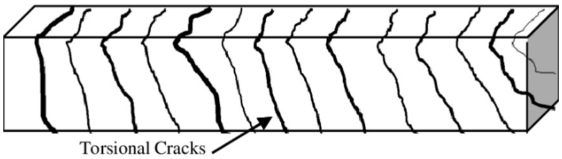


Figure 6 torsional cracks shape [9]

Figure 7 tension crack shape [9]

3.4.2 Shrinkage cracking

Water loss during the concrete's hardening brings to a loss in volume of the concrete specimen, consequently tensional stress may be developed in the structure and so as well cracks.

A good way to counter shrinkage using low w/c ratio in the concrete and keeping high humidity on concrete during the first days of hardening. The evaporation of the water present in the voids is not cause of high-volume contraction, but once that water evaporated, if concrete is kept exposed to a dry environment, concrete hydration products may also evaporate. This part of the water loss leads to a higher volume contraction. Consequently, we can understand that the only part interested in the shrinkage is the cement paste, and not the aggregates in the concrete mix. The aggregates have an action of opposing to the volume contraction, depending by their rigidity.

Also, the structure geometry is influencing shrinkage. High surface/volume ratio structures will be subjected to a higher water evaporation, and consequently to a higher shrinkage.

So, influencing shrinkage parameters will be:

- The w/c ratio, lower it will be and lower will be the volume loss.
- The cement paste volume, the higher it will be, and the higher will be the contraction.
- The relative humidity of the environment in which the concrete is places, in an environment with low relative humidity a higher water quantity will be lost, and so higher volume loss as well.
- The geometry of the structure, depending on the surface/volume ratio.

Plastic shrinkage

Plastic shrinkage is the diminution of volume in concrete structures due to the water evaporation in the concrete in the short time.

This kind of shrinkage is usually about the 1% of the total volume and is countered by the friction between the concrete and the steel reinforcement bars. Cause of this resistance some cracks develops. This type of cracks can reach dimensions of 2-3 mm and are usually concerning the external part of the concrete specimen if in dry environment. The shape of those cracks usually is composed by different cracks all starting from the same point. In presence of reinforcements the cracks can develop along them [4]. Concrete hardening under controlled humidity conditions can help in avoid the cracks opening.

Hydraulic shrinkage

This type of shrinkage is developed after the drying of the concrete.

Usually, the most of this type of shrinkage, up to ¾ of it, is developed in six months after the concrete casting. Shrinkage will also in this case develop tensional stresses due to the friction, which is opposing to the loss of volume, any kind of obstacles in the geometry of the structure will be cause of the opening of new cracks.

In both cases, shrinkage cracking can be avoided in the design phase by using geometries and systems which allows the free contraction of the material, and mainly by avoiding points that may represent obstacles from this point of view.

3.4.3 Creep cracking

Concrete response under permanent loads is determined by two parts:

- An initial elastic response
- A viscous deformation, called creep, which can be developed in long times, even years

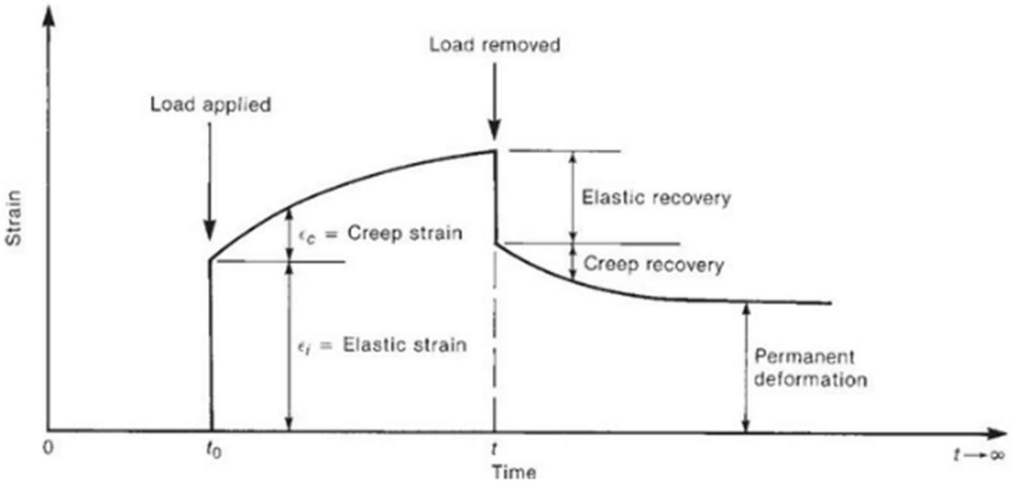


Figure 8 creep deformation time / strain graph [10]

The viscous deformation entity is strongly related to the time of application of the load, is known that a fresh concrete is more subjected to this type of deformations, instead of an old concrete, which develops higher resistance and shows less creep deformations.

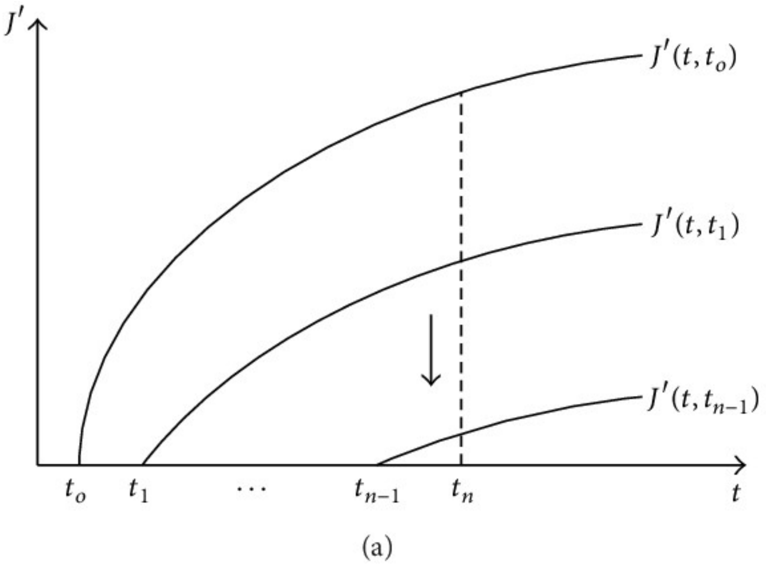


Figure 9 Creep deformation / time graph, curves for different time of application of the first load on the specimen [11]

Concrete behaviour is strongly related to the time variable, and in design and in diagnostic of buildings this topic must be analysed.

In general, both shrinkage and creep need to be considered in static analysis. By the way, the creep effect is not easy to determine.

In columns, creeps lead to a slow movement of the static load from concrete to reinforcement bars. It can become dangerous if the steel reaches the yielding limit, in that case the load would be entirely moved on the concrete. Sometimes creep can have also good effects, as for example in hyperstatic structures it can lead to a redistribution of stresses, and so decrease the cracks dimension and number.

Creep becomes fundamental in bridges behaviour, especially in pre-tensioned and post-tensioned structures, that's because it can lead to big displacements which are not compatible with the structure behaviour, causing the opening of cracks and accelerating the deterioration phenomenon in concrete, so in this case maintenance becomes fundamental to avoid big damages in structures. A good mix design can help to counter creep, as for example by avoiding the use of light aggregates. A good understanding of the construction procedure is fundamental to predict the creep developing, and so select the right way to construct to avoid creep problems.

3.4.4 Thermal variation cracking

When a structure is subjected to thermal source, or generally to a variation in temperature, the material naturally tends to expand, if it is warmed up, or to shrink, if it is cooled down, this process may lead to the formation of cracks in the structure, with consequent issues about durability.

The cracking can be due to so much different causes, but in general we can define two types of thermal variation cracking [4]:

- **External thermal variation** can involve the full structural element, that can shrink due to the lowering of the temperature of expand due to the increase of it. If this movement is not allowed (that can be dangerous in big structures, as bridges), the consequent accumulated stress can lead to cracks formation. This type of cracks is increasing and lowering following the thermal variation, so by checking the evolution of the cracks in time it can be seen a cyclic increase and decrease of their dimensions.
- **Inhomogeneous thermal variation**. If thermal variations are not interesting in a homogeneous way all the structural member, local stresses will be developed in the structure. The crack opening in this case will be more unregular and so a specific solution is necessary to solve the problem.

3.4.5 High temperature exposition

If subjected to high temperature exposition, free water present in concrete tends to evaporate.

Usually reinforced concrete structures have a good resistance to high temperatures, because concrete is bad heat conductor and can protect in a good way the steel, but because of the thermal shock of the water used to extinguish fire the concrete tends to disaggregate, exposing the steel reinforcement. Temperatures lower than 300 °C are not affecting the concrete resistance, but in case of temperatures with higher values, the compressive strength of concrete reduces dramatically, up to being lost for temperature values about 800°c [12]. At high temperatures, concrete hydration products will start losing the free water present inside them and will completely loose the capillary water at 400 °C [13].

From a chemical point of view, we can describe what happens to the hydration products as [13]: "AFt/AFm dehydrates at 110–150 °C.

Above 350 °C, calcium hydroxide either decomposes into lime and water or further converts into C–S–H due to the accelerated pozzolanic reaction at a high temperature.

The decomposition of Ca(OH)2 has no critical influence on the reduction of strength for concrete. However, if concrete is water cooled after exposure to high temperature, the rehydration of lime causes a great reduction of strength for concrete due to a considerable expansion.

C–S–H starts to decompose at around 560 °C and it decomposes into β-C2S at around 600–700 °C. C–S–H (I) decomposes at 800 °C, which, however, only results in a slight reduction of strength for concrete. During 580–900 °C, decarbonation of carbonates occurs."

The cement pore size increases during the exposition to high temperatures, this may favourite the future introduction of damaging agents. In high strength concrete, explosive spalling had been considered as a common phenomenon occurring inconsistently when high strength concrete is subjected to high temperature [14].

A factor that influences the concrete resistance to high temperatures is the type of aggregates, it is better to use limestone and dolomite aggregates that shows a better behaviour if subjected to high temperatures. Also aggregates that decreases the heat conductivity, as lightweight aggregates, can help in increasing the concrete resistance when exposed to this kind of phenomena.

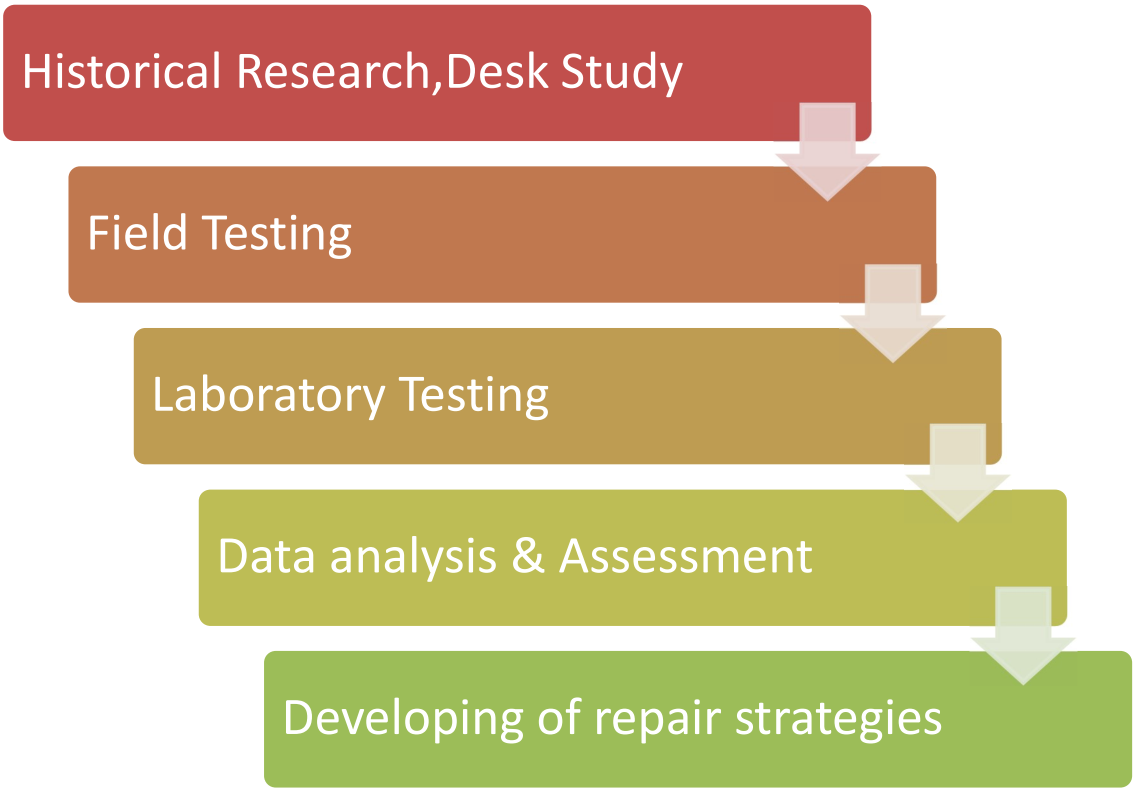
4 STRUCTURAL DIAGNOSIS

Italian building and infrastructural heritage need intervention and unachievable without good knowledge in buildings structural diagnosis, for this reason structural diagnosis is becoming a very important topic nowadays.

The construction world, for what regards the Italian area, is not focusing on new buildings anymore. That's due to the high number of buildings that exists and their origin, which is mostly from 1960's. Due to the age of the buildings, and the material used during construction (mainly concrete), several degradation phenomena are typically affecting these buildings. Structural diagnosis becomes so fundamental for renovating the building heritage.

Diagnostic process passes through a series of mandatory steps before the diagnosis output:

- First step: Historical investigation and archival research. Review of previous repair campaigns if conducted;
- Field Testing: In situ tests to assess the condition of the structure;
- Laboratory Testing: Perform laboratory testing and analysis to determine the quality of the material;
- Data Assessment: Assessment of the data collected in the field;
- Development of a repair program for intervention.



4.1 HISTORICAL RESEARCH

The historical research is the process of collecting all available information about the structure including drawings, documents, photos, and videos.

All these information can assist the diagnosis process by:

- The definition of the time in which the structure has been built, and when repair or maintenance interventions that could have modified the structure were carried out. Knowing that irregularities in the building can be known before the on-site inspection, and the planning of the check for the efficacy of different solutions on the building can be analysed in a more efficient way.
- The definition of how, in origin, the structure was thought to be, so the pillars and loads positions, the reinforcement quantities and geometries, and the structural configuration of the building. This is important to understand which one can be the strong and weak points of the structure.
- The understanding of all components and materials used in the structure, to understand which elements can have weakness due to high stress conditions or missed maintenance.

4.2 UNDERSTANDING BUILDING COMPONENTS

A good understanding of the building components is fundamental to determine which places are the most suitable for corrosion and deterioration processes. The general state of being of the structure and the planning of field tests on the structure can be developed from this.

A deep investigation allows to list and catalogue all the possible damages, as cracks position, the presence of high humidity in some part of the structure, swelling of the floor and all the elements that may lead to problems in the structure. All the details will then be deeply analysed in a second moment of the inspection, with specific instruments, to get various data on each problem.

Both historical investigation and good understanding of the building components is needed to develop the field tests planning in a proper way and consequently the equipment needed to perform the diagnosis. Reporting all the acquired issued in a simplified 3Dimensional or 2Ddimentional models as plants and views can help to get a better understanding of the structures and how the different deterioration effects may influence each other.

Is useful to notice how this type of inspection reveals only damages on the outside part of the structure, once the structure has already been damaged [15].

4.3 FIELD TESTING

Field Testing is mandatory to understand the state of being of the structure and demonstrate problems developed in structure elements.

Field testing is fast and consistent approach to collect a big amount of data, which can be then used to select points where to perform deeper analysis (as destructive tests, if necessary) or also just as data to interpolate to understand the possible phenomenon happening in the structure. Different types of tests must be performed to compare data properly perform the diagnosis.

Data are collected by indirect measures on the structure, because from a good quality material there must be high values of the different mechanical parameters. The fast and relatively easy inspection of the buildings allows the continuous monitoring of the energetic and structural state of being of the structure.

4.3.1 Video inspections

Endoscopic images allow to extend the visual inspection inside areas that would usually not be reachable, as for example the inside of a beam, by using holes (which can be both natural and artificial one) where a sonde is inserted. With this instrument is possible to verify the state of being of the material, checking for anomalies, and even perform some geometrical measurements. There exist three types of endoscopes [16]: Rigid, flexible, and video endoscopes.

A **rigid endoscope** is constituted by a rigid tube with prisms and lens, which allows a transfer of the image from one side to the other of the tube. Generally, this instrument can reach just some meters of length, due to the influence that the length of the system has on the resolution of the output image. Light is also highly influencing the resolution of the image; a good illumination must be provided to the system provide good output.

Flexible endoscope is made up by two optic fibres bundle, one inside the other one. The internal one provides the transmission of the recorded image, the external one provides illumination to the investigation area. The clear advantage of this type of system, is the capability to investigate even in areas difficult to reach.

A **video endoscope** is composed by a micro camera connected to a monitor. The images can be recorded and checked later. The use of a video endoscope is practically the same as a flexible one, so a flexible tube with a camera on one side and a monitor on the other provides the images.

Figure 10 endoscopy test [17]

4.3.2 Thermographic tests

Infrared rays' thermography allows to measure the temperature of an object in real time. The image is realized using a thermal imaging camera that gets a thermal image without touching the object.

That's cause the thermographic image is using only a specific area of the thermographic spectrum, which are:

- 3 – 5 µm, short waves, for high temperatures, as for example for industrial field
- 8 – 14 µm, long waves, for common temperatures, in civil field

Different materials are reflecting differently radiation waves, consequently, is possible to detect elements of discontinuities in structures with the thermographic images output, which can be due to the presence of different materials, water infiltration or other causes.

The thermographic survey can be qualitative of quantitative.

The **quantitative** thermographic survey requires the exact value of thermal variation found in the element.

The **qualitative** thermographic survey is based on the analysis of how the thermal variations are disposed and so where something wrong may be developed in the building. For this reason, it is the most used in the civil field.

Table 2 Emissivity of common materials. [18]

Materials	Temperature (K)	Wavelength (μm)	Emissivity
Aluminium (heavily weathered)	290	–	0.83–0.94
Cast iron (heavy oxidation)	377	–	0.95
Cement	298	8–14	0.54
Clay (fired)	298	8–14	0.91
Common brick	290	2–5.6	0.81–0.86
Concrete (dry)	309	5	0.95
Copper (oxidized)	311	–	0.87
Fiberglass	293	–	0.75
Granite (natural surface)	309	5	0.96
Graphite	293	–	0.98
Limestone	311	–	0.95
Marble (grey, polished)	311	–	0.75
Masonry brick	273	5	0.94
Mortar (dry)	311–533	2–5.6	0.94
Tempered iron (polished)	313–523	–	0.28

4.3.3 Cover Survey

Cover meter tests allows an investigation on concrete surfaces for the concrete cover and the reinforcement position.

Is composed by a sonde, which receives and transmits an electromagnetic field influenced by the presence of steel inside concrete. Cover meter test works by measuring the quantity of the electromagnetic field absorbed by the steel.

An analogic-digital system connected to a sound device helps the individuation of the steel bars. The signal will be stronger if the concrete cover on the steel is lower, or if the steel bar is bigger.

The aims ca be:

- Analysis of the reinforcement's position and number.
- Concrete cover thickness determination.
- Individuation of the areas of the element without reinforcements at all, where concrete diagnostic tests can be executed (for example a sample can be extracted in that area and so, before having a destructive test on the concrete, a cover meter test analysis is fundamental to avoid the intersecting of undesired elements).

The steel dimension and the concrete cover cannot be determined at the same time. Having information about one of the two parameters will so be fundamental to perform a consistent verification about the inspected quantity.

Small diameter steel can be difficult to measure if the concrete cover is too big and having too many steel bars will generate a lot of difficulties in measuring their position, because it would not allow to appreciate the variability of the magnetic field.

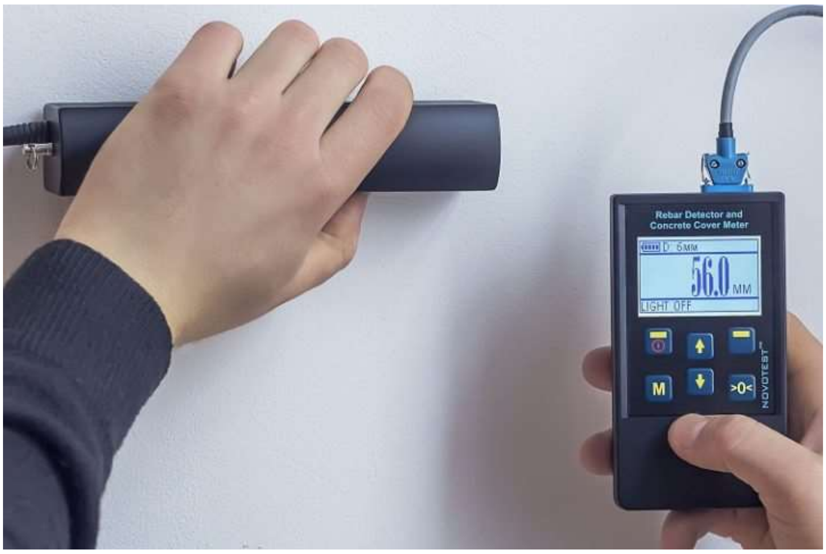


Figure 11 Cover meter during usage [19]

4.3.4 Corrosion potential measurement

Corrosion potential test is capable to determine corrosion condition in concrete providing a probability of acting corrosion, useful as a data for deeper inspections.

It is based on the principle for which each corrosion condition is affecting the corrosion potential, in determined ranges, and so it can be detected and mapped. This corrosion potential is measured by the potential difference between a reference electrode and the concrete's surface[4]. Concrete's surface is usually wetted before performing the test, in this way the electricity flow is favoured, and the corrosion potential measured more representative.

To have a comparable value of the corrosion potential, is fundamental to have standard reference electrodes, the three main ones used (versus standard hydrogen electrode: SHE) for it are [20]:

- Copper / copper sulfate sat CSE + 0.318 V SHE
- Calomel (Hg / Hg2Cl2) KCl sat. SCE + 0.241 V SHE
- Silver chloride (Ag / AgCl) KCl sat. SSCE + 0.199 V SHE

Of those ones, the first one (Copper – copper sulphate electrode) is the most used in on-site applications, the other two are mostly used on laboratory work [20].

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[4] Steel rebar is not directly reachable, but corrosion in it will have an effect on the corrosion potential of all the concrete around the bar, so even on concrete the corrosion effect can be seen.

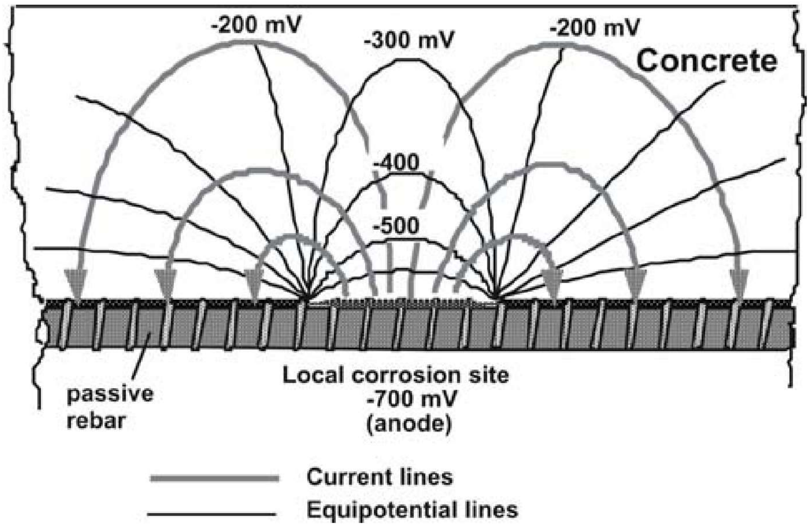

Figure 12 corrosion potential level map on steel and concrete [20]

The corrosion potential (**E**) values range and corresponding corrosion probability are:

- **E** > -200 mV: implies a low corrosion probability (lower than 10%)
- -200 > **E** > -350 mV: supposes an uncertain corrosion probability
- **E** < -350 mV: means a high corrosion probability (higher than 90%)

Corrosion potential is obtained by point measurements, many ways may be used to interpolate the point data and plot an output of the corrosion potential map, the shape of the influence of corrosion may help to select the best one. Cover depth is another important data to consider calibrating this data: the bigger will be the concrete cover thickness, and the more positive the corrosion potential results.

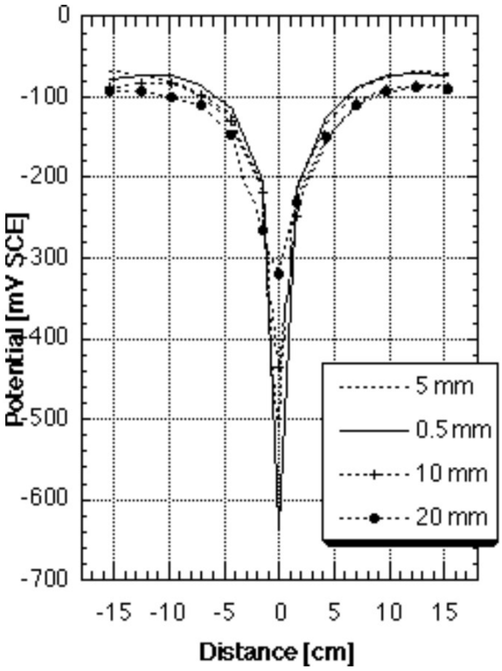

Figure 13 cover depth influence on the half-cell corrosion potential [21]

The different conditions of the concrete cover surface, in terms of treatments applied on the surface and concrete conservation state, may affect the corrosion potential, by increasing or decreasing its value. This must be considered when performing a measurement to compare data in a consistent way.

Measuring both the diameter of the reinforcement bars and the corrosion potential, a correlation between the corrosion potential and the reduction in strength and section of the material can be found out, this can help in quantify the expected reduction in resistance in structures in a deeper and more accurate way [22].

4.3.5 Georadar test

Georadar tests are based on the use of radar waves, which are capable of identify the different interfaces inside a not homogeneous material, and consequently provide feedback about the position of those interfaces.

From the georadar, an electromagnetic pulse is sent to the material, the signal lasts some nano seconds and is reflected by the layers inside the material, depending by the reflection of the signal, a receiving antenna can collect the time of traveling of the signal, and by this collection is possible to perform linear diagrams or even area ones.

In this way is possible to investigate elements which are difficult to be found without destroying and consequently damaging the material. The frequency of the signal influences the result, high frequencies can inspect even little details, with a better resolution, low frequencies will, on the opposite, lower the resolution but allowing a deeper inspection, because they will be capable to get in depth in the material without being stopped by the little details.

GPR test is generally used with the following investigation purposes [23]:

- estimation of the thickness elements from one surface.
- localization of reinforcing bars and metallic ducts and estimation of the concrete cover depth.
- determination of most important features construction.
- localization of moisture variations.
- localization and the dimensions of voids.
- localization of cracking.
- estimation of bar size.

Georadar output can be visualized in one dimensional scan, bi-dimensional or even tri-dimensional one. The visualization and the interpolation of the information provided by the different types of scans can provide a better understanding of the analysed material.

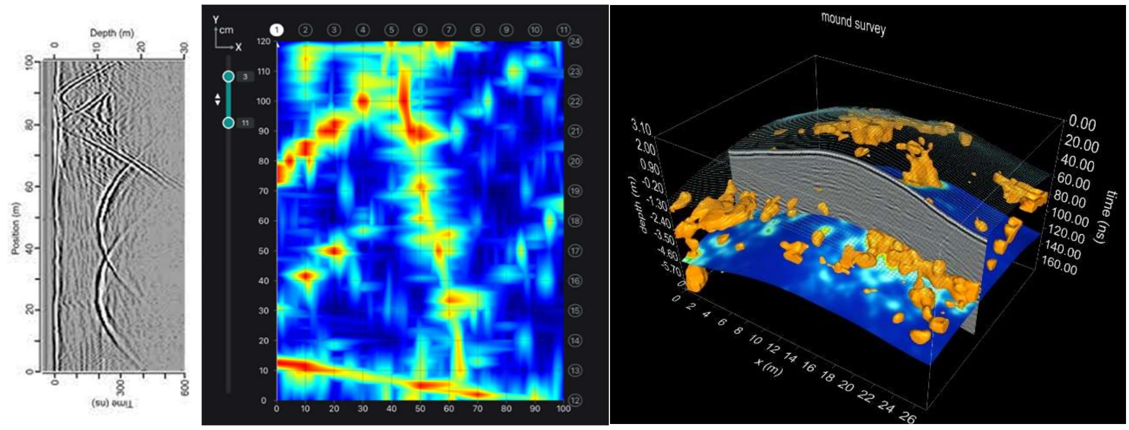

Figure 14 Different georadar scan output, from the left: 1D scan [24], 2D scan and 3D scan [25]

4.3.6 Impulsive response test

Is performed with the aim of investigating the aggregation state of a structure. It is based on measuring the time required from a wave, generated by an impulse, to reach sondes previously positioned and defined as reception points.

The mechanical impulse is constituted by a hammer which hits the material and generates the wave. The wave's transmission speed is correlated to the density of the material: the higher the density is, the higher is the transmission speed and higher time is required for the wave travelling in bad quality concrete. The test can provide a fast evaluation of the state of being of the material.

Generally performing acoustic waves inspection, the focus can be [15]:

- Local: if the integrity of a specific part of the structure is analysed
- Global: if the focus of the test is the integrity of all the structure

4.3.7 Ultrasonic test

Ultrasonic tests provide info about the material's homogeneity by measuring the speed of an ultrasonic signal.

Is possible to perform fast inspections on the material in wide areas. The test is performed by placing two sondes, one emitting the signal and one which is receiving it, on opposite faces of the investigated element, or in several different combinations.

Using this test is possible the investigation of the presence of defects in the material, with the definition of their dimensions as well, and the thickness of the materials. The time that the signal takes to pass through the material is measured in memorized by the instrument. A lowering of the signal will show defects in the material.

An issue about working with acoustic emissions is the fact that is not possible to have a standard procedure for all the types of structure, so case by case different trials will be necessary to delete the noise from the recording and get a clean result of the analysis.

Figure 15 impulsive response test [15] (left), ultrasonic test [26] (right)

4.3.8 Sclerometer test

Sclerometer tests are non-destructive tests based on measuring how much a known mass with a known elastic modulus which hit with a piston the analysed surface, bounces back on the material, measuring the hardness of the surface. The more energy is absorbed by the surface, the harder the surface is.

The value of the hardness is then correlated to the concrete's resistance by empirical curves which can be written as [26]:

$$R_c = aR^b$$

Where a and b are calibration coefficients, and R is the sclerometer bouncing index. Linear calibration can also be used (b=1).

Different parameters influence the measure:

- Superficial defects on concrete may influence the test result, so irregularities must be avoided or eliminated before the test,
- The thickness of the investigated element should be higher than 150 mm.
- Sclerometer test can provide information about the decrease of resistance in concrete after heating or fire [27], but the investigated data might be not totally realistic, because of the tendency of the sclerometer to investigate the external part of the material, and in heating or fire conditions the external part will always be more influenced respect the internal one.
- Carbonation of the concrete element influences the measured value [26]
- The measuring must be orthogonal to the surface, inclination might affect the result
- Superficial reinforcement may affect the results
- Instrument calibration can provide wrong values of the measure

The results of the test must be corrected by a coefficient depending on the concrete's conditions.

Table 3 corrective coefficient value [26]

Concrete age	Corrective coefficient	Concrete humidity	Corrective coefficient
< 57 d	1.00	Dry	0.85
57 – 180 d	0.95	Humid	1.00

181 – 360 d	0.93	Saturated	1.05
> 360 d	0.90		

When the measuring is performed, the maximum and the minimum value are not considered for determining the hardness value. This test is particularly fast and cheap, even if is based on the interpolation with empirical curves, it can provide a good data base for comparison but cannot be used as a main reference, due substantially to the lack of a theoretical correlation between two different mechanical characteristics: hardness and mechanical resistance.

4.3.9 Carbonation depth determination

This type of test is useful to determine the carbonation depth in concrete sample, and as a common rule this test is performed on every sample extracted from the structure. It is useful because in this way is possible to correlate the carbonation of the element with the other parameters that can be measured in different tests[5].

The sprayed mix is a 1% Feno Naftalin solution in ethylic alcohol, if concrete's PH is higher than a value between 8.0-9.8 [3] the mix, in contact with the surface changes its colour, if not the solution will remain uncoloured. It this way it can be seen clearly the carbonation depth in concrete.

The test is carried out immediately after the sample extraction.

Figure 16 Feno Naftalin test on concrete sample

4.3.10 Extraction test (pull-out)

This test measures directly concrete's resistance by extracting an expansion plug inserted in the concrete area and measuring the force necessary in doing it. The test requires to damage an area of 55mm of diameter and 25mm of depth.

A correlation between the force necessary for the extraction and the concrete's compression resistance provides the tests results, which can be expressed from two correlations as [26]:

$$R_c = aF + b \quad [MPa]$$

$$R_c = \frac{cF^2 + dF + e}{f} \quad [MPa]$$

---

[5] Carbonation is concrete is affecting other parameters, tests as the sclerometer test and the ultrasonic test can have different values if carbonation is present in concrete

Where:

- F is the required extraction force
- The constants a, b, c, d, e, and f are influenced by the expansion plug used[6].

The area where the test is performed must be free from steel and irregularities, those elements can highly influence the result of the test. The failure mechanism in the structure can evidence how the test involves mainly the concrete's traction resistance.

The test is usually performed on compressed elements, in elements subjected to tension stresses the test results can be different due to the different calibration of the instruments.

If the test is not performed in standard condition, the empirical correlation between the pull-out force and the tensional force of the concrete cannot be obtained very easily.

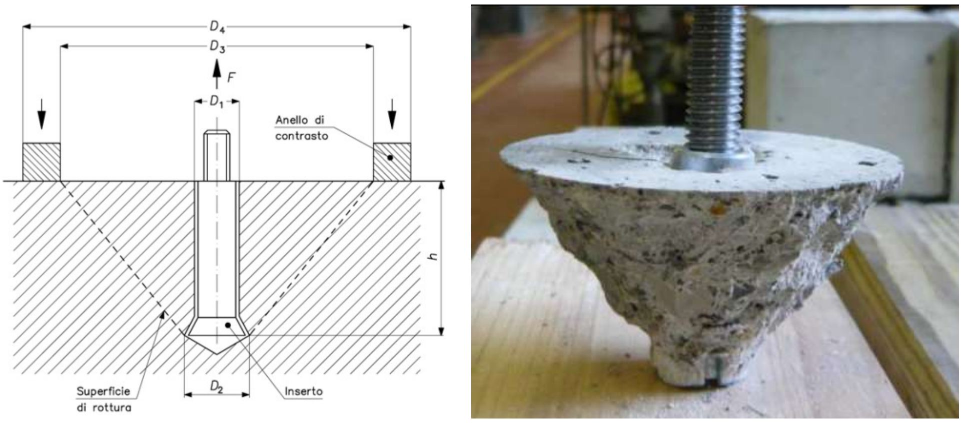

Figure 17 [26] Pull-out test scheme and pull-out cone scheme

4.3.11 Pull-off

Pull-off test is a traction test performed on a concrete cylinder when still connected to the structure. It provides a value correlated to the traction resistance, and is performed in the following steps:

- Using a diamond crown, cooled with water a cut of 50mm inside the structure is performed.
- The surface is dried by using infrared lights.
- Using episodic resin, the external part of the cut cylinder is fixed to an aluminium disk with a diameter of 75 mm.
- The disc is then pulled off and the necessary force is recorded

Due to the need of waiting the resin to dry to guarantee resistance in traction between the aluminium plate and the concrete sample, two days are required for each test [26], cause of this the number of tests which can be performed in limited time inspection campaign decreases. The test is considered valid only if the peak value of tension resistance is higher than 0.9 MPa and the braking surface is localized mainly under the substrate/composite interface [28].

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[6] Typical values for Fisher Zykon M10TCP (12) are a=0.0094, b=9.6, c=-12.5 E-6, d=0.157, e=10, f=10

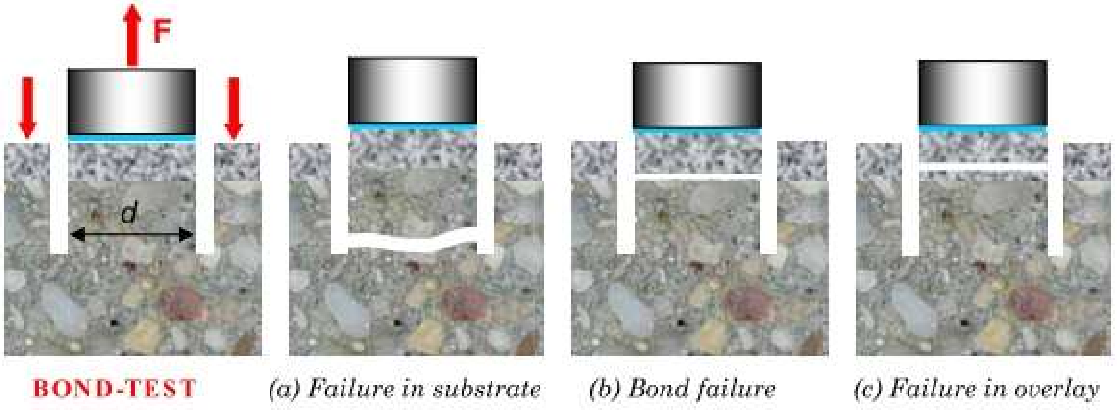


Figure 18 Pull-off test scheme and possible failure mechanisms [29]

4.4 LABORATORY TEST

Laboratory tests represents a fundamental part of the structural diagnosis. The tests allow the determination of the material's mechanical, physical and chemical properties, fundamental to understand the building behaviour.

Concrete properties are changing in different conditions, in function of the time passed from the casting, the sample humidity or the temperature, cause of this the condition in which the test is performed needs to be known.

Laboratory test can be both destructive and not destructive, which mean that the tests can be performed once or more than one time on the time and allows to determine the change of determined properties in time.

As all the other diagnostic topics, laboratory tests are not providing a complete view of the building situation, and the output are not always directly understandable. Critical data comparison, between all the lab test results, all the diagnostic on site output and all the info about the building will provide a complete picture of the building state of being.

The number of laboratory test for concrete is very high, the ones which are the most important for this thesis work are described in this chapter.

4.4.1 Laboratory tests for mechanical properties (EN 12504-1)

Test for mechanical quantities provides data useful for the computation of structural resistance, if combined with aging procedures those tests can provide comparison about the efficacy of treatments or about the predicted decrease of resistance in materials.

Compression resistance test

This test is a destructive test for a cylindrical or cubic concrete sample, it works by subjecting the sample to an increasing compression force and measuring the corresponding deformation. Generally, this test is made up at 28 days from concrete casting to get a standard value.

Concrete behaviour in compression can be described by dividing the stress-strain response in three phases:

- 0-0.4 fc: in this phase concrete is behaving in an elastic-linear way. No cracks formation.
- 0.4-0.85 fc: in this phase concrete behaviour becomes quite non-linear. Microcracks propagates if load increases, but not with stable load. Stable condition can be reached.

- 0.85-1.0 fc: microcracks propagation becomes unstable and those can be noticed at macroscopic level. Once fc is reached, concrete sample is subjected to brittle failure.

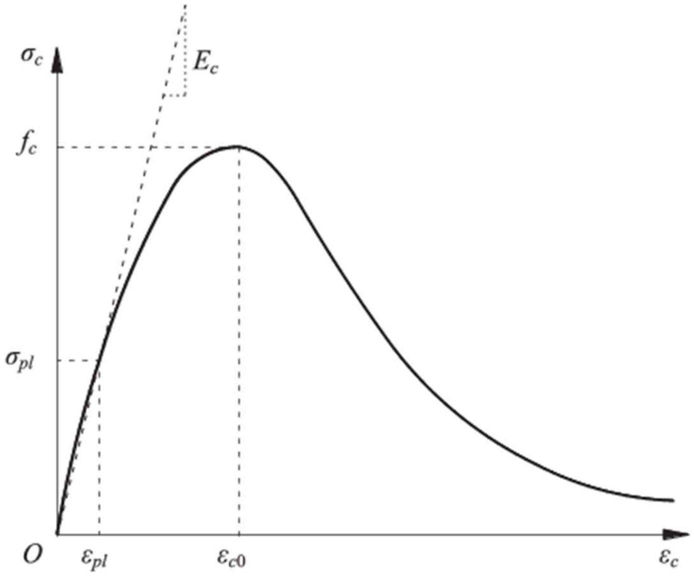


Figure 19 stress-strain compression behaviour in concrete [30]

Compression test can be performed on semi-prisms, which are obtained from flexural tests. The samples are in this case placed on the side face, and the tested area will be a square with the side equal to the width of the sample. The upper and lower face of the tested sample must always be flat, parallel each other and orthogonal to the central axis, to guarantee the tests precision.

Concrete's elastic modulus can be obtained from the stress-strain relationship, which can be measured during the test.

Direct traction test

Concrete is usually never working in traction, due to its tendency to a brittle behaviour in tension, but the study of the tensile resistance in concrete allows to understand the load which can bring to crack opening and so preservation issues.

This test works by subjecting a concrete sample to direct traction, by anchoring both the sides using a grip. The applied force is increased until breaking of the sample. The maximum traction resistance f_{ct} is obtained dividing the force applied by the area of the sample, which can be cylindrical or prismatic.

$$Fct = \frac{F}{A}$$

This test is usually difficult to carry on, because of the difficulty on locking the sample in the traction machine. Different types of tests are usually preferred: the undirect traction test or the bending test.

Undirect traction test

The undirect traction test is performed compressing a cylindrical sample, placed in horizontal position between the plates of the test machine, by the sides, in this way a tension state is generated in the section, so the central axis of the sample will be vertically subjected to pure compression, and in the orthogonal direction will be subjected to tension. From this consideration, and from the failure mechanism, is possible to determine the tension resistance in the concrete sample.

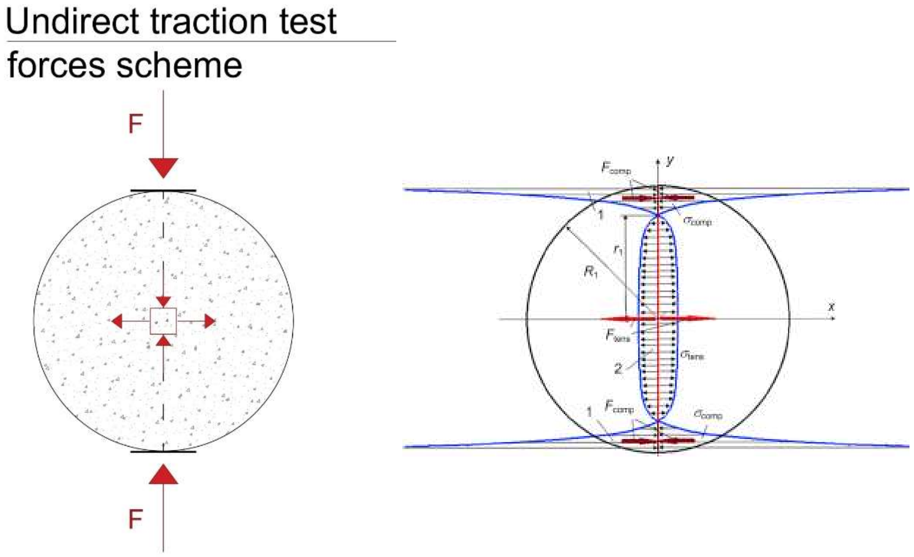


Figure 20 Undirect tension test, forces scheme and [31] stress schemes

Bending test

This test provides an indicative value for the maximum tension or shear resistance in concrete.

Bending test is performed on a prismatic sample, simply supported on two points at its sides. Forces are applied in one or two points of the sample and the force-displacements relationship is constantly recorded up to the failure.

Using one force the main stress will be concentrated in the middle of the sample, and failure happens due to the tension generated from the bending moment.

Using two forces is to have a wide area with constant moment and no shear stress in the middle, and a constant value of the shear on the sides, in this case if the failure happens on the sides the maximum concrete's shear resistance can be determined.

From the stresses which develops in the section, the maximum tension resistance can be determined if linear elastic behaviour is considered, by considering the flexural resistance R_f as [32]:

$$R_f = \frac{3PL}{bh^2}$$

And considering: P the load at failure, L the distance between the supports, b the width and h the height. In case the applied forces are two, each one of them have a value of P/2.

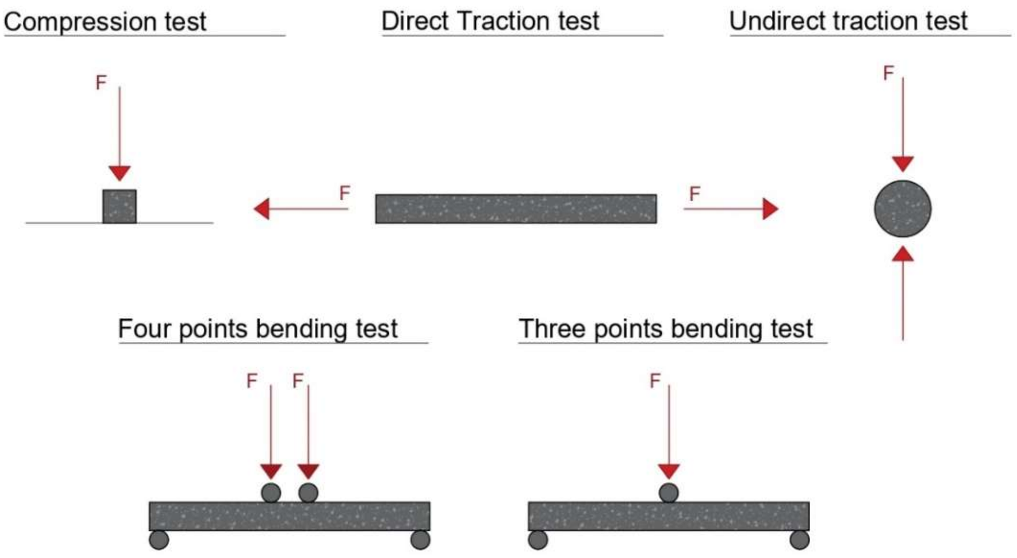


Figure 21 Mechanical tests scheme

Effects of test conditions on results

Test conditions can highly influence the test results, for this reason investigating the effect that different conditions might have on the test can help to interpret the output in a valid way and avoid mistakes.

Load application speed. The effect of the application speed of the sample is due to the different reaction that the material would have with static or dynamic loads. The higher is the application speed and the higher will be the mechanical resistance [32].

Saturation degree. The flexural and compression resistance of a rapidly dried sample is lower than the one of a humid one, this is due to the internal tension developed with the hydraulic withdrawal. If the sample is slowly dried the internal tension can be dissipated by creep phenomena, in this case the flexural and compression resistance increases and gets higher than the humid case [32].

Sample dimension. The mix which composes the concrete is highly unregular, for this reason the variability of the mechanical characteristics in relation to the tested sample dimension are very high. The mechanical resistance decreases if the sample volume increases [32].

4.4.2 Laboratory tests for physical and chemical properties

Physical and chemical properties of concrete needs to be investigated particularly for durability issues. The mineralogical composition and the rate of resistance to different deterioration phenomena are fundamental to deeply understand the material weaknesses.

Volumetric mass determination

The volumetric mass (or density) is the ratio between the mass of an object and its volume, measured in kg/m^3.

The concrete sample weight can be measured in three conditions:

- Natural state
- Water saturated

- Hoven dried

The steps for measuring the volumetric mass are the following:

- sample selection
- sample dimensions measuring by using a gauge
- sample mass determination (as in received form the in-situ state or as it is in the lab before the analysis)
- the sample is dried in hoven with a temperature of 105°C for 24h,
- sample mass determination (dry mass)
- the sample is saturated by immersion in water at a temperature of 20°C for 24h
- sample mass determination (saturated mass)

Weight and volume of the sample are determined and so the volumetric mass is computed in the different conditions. From this test also the void ratio can be determined, considering the mass difference between saturated and dry sample.

Contact sponge method for porosity testing

Contact sponge method is a test for measuring the water absorption of a material.

This test works by keeping in contact a sponge of predetermined type and size with the material surface, with constant pressure for three minutes time. The sponge is weighted before and after the contact, and so the amount of water absorbed by the material is computed. The sponge is kept in contact with the material using a circular plastic plate. In this way porosity of the system can be determined.

This test can be performed both in situ and in lab. It allows the measurement of the porosity also in cases in which the samples cannot be picked up in situ, as in historic buildings [33]. It is useful to both understand the conservation state of a material and the efficacy of a waterproofing surface treatment.

Petrographic analysis

Little samples from the structures can be analysed by a petrographic analysis to determine the mortar composition and the degradation state. This analysis is composed by different procedures for the determination of a wide range of characteristics of the material.

It is an examination, performed by optical and scanning electron microscopy [34]. The output is the determination of microcracking presence, reaction products, eventual aggregates breakdown, cement hydration level and freeze-thaw performance.

X-ray diffraction

This test allows the determination of the mineralogical phases of a collected sample. Is based on the principle for which every material is capable to interact with electromagnetic radiation, and different materials will react differently to it.

[35] The output of the test is a diffraction spectrum, a series of distinguished reflections, each one with its own intensity, amplitude, and position. By determining this parameter and comparing them with reference spectra, is the material type and the different phases which composes it can be determined.

Accelerated weathering

Accelerated weathering consist in subjecting reinforced concrete samples in a closed environment to wet and dry cycles with a blend of water with 3.5% NaCl. The cycles are repeated for three months.

The NaCl water solution simulates the most aggressive condition for reinforced concrete, and so favourites rust formation and samples deterioration. From experimental results [36] is proved that significant carbonation from the aging procedure in concrete specimen is shown up only after eight or even sixteen weeks exposure, so even if the sample condition is highly aggressive, some time is necessary to develop the samples degradation.

Using this test is possible to check the performances of different types of concrete mix and treatments for managing conservation issues.

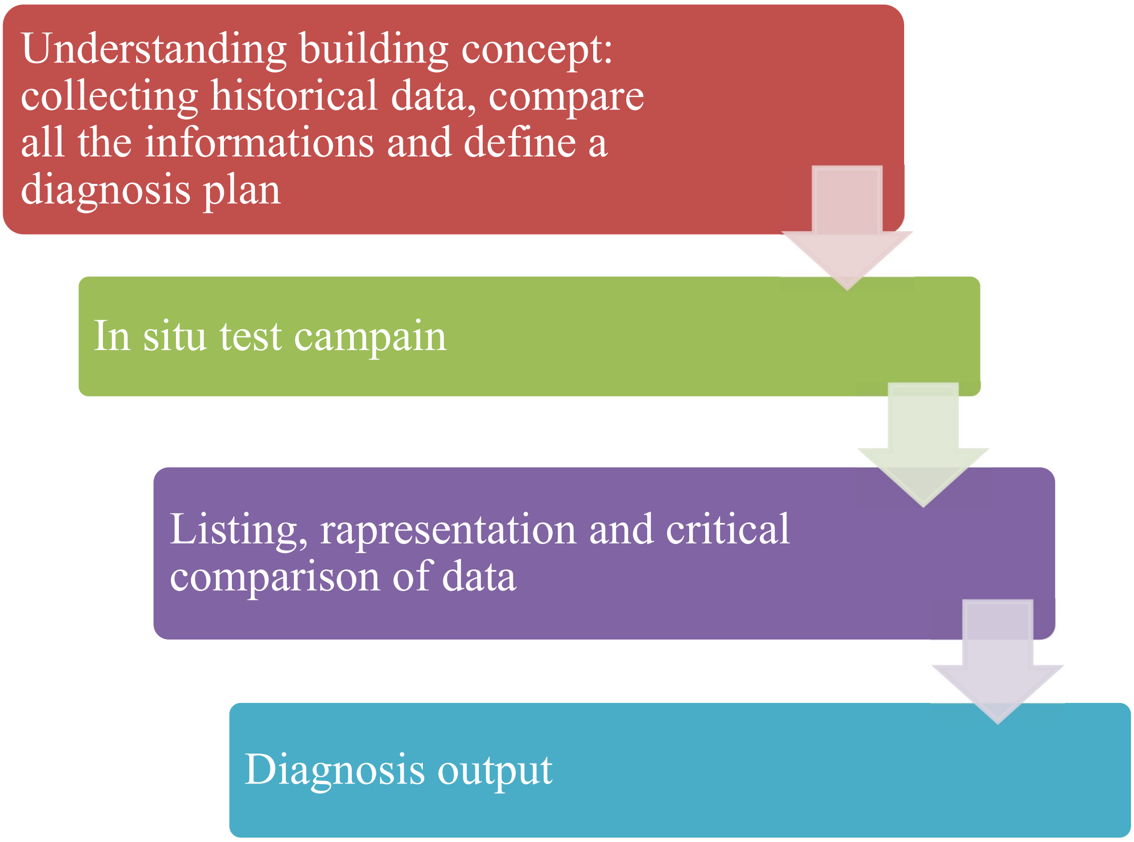
5 HALL B IN SITU DIAGNOSIS

5.1 INTRO

To expo halls are structures realised whit materials, shapes and methodologies which have been innovative for the construction times. By the way the use of innovative materials clearly identifies unpredictable consequences in the material behaviour in relation of the time factor, so the analysis of the buildings is mandatory to achieve the goal of preserving the structure from the time influence. In this context Getty foundation commissioned the realization of a conservation plan for the To-expo halls B and C. To develop a conservation plan, in situ diagnosis of the building is performed, this is important for the collection of quantitative data which can allow as first critical considerations and then consistent actions to preserve the building integrity.

5.2 METHODOLOGY

The structural diagnosis passes from fundamental steps. As first the collection of historical data regarding the building construction and modifications, in this way a first considerable database is constructed. Then, basing on the historical information, the building concept is studied in deep, from this the diagnosis plan is planned. The diagnosis is then performed between the months of July and September of the year 2021. All the collected data are then listed and analysed.



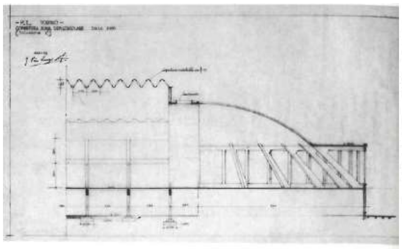
5.3 BUILDING CONCEPT AND HISTORY

The hall B is commissioned to P.L. Nervi and built in the post-war period, by a project with the aim of recovering the fashion palace. It is realized as a rectangular space, covered by a ferrocement dome, and a half-dome in the direction of the Po River. The use of prefabricated elements has large impact for the construction, allowing a fast and safe construction procedure. The historical period is a key factor for the design: materials are expansive and labour cheap, ferrocement allows the combination of those elements, and a strong prefabrication highly reduces the construction time.

Figure 22 Torino exhibition centre [37]

A0The roof is so designed as a ferrocement roof, a strategy which allows the use of a small amount of material (if compared with a traditional reinforced concrete roof), as ferrocement resistance is fundamentally based on element's shape.

The side pillars are initially thought as vertical, but during the design phase the solution switched to an inclined one, following the forces direction, using this adjustment the free space allowable between two pillars is significantly increased. As an initial purpose the pillars under the semi-spherical dome are also inclined to follow the forces direction.



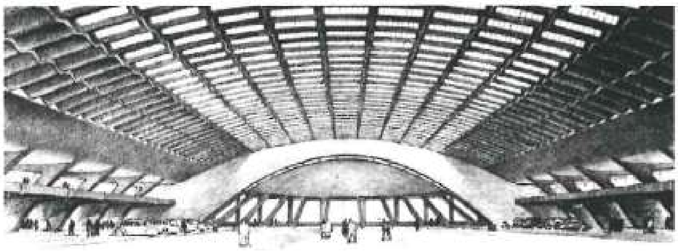


Figure 1 drawing of the proposed scheme from P.L. Nervi, [1] Figure 2 Drawing of the proposed scheme of P.L. Nervi [1]

The solution is not adopted by Nervi, that prefers to use a system of an edge annular beam, supported by thin pillars.

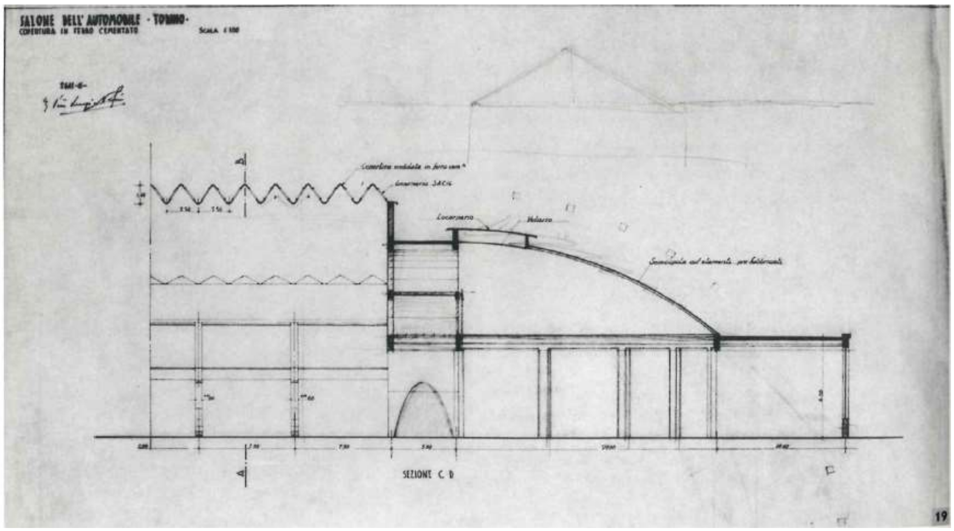


Figure 3 Definitive solution for the support of the half dome of hall B [1]

Another detail that is developed during the design, is the connection between the waves of the roof of the hall and the inclined pillars, it is realized as a fan-shaped connection between one pillar and three waves of the arch.

The areas of Hall B can be divided as:

- a big exposition space, 95 m large and 111 m long, where usually the exposition where taking place, covered by a ferrocement roof.
- an apse area, where a half-dome with a diameter of 40m is placed.
- An underground floor in the first 30 m of the hall, in the Po river direction.

The construction of the first part of the hall must be fast, the large use of prefabricated elements gives Nervi the possibility of building the Hall in less than one year. A sliding formwork, where precast elements constituted by multiple steel layers of 4.5 m long and 2.5 m wide are placed and concreted together, is used to realize the dome in record time. 7.5 m wide concreting was done at each time, so three elements where casted per each time.

The wave ferrocement elements that constitutes the roof of the hall are also skylights, that allows the natural light to enter in the hall. 13 elements are prefabricated and assembled to create the roof. The side ones, from 1 to 3 and 13 to 15 are solid ferrocement elements, the other ones are the elements with skylights. The resistance of those elements is guaranteed by their shape, so they come out to be very light elements that can be used in a very wide range of structural solution, but still in a very fast way due to the strong prefabrication process behind them. Of course, those elements are some of the most typical elements of the hall and distinguish the Nervi's design. The covered distance between the connections with the pillars is of 63 m.

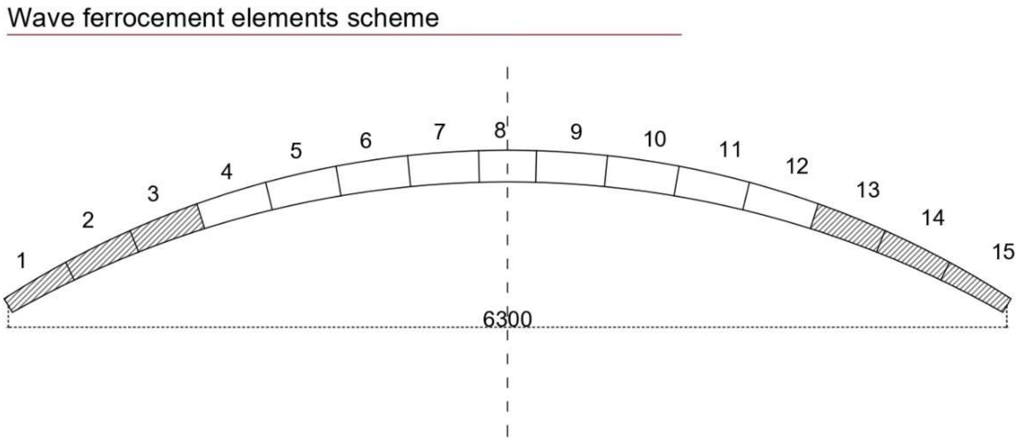


Figure 23 Ferrocement elements scheme

Ferrocement has also been used in **the fan-shaped elements** that connects the roof to the side pillars, as has been said, three waves of elements converge by the fan-shaped element, in one inclined pillar and the forces are so transmitted to the ground. Those elements were also realised using three prefabricated elements composed by steel nets, with a maximum wide of 7.5 m in correspondence of the connection with the roof, so the element can transmit the loads to the pillars.

The architectural concept followed by Nervi in its projects is evident: following the natural forces distribution and direction with the structural elements, the result must be aesthetically nice.

The inclined pillars are realized in four different phases, starting from the bottom to the upper part, their aim is to transmit the forces from the roof to the foundation in a direct way, the inclination of the pillars allows to limit the bending stresses.

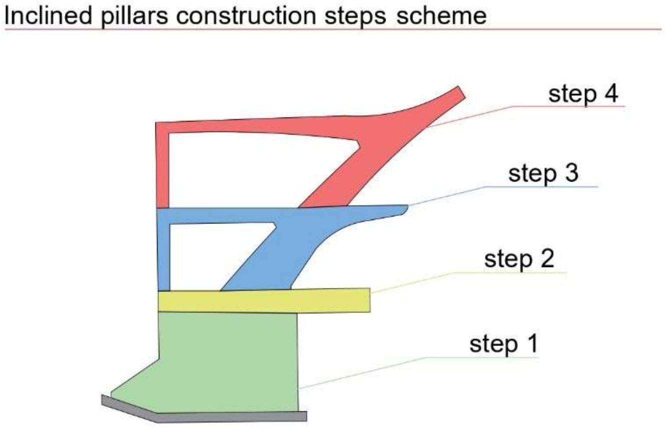


Figure 24 inclined pillars construction steps scheme

Ferrocement is also used in **the half dome**, where the surface of the half dome is realized using ferrocement rhomboidal boards, with a thickness of 2 cm, placed on reinforced concrete ribs acting both as structural member and formwork for the dome. The rhomboidal elements are prefabricated, several dome elements have the same shape. This allows a faster construction of the dome well.

The dome is surrounded by an **annular floor**, with the aim of resist to the horizontal force coming from the half dome.

The connection between the half-dome and the ferrocement roof is guaranteed by an archway composed mainly by three elements:

1) R.C. structure, in the direction of the wave-shaped ferrocement roof,
2) R.C. structure in the direction of the half-dome,
3) A SAP archway for connection. The SAP archways are typical connections used between the 1930 and the 1960, mainly composed by reinforced bricks on-site assembled by using smooth bars.

On the west side of the structure, the infill structure is realised as a R.C. and bricks structure. This element has been first constructed in 1948 and then demolished in 1953 to enlarge the structure, to construct a similar structure on the new Hall B's perimeter. The rigid connection between the structure and the wave-shaped element is guaranteed by a 10 cm concrete layer casted on site.

Figure 25 Hall B elements

All the structure comes out to be regularly shaped and mostly symmetrical. In a structure like this the parts that can be subjected to the higher stresses are the ones where the symmetry is changing, as for example in the connection between the half-dome and the rest of the hall.

The state of being of hall B is salutary checked, for some events[7], in those moments some cracking defects are detected in the horizontal structures of ground floor and balconies, carbonatation tests are performed on some samples for evaluation of durability issues, with satisfactory results.

The big dimensions of the hall represent a big issue for the usage destination and so the structure is not subjected so usually to maintenance.

5.4 ON-SITE TESTS RECAP

A large number on site tests is performed on the Hall B on To-expo. The structure is deeply investigated to collect a high amount of data which, combined with laboratory analysis, represents a consistent database for the realization of a conservation plan.

Performed on site tests described in this work are:

---

[7] the Winter Olympics in 2006

- Plaster cover measurement
- Steel bars dimension measurement
- Corrosion potential measurement
- GPR scan

The reinforced concrete elements are analysed using instruments described in the previous part of this thesis work, but for the ferrocement elements the inspection is much more difficult, due to the complexity of the material itself and to the position of the ferrocement elements. For this reason, the performed test mainly regards the reinforced concrete elements.

The elements are categorized as shown in the following figure.

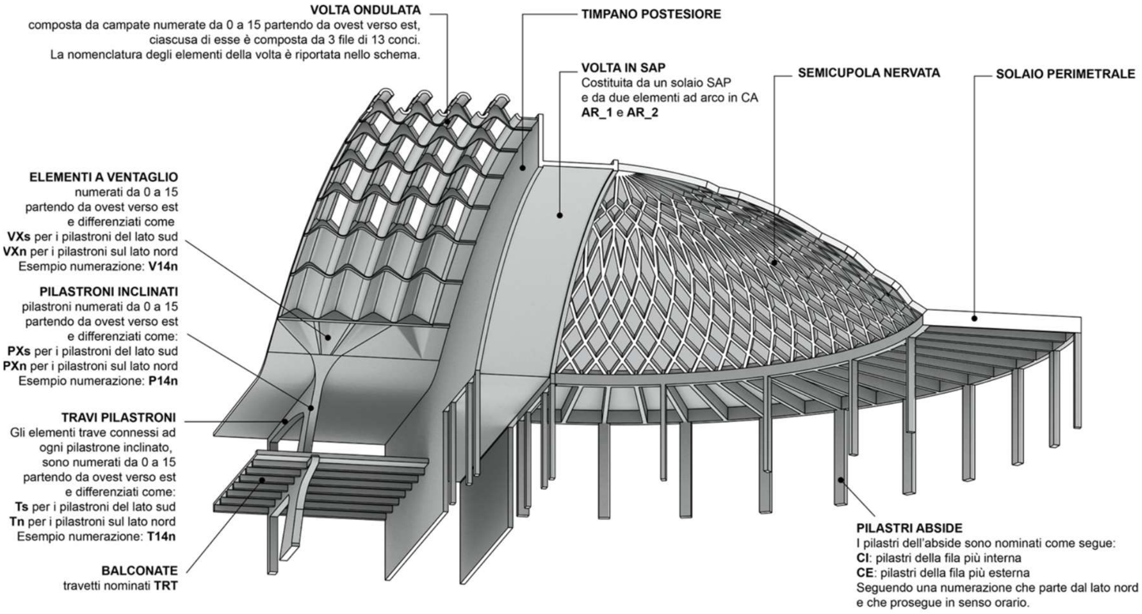


Figure 26 Hall B elements categorization [38]

The elements' identity code is the one used in the SCR diagnosis report, as follows:

Table 4 Structural elements ID code list [38]

Element	ID code
Pillars underground floor south side	Pi_Px^{1}s
Pillars underground floor north side	Pi_P^{x}n
Pillars ground floor south side	PT_Pxs
Pillars ground floor north side	PT_Pxn
Apse columns external raw, underground floor	PT_Txs
Apse columns external raw, ground floor	PT_Txn
Apse columns third internal raw, underground floor	Pi_CE-x
Apse columns third internal raw, ground floor	PT_CE-x
Apse columns forth internal raw, underground floor	Pi_CB-x

Apse columns forth internal raw, ground floor	Pi_CA-x
Apse columns internal raw, underground floor	Pi_CI-x
Apse columns internal raw, ground floor	PT_CI-x
Apse beams underground floor	Pi_Tx
Apse beams ground floor	PT_Tx
Fan-shaped elements south side	Vxs_Y[2]
Fan-shaped elements north side	Vxn_Y
Wave elements	CAMx_CON_xY
Arch beam apse west side	ARC_1
Arch beam apse east side	ARC_2

5.5 ON SITE TESTS RESULTS

The results of the on site test are here plotted, dividing them in accordance with the area of the structure in which them are performed.

Steel bars diameter investigation

This type of investigation is useful for two main reasons. The first is the correspondence between the original drawings and the real structure. The second is that for each element where corrosion is happening, the reinforcing bar diameter is decreasing, for this reason investigating on the thickness of the pillars steel bar is useful to plan operations of replacements of the bar itself. In the following tables the results about the measuring are showed. Generally, where the pillars are protected by the structure is difficult to have bad conservation states, unless in case of floors with high relative humidity, as underground ones, or water loss from plumbing systems.

The results are listed by element name, position of the measure, on site measured diameter (mm) and photo documentation.

Corrosion potential measurement

Pillars and beams corrosion conditions are controlled by the on-site test of the corrosion potential measurement. For each analysed element, a steel bar is exposed, the reference electrode is connected to the steel bar and is kept in contact with the concrete surface. In this way the corrosion potential is acquired. Data are then post processed and an output is provided by merging the corrosion potential maps and the elements photos.

Corrosion potential is measured of the following elements:

Table 5 Corrosion potential measurements elements list

Corrosion potential measurement					
Apse Ground floor Columns	Apse underground floor Columns	Underground floor beams	North side pillars	North side beams	South side beams
CI-7	CE-0	Pi_T3 E	PT-P2N	P1-T12N-E	P1-P4S
CI-17	CI-8	Pi_T3 W	P1-P4N		PT-P7S
CI-20	CB-3		PT-P8N		P1-P7S
CE-10			PT-P10N		PT-P13S
CE-14			P1-P10N		P1-P13S
CE-18			PT-P12N		
			P1-P12N		
			P1-P14N		

For each columns group, a statistic analysis of the data has been performed and in the following pages a graphical representation of the data is provided.

Corrosion test needs to be used as a qualitative comparison for analysing the corrosion rate and so all the data that has been acquired needs to be compared with different tests, to give a complete information about the state of being of the structure. Is important to remember that for the corrosion process oxygen and humidity are fundamental, consequently environmental conditions will be an important parameter to check.

Georadar

The scope of this georadar investigation is to check the correspondence of the real reinforcements with the original drawing's ones. The investigation has been performed on one pillar, P12_N, both on the ground floor and on the first floor

Internal humidity and temperature monitoring

Humidity and temperature are the fundamental conditions necessary for corrosion, their monitoring is so fundamental, in hall B three sensors have been placed inside three different elements:

- PT_P12N

- P1-P7S

- CB-3

The test plan is resumed in the following figures as exposed in activities report for SCR.

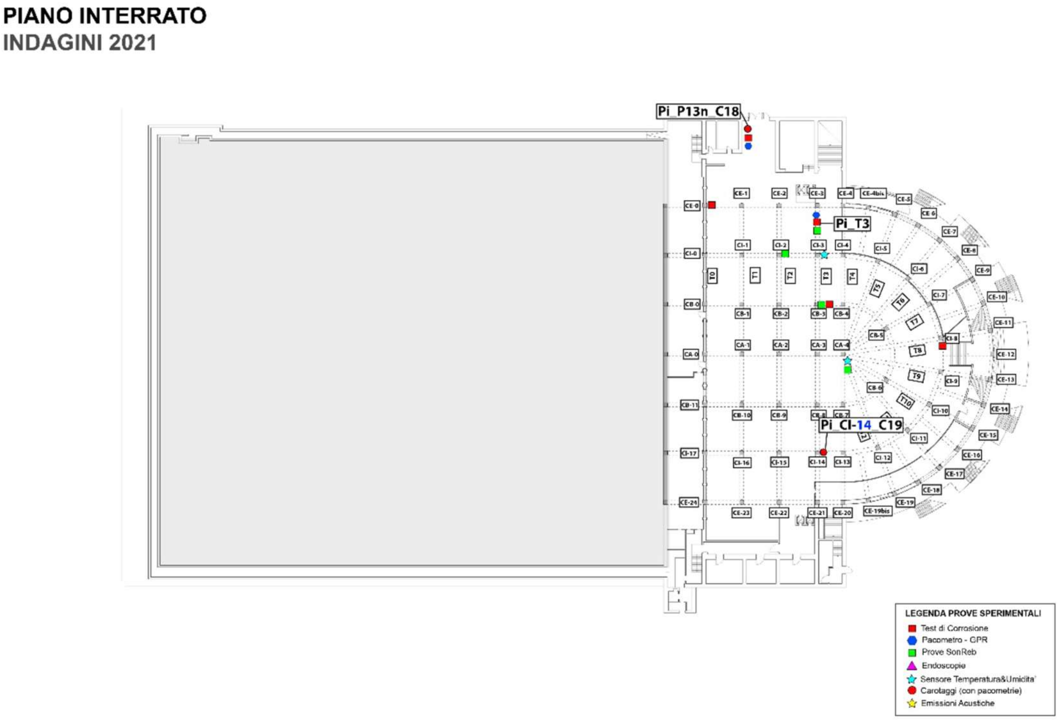


Figure 27 Underground floor diagnosis plan [38]

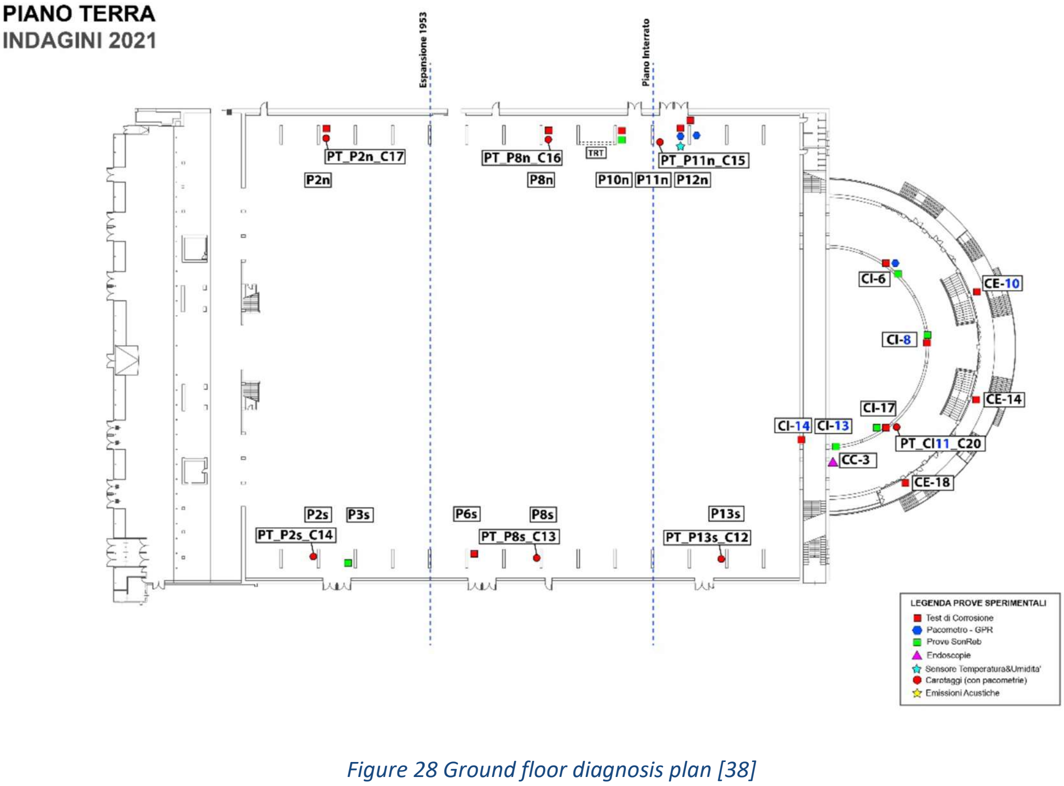


Figure 28 Ground floor diagnosis plan [38]

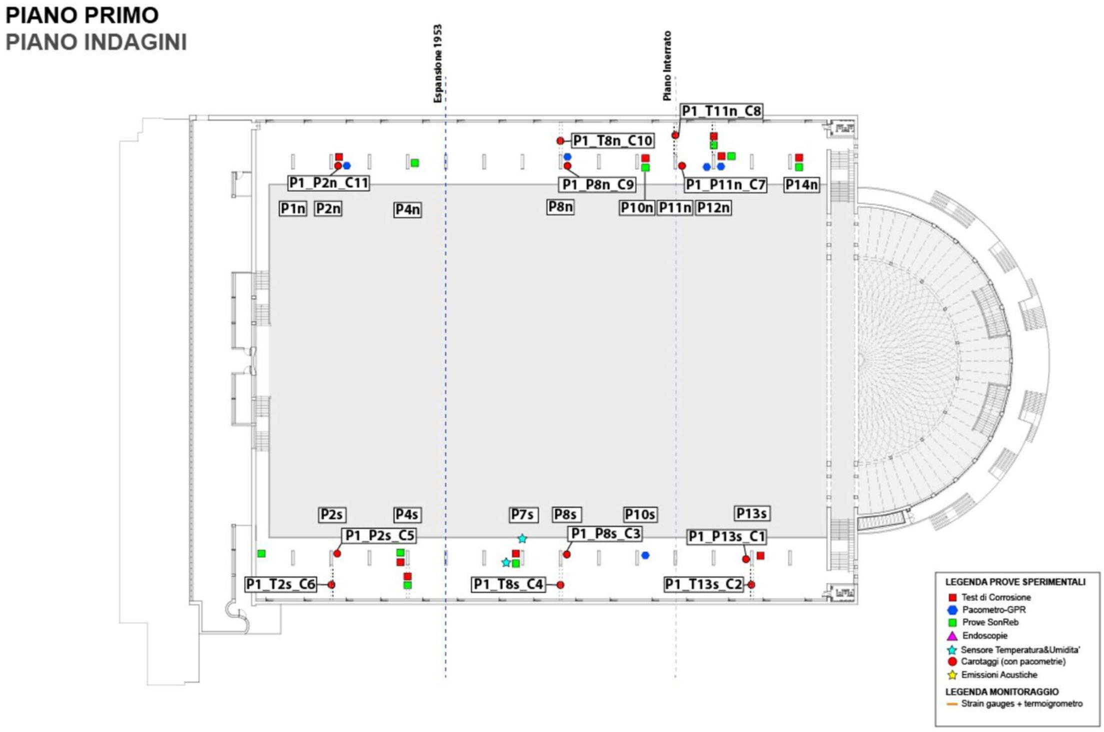


Figure 29 First floor diagnosis plan [38]

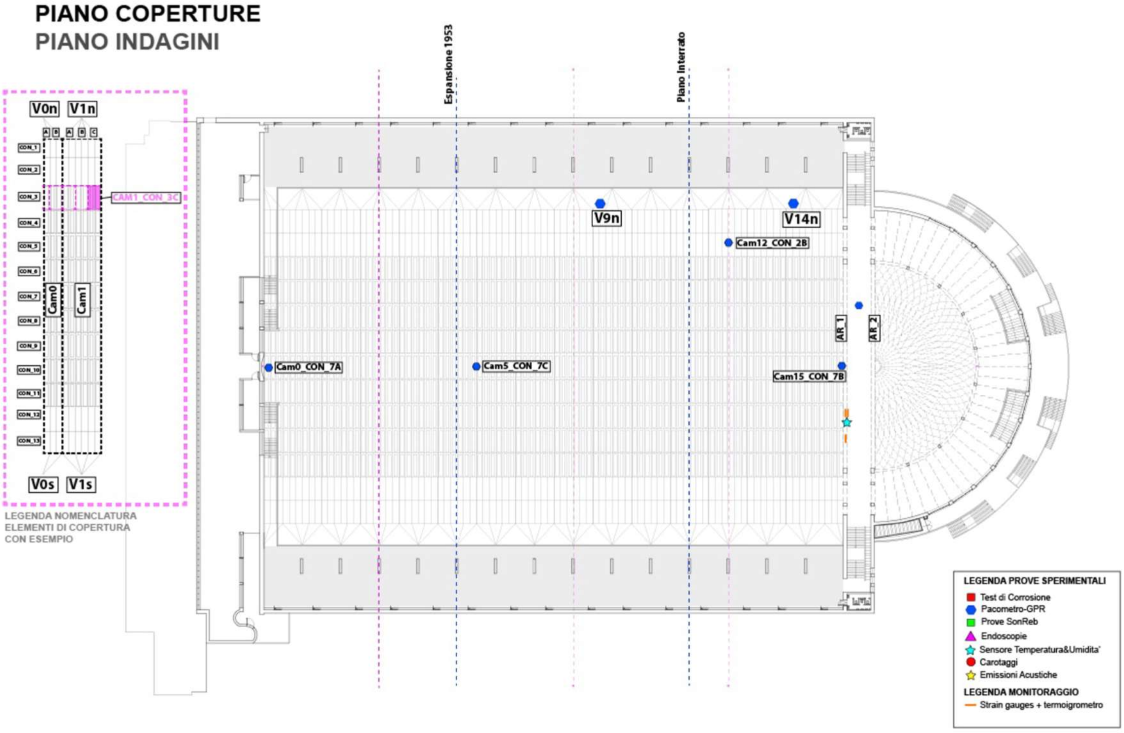


Figure 30 Roof diagnosis plan [38]

Plaster cover measure

Plaster cover thickness is measured on different elements using an electronic gauge. Plaster cover measure is performed on the following elements:

Table 6 Plaster cover measure inspected elements list

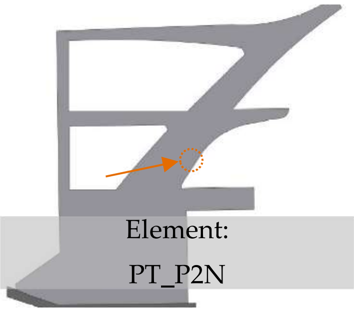
North side	South side	Apse ground floor
PT - P2 - N	P1 - P0 - S	PT - CI - 6
P1 - P2 - N	PT - P2 - S	PT - CI - 8
PT - P8 - N	P1 - P2 - S	PT - CI - 11
P1 - P8 - N	P1 - P4 - S	PT - CI - 13
PT - P10 - N	PT - P7 - S	
P1 - P10 - N	P1 - P7 - S	
PT - P11 - N	PT - P8 - S	
P1 - P11 - N	P1 - P8 - S	
PT - P12 - N	PT - P13 - S	
P1 - P12 - N	P1 - P13 - S	
P1 - P14 - N		

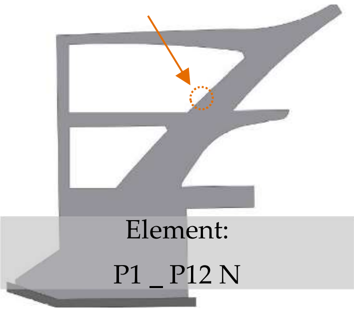
5.5.1 North side

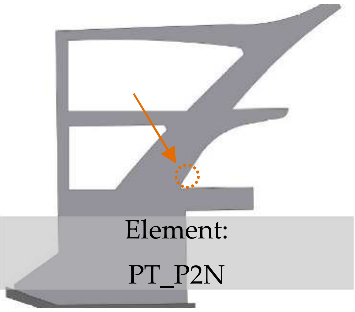
The inspections performed in the Hall B's north side are here described.

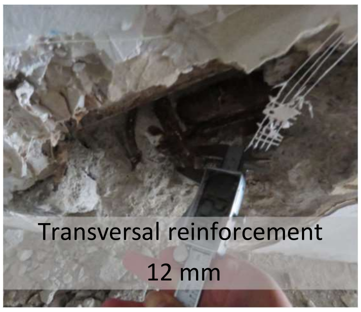
Reinforcement bars diameter analysis

From the analysis of the north side of the structure, a humid environment with some deterioration conditions is noticed. This do not affect the reinforcements; no important corrosion has been found on the pillars reinforcing bars.









North side pillars corrosion potential test result

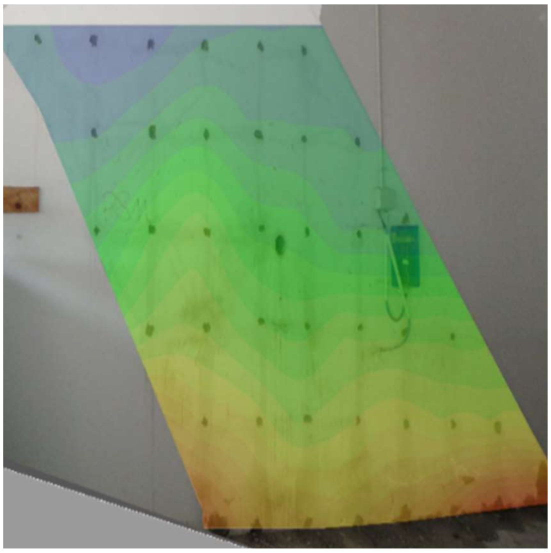
On the north side the corrosion potential has been measured on nine elements in total. Four of them are ground floor pillars, where the corrosion potential value is generally found in a good range, unless for the PT_P12N, where a water loss from a fire-fighting system affected the pillar. The same can be seen from the first floor, where four pillars and one beam has been checked, and it came out that the only one in worst conditions is the element P1_P12N, the beam of the same pillar is not presenting any critical value of the corrosion potential at all.

Table 7 statistical analysis of the corrosion potential - north side pillars

Statistical analysis corrosion potential north side										
w.r.t Cu/CuSO4			Percentage							
Evalutation	Millivolts		P1-P14N	P1-P12N	P1-T12N-E	P1-P10N	PT-P12N-W	PT-P10N	PT-P8N	PT-P2N
	Min	Max	%	%	%	%	%	%	%	%
90% Probability of no acting corrosion	< - 200		98%	71%	100%	98%	77%	84%	91%	90%
Uncertain range	-200	-350	3%	29%	0%	2%	23%	16%	9%	10%
90% Probability of acting corrosion	>-350		0%	0%	0%	0%	0%	0%	0%	0%
	Total		100%	100%	100%	100%	100%	100%	100%	100%

PT_P8N

- Corrosion potential map

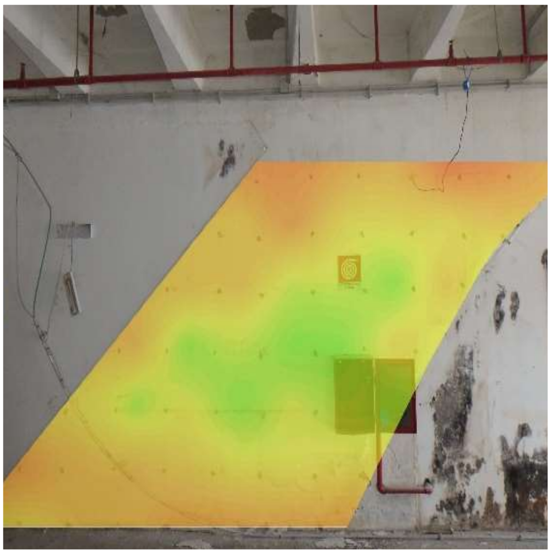


P1_P10N

- Corrosion potential map

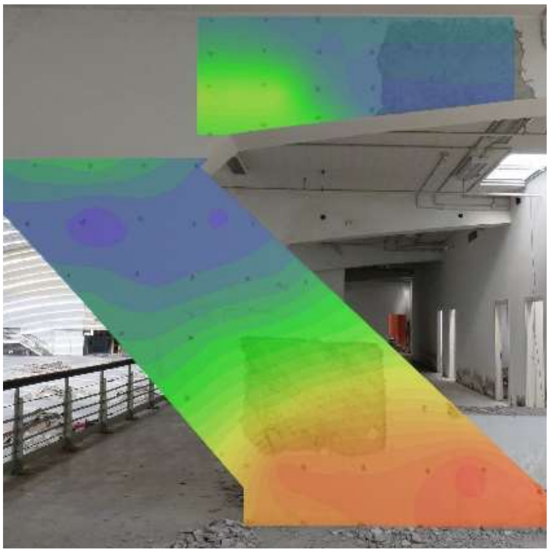
PT_P12N

- Corrosion potential map



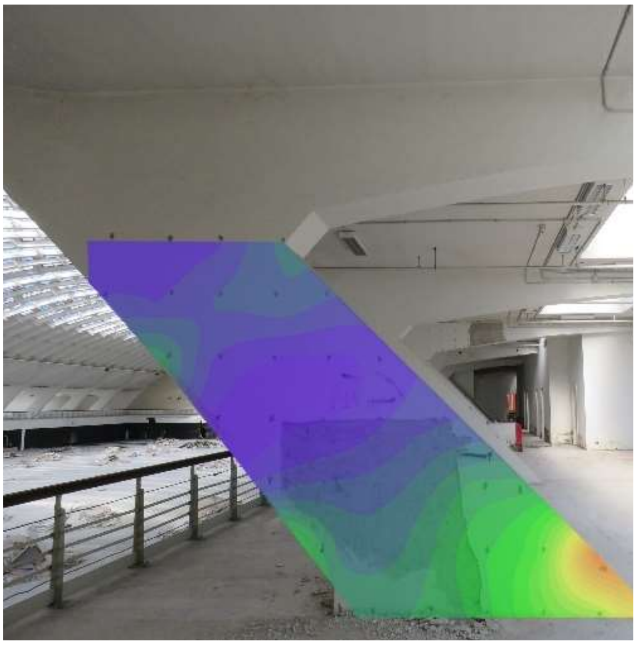
P1_P12N

- Corrosion potential map



PT_P8N

- Corrosion potential map



Georadar analysis

The results show how the steel arrangement is mostly the same of the one designed by Nervi, even if is not following the same direction in some places, this can be due to some deformations in the steel during the casting.

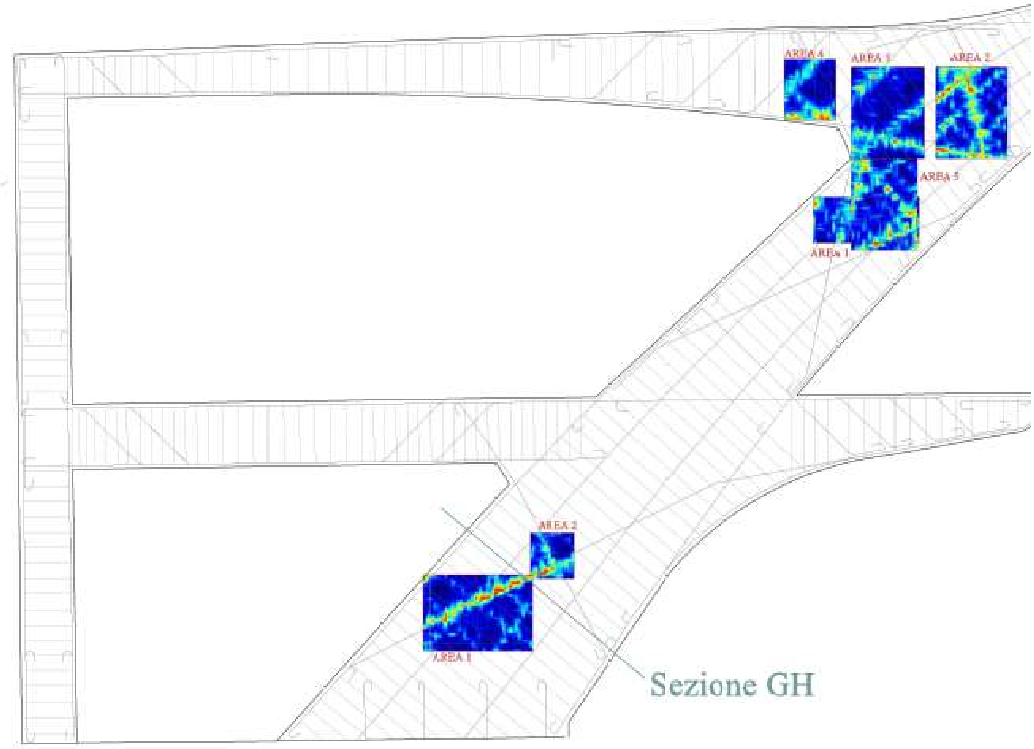


Figure 31 Georadar scan P12

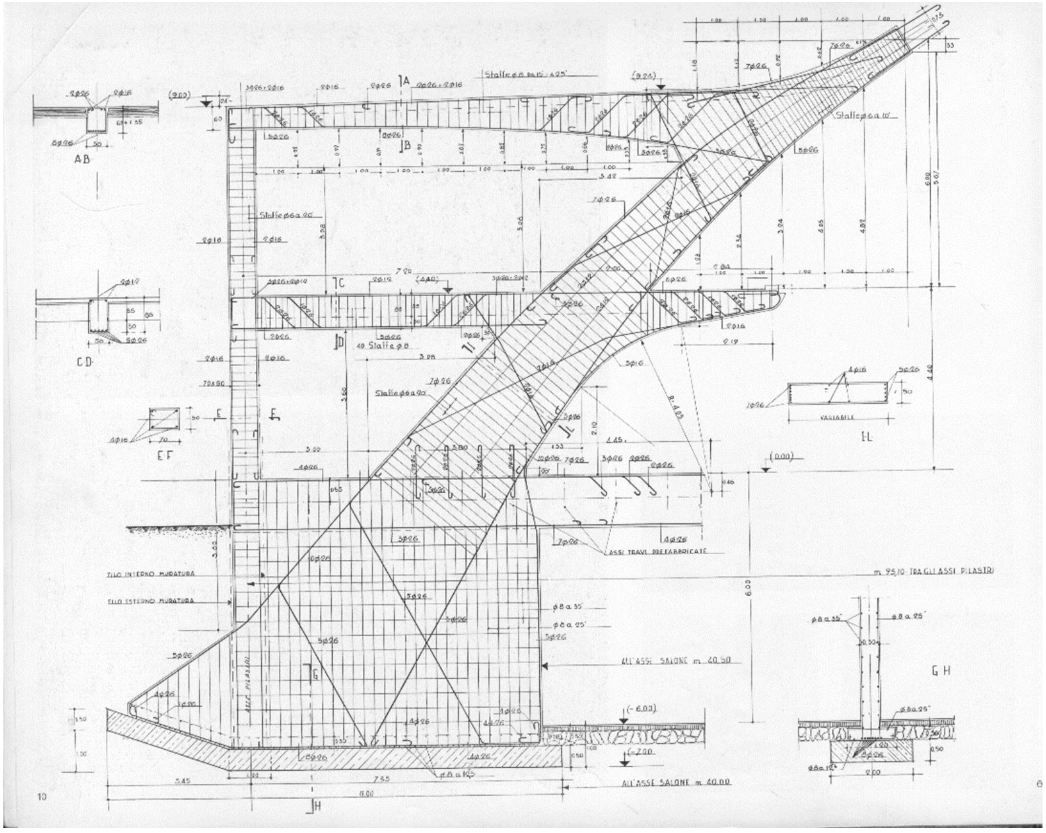


Figure 32 P12 original pillar drawings (P.L. Nervi)

Starting from the georadar data, is possible to generate deeper models of investigation.

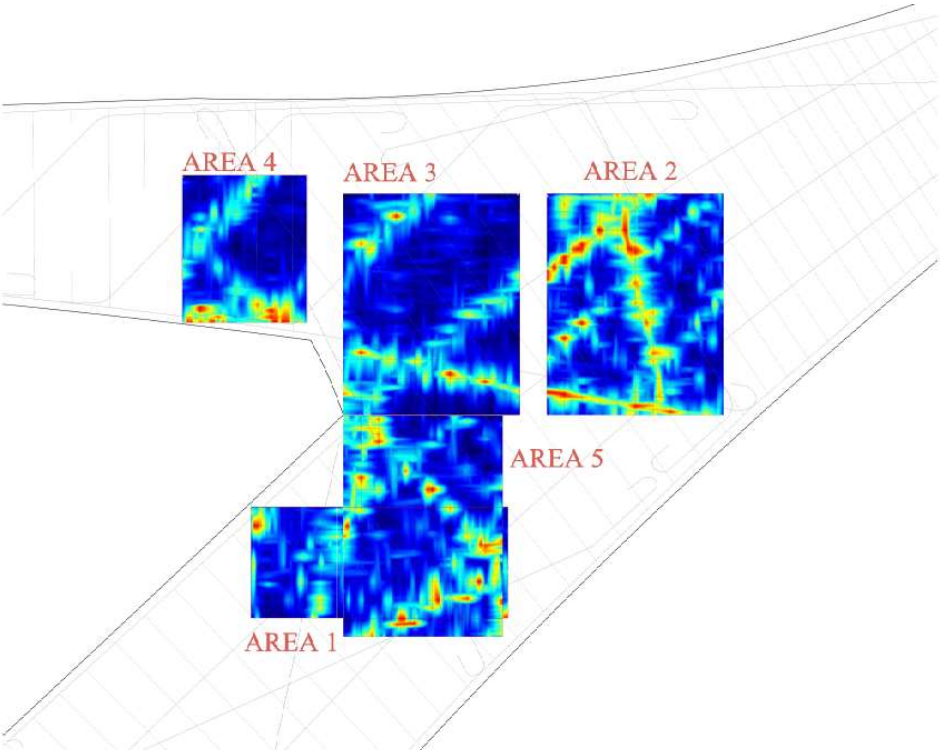


Figure 33 Georadar scan, zoom of the scan P1_P12N

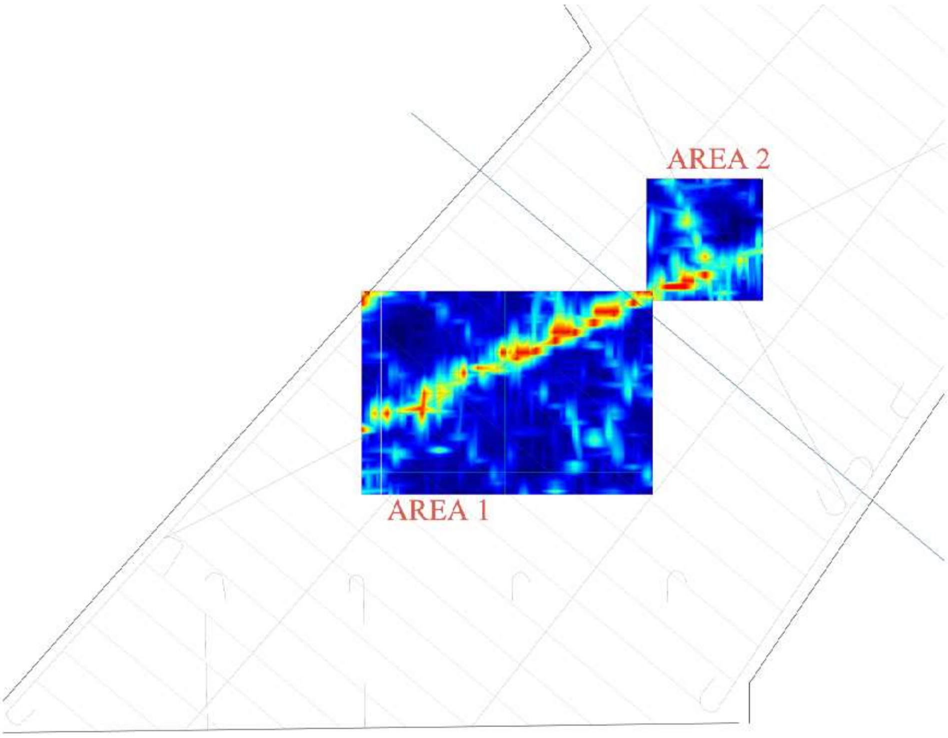


Figure 34 Georadar scan, zoom of the scan PT_P12N

Humidity and temperature monitoring

PT_P12N. This sensor showed the pillar is saturated by humidity, that's due to a loss in a fire-fighting system placed at the first floor. Corrosion came out to be acting in this pillar.

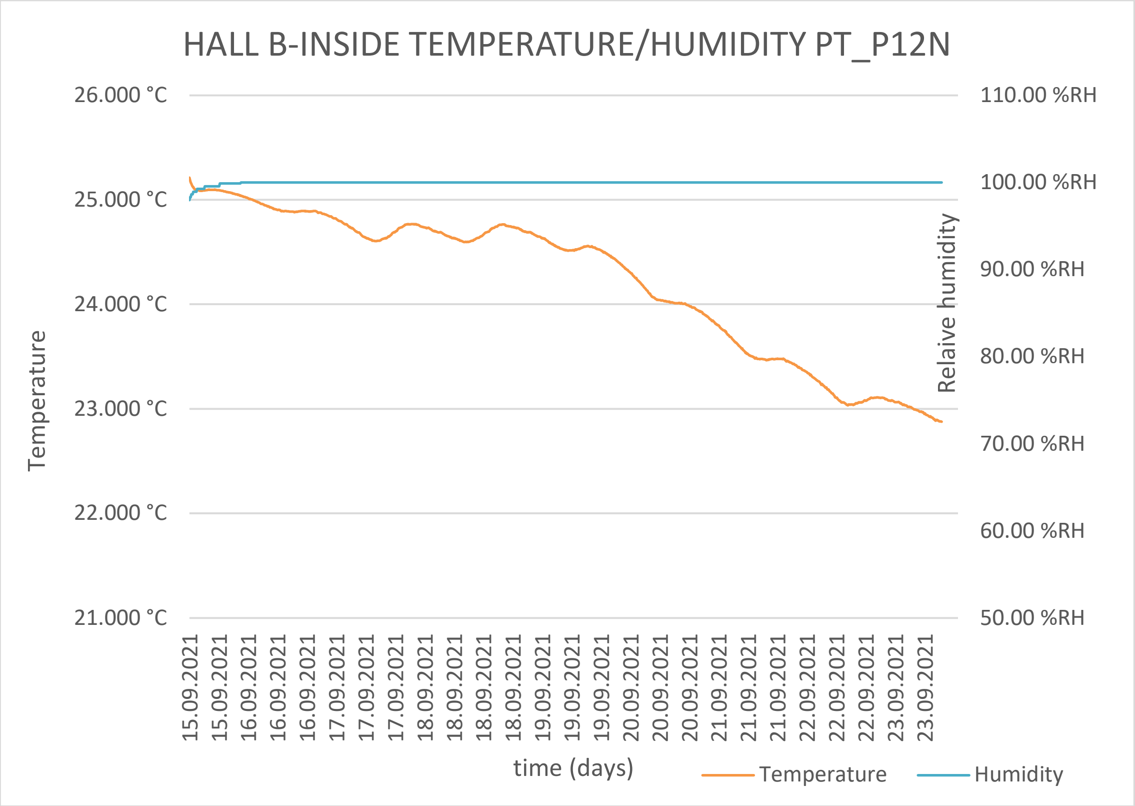


Figure 35 PT_P12N Hall B temperature/humidity sensor output

Plaster cover measure

The plaster cover measure for the north side elements is exposed in the following table.

Table 8 plaster cover measure for the north side elements

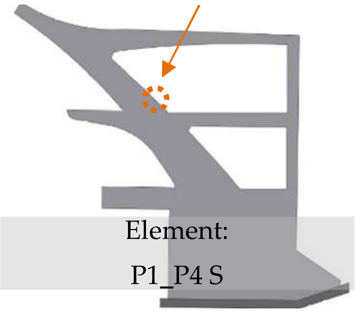
Element ID	Maximum value [mm]	Minimum value [mm]
PT - P2 - N	10	25
P1 - P2 - N	4	4
PT - P8 - N	3	3
P1 - P8 - N	6	6
PT - P10 - N	9	9
P1 - P10 - N	11	11
PT - P11 - N	6	6
P1 - P11 - N	11	11
PT - P12 - N	7	7
P1 - P12 - N	10	10
P1 - P14 - N	9	11

5.5.2 South side

South side structural diagnosis output is here described.

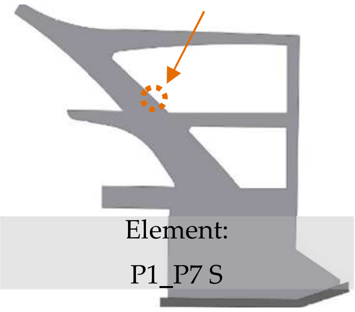
Reinforcement bars diameter analysis

All the elements of the south side are found in a good conservation state, this is helped by the low humidity conditions in the south side of the structure. The only unregular element found in the structure is the longitudinal reinforcement of PT_P7S, which presents a diameter of 20 mm, 6 mm lower than the designed one (26mm).

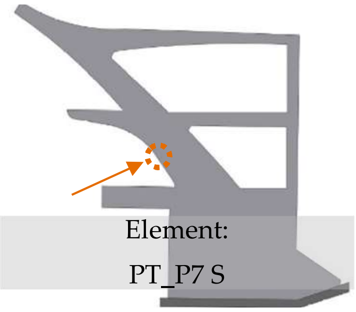

Element:
P1_P4 S

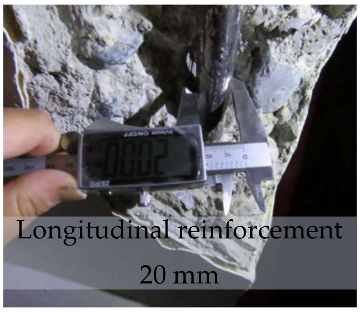

Longitudinal reinforcement
26 mm

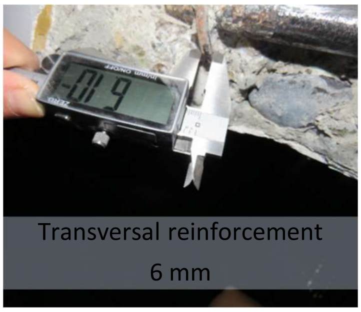

Transversal reinforcement
6 mm

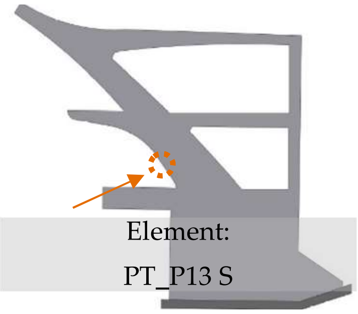

Element:
P1_P7 S

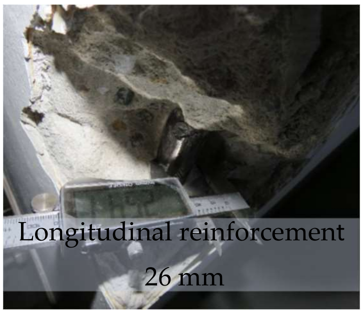

Transversal reinforcement
6 mm

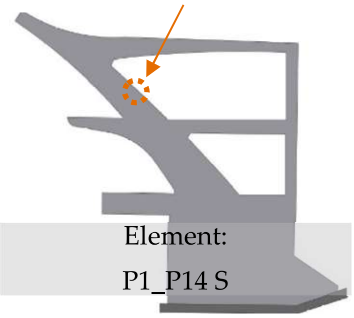

Element:
PT_P7 S


Longitudinal reinforcement
20 mm


Transversal reinforcement
6 mm


Element:
PT_P13 S


Longitudinal reinforcement
26 mm


Element:
P1_P14 S


Longitudinal reinforcement
26 mm

South side pillars corrosion potential test results

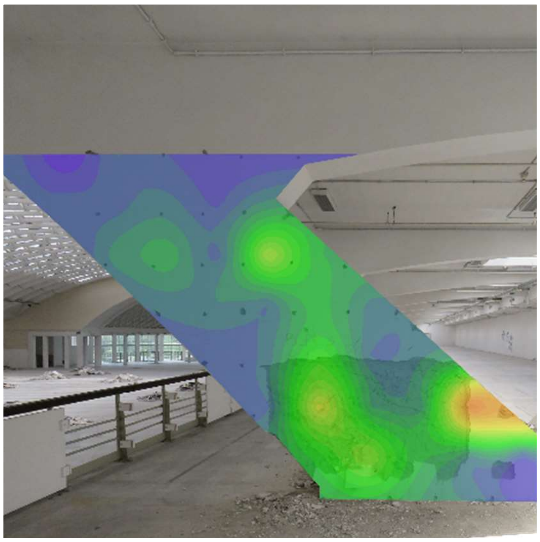
On the south side 5 elements have been analysed, three pillars on the first floor and two from the ground floor. The conservation state of this side of the structure is practically perfect, that's probably because the higher temperature is guaranteeing a good environment for the cement. No one of the elements of this group has been found to be critical.

Table 9 Statistical analysis of the corrosion potential - south side pillars

Statistical analysis corrosion potential south side							
w.r.t Cu/CuSO4			Percentage				
Evaluation	Millivolts		PT-P13S	P1-P13S	PT-7S	P1-P7S	P1-P4S
	Min	Max	%	%	%	%	%
90% Probability of no acting corrosion	< - 200		100%	97%	100%	98%	98%
Uncertain range	-200	-350	0%	3%	0%	2%	2%
90% Probability of acting corrosion	>-350		0%	**0%**	**0%**	**0%**	**0%**
	Total		**100%**	**100%**	**100%**	**100%**	**100%**

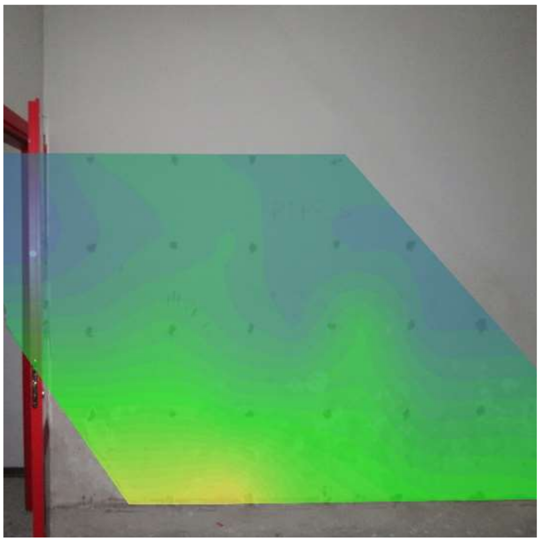
P1_P4S

- Corrosion potential map



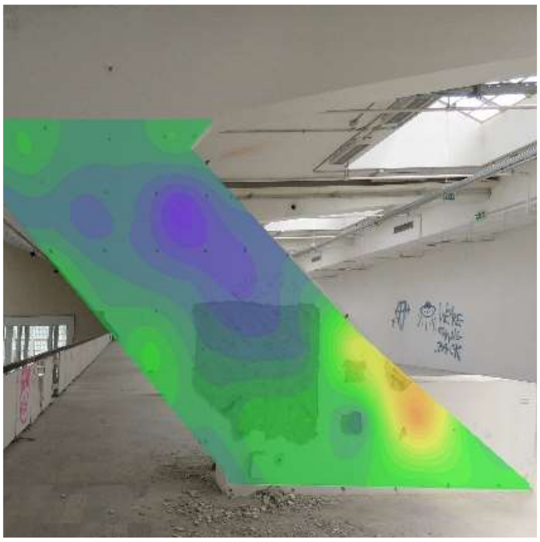
PT_P7S

- Corrosion potential map



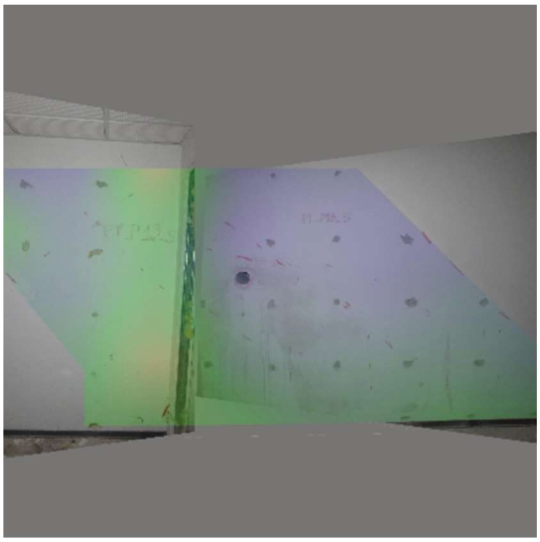
P1_P7S

- Corrosion potential map



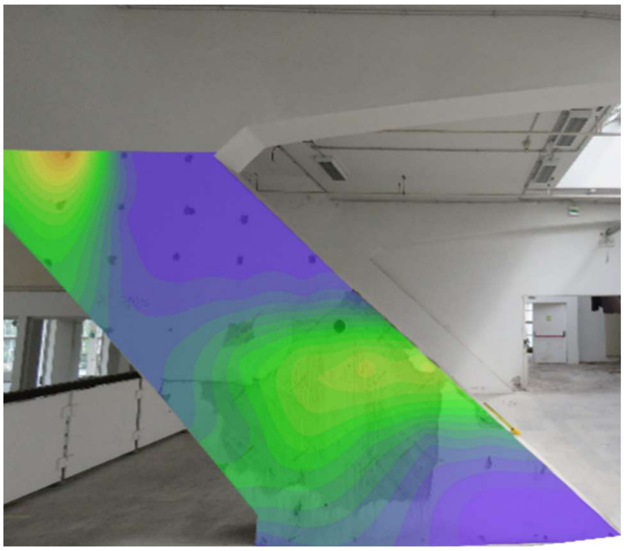
PT_P13S

- Corrosion potential map



P1_P13S

- Corrosion potential map



Temperature and humidity monitoring

P1-p7S. This sensor showed a relative humidity which is not critical, the threshold of 65% for humidity, which is considered the value for which corrosion is favourited, in this pillar is reached only in some days.

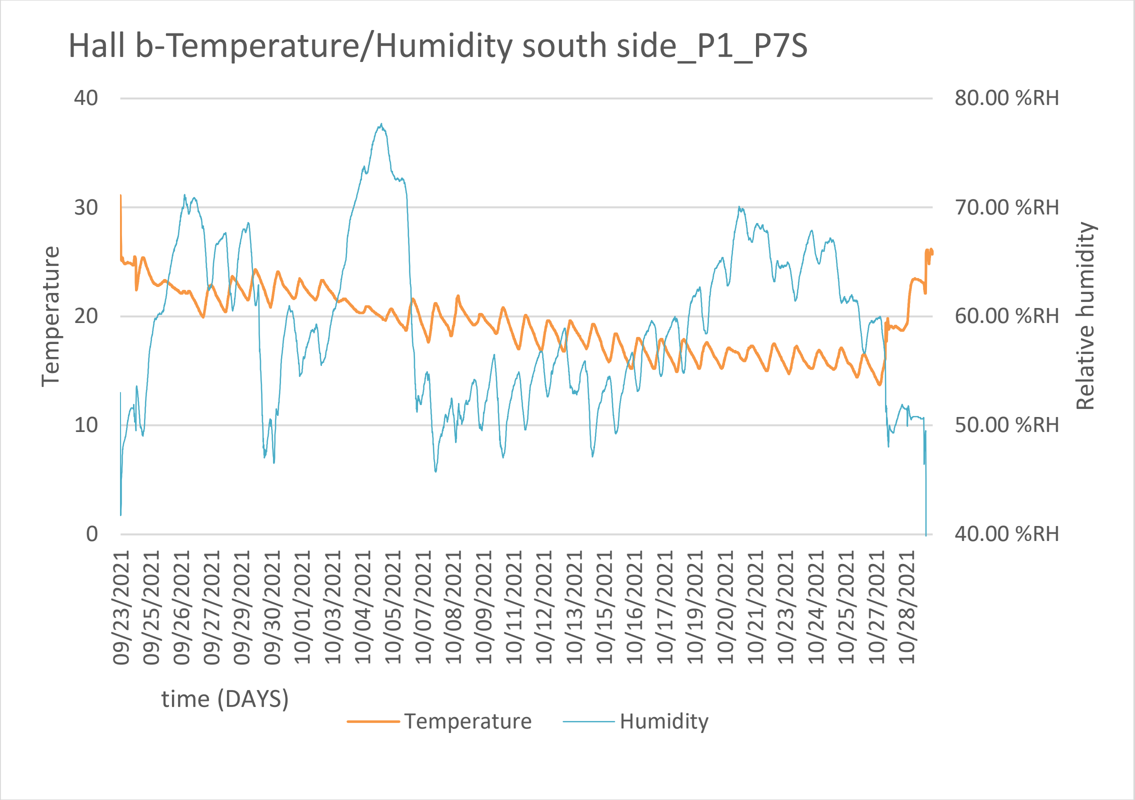


Figure 36 Hall B P1_P7S Temperature and humidity sensor output

Plaster cover measure

The plaster cover measure for the south side is exposed in the following table.

Table 10 plater cover measure south side elements

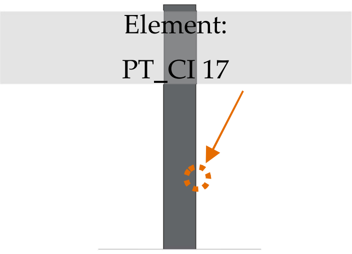
Element ID	Maximum value [mm]	Minimum value [mm]
P1 - P0 - S	17	17
PT - P2 - S	5	6
P1 - P2 - S	8	8
P1 - P4 - S	20	22
PT - P7 - S	3	14
P1 - P7 - S	9	14
PT - P8 - S	4	4
P1 - P8 - S	7	7
PT - P13 - S	7	7
P1 - P13 - S	6	9

5.5.3 Apse ground floor columns

Apse ground floor columns diagnostic output are here described.

Reinforcement bars dimension analysis

Apse ground floor columns behaves in a good conservation state, the bars diameter measured is the same of the design elements.



Apse ground floor columns corrosion potential test results

Corrosion potential in ground floor has been measured on four internal columns and three external ones. The following table shows that in most of the internal columns the conservation state is good, and there is a low probability of active corrosion. External pillars, as they are in an open environment, are more exposed to corrosion and deterioration and this results in a higher corrosion potential on them.

Table 11 Corrosion potential statistical analysis - ground floor columns

Statistical analysis corrosion potential ground floor columns									
w.r.t Cu/CuSO4			Percentage						
Evaluation	Millivolts		CI-7_PT	CI-11PT	CI-17_PT	CI-20_PT	CE-10_PT	CE-14_PT	CE-18_PT
	Min	Max	%	%	%	%	%	%	%
90% probability of no corosion activity	< - 200		94%	85%	77%	71%	38%	68%	16%
Uncertain range	-200	-350	6%	15%	23%	29%	63%	32%	84%
90% probability of corrosion activity	>-350		0%	0%	0%	0%	0%	0%	0%
	Total		100%	100%	100%	100%	100%	100%	100%

CE_10

Corrosion potential map

CI_17

Corrosion potential map

Plaster cover measure

The measure of the plaster cover for the apse ground floor columns is exposed in the following table.

Table 12 Plaster cover measure for the abse gound floor elements

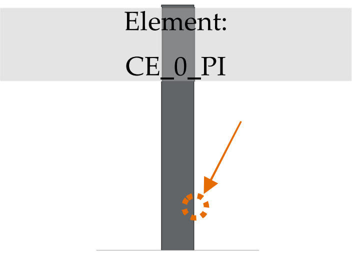
Element ID	Maximum value [mm]	Minimum value [mm]
PT - CI - 6	5	5
PT - CI - 8	5	11
PT - CI - 11	2	14
PT - CI - 13	8	8

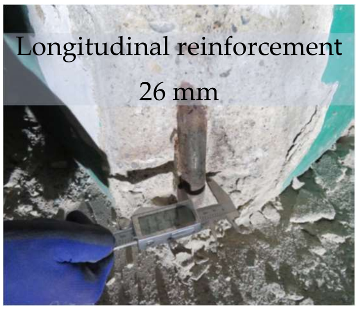
5.5.4 Apse underground columns

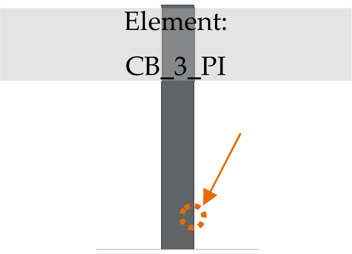
Apse underground columns structural diagnosis output are here described.

Reinforcement bars dimension analysis

Underground columns behave in a bad conservation state, the measured reinforcement corresponds to the one of the original drawings from P.L. Nervi.







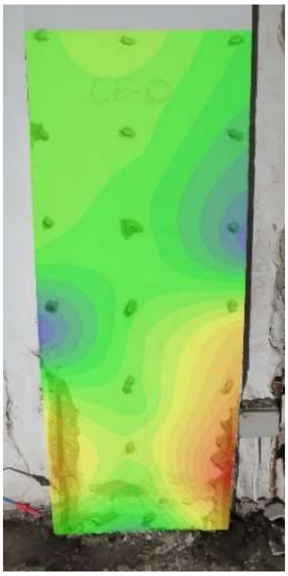
Apse underground floor columns corrosion potential

As those columns are placed in a more humid environment, the values of the corrosion potential in those elements results to be quite high, different spots (as CI_11_PI) results to be subjected clearly to corrosion. Beams are not interested by this phenomenon.

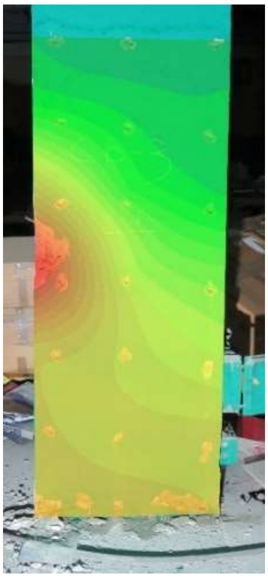
Table 13 Statistical analysis of corrosion potential - underground floor columns

Statistical analysis corrosion potential underground floor columns							
w.r.t Cu/CuSO4			Percentage				
Evaluation	Millivolts		CI-11_PI	CE-0_PI	CB-3_PI	Underground beam street side	Underground beam Po river side
	Min	Max	%	%	%	%	%
90% probability of no corosion activity	< - 200		57%	0%	95%	100%	100%
Uncertain range	-200	-350	38%	95%	0%	0%	0%
90% probability of corrosion activity	>-350		5%	5%	5%	0%	0%
	Total		100%	100%	100%	100%	100%

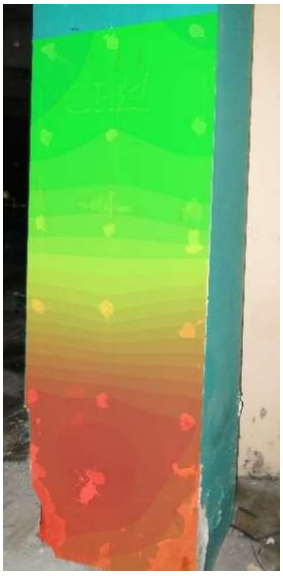
CE_0



CB_3



CI_11



Humidity and temperature monitoring

Underground floor. Here the sensor showed critical values for humidity, the values are oscillating between the 70% and the 60% of RH.

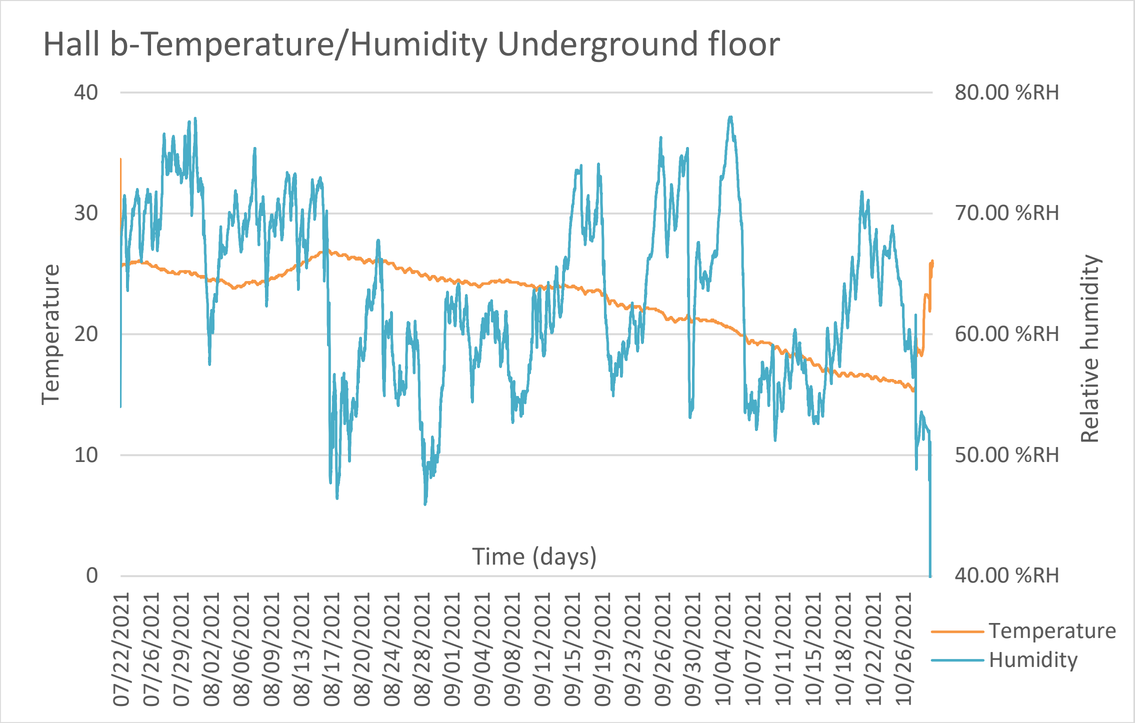


Figure 37 Hall B underground floor pillar temperature/humidity sensor output

The on-site diagnosis showed how a reinforced concrete structure, even if protected by good construction details and even in a not aggressive environment, can be subjected to some deterioration mechanisms and relative problems. For this reason, a deeper investigation with laboratory analysis is fundamental, to understand the deterioration mechanisms and develop conservation strategies.

6 LABORATORY ACTIVITIES

6.1 INTRO

Ferrocement corrosion process is nowadays mostly unknown that’s due to the not large use of the material and because of the difficulties on performing on-site inspections on ferrocement elements, as they are usually very thin, with highly uniform reinforcement, all characteristics which does not allow the use of a lot of on-site tests.

Laboratory tests allows the reproduction of ferrocement samples and different tests on them, so even in structures where samples cannot be taken, as in To-expo halls, ferrocement elements can be reproduced and tested.

The goal of the laboratory activities is to study the behaviour of ferrocement when corroded, and how to contrast the possible corrosion mechanisms.

To achieve the goal, an analysis of cement paste composition is carried out, and based on the results of the analyses, 30 ferrocement samples, 6 cement samples and a Mock-up of a beam selected from Room C are cast.

To test different solutions for the ferrocement conservation, some of the elements are exposed to an aging treatment and the corrosion potential is measured to compare the possible differences between the treatments.

The resistance loss in the different samples is then planned to be checked after the aging procedure by bending tests.

6.2 METHODOLOGY

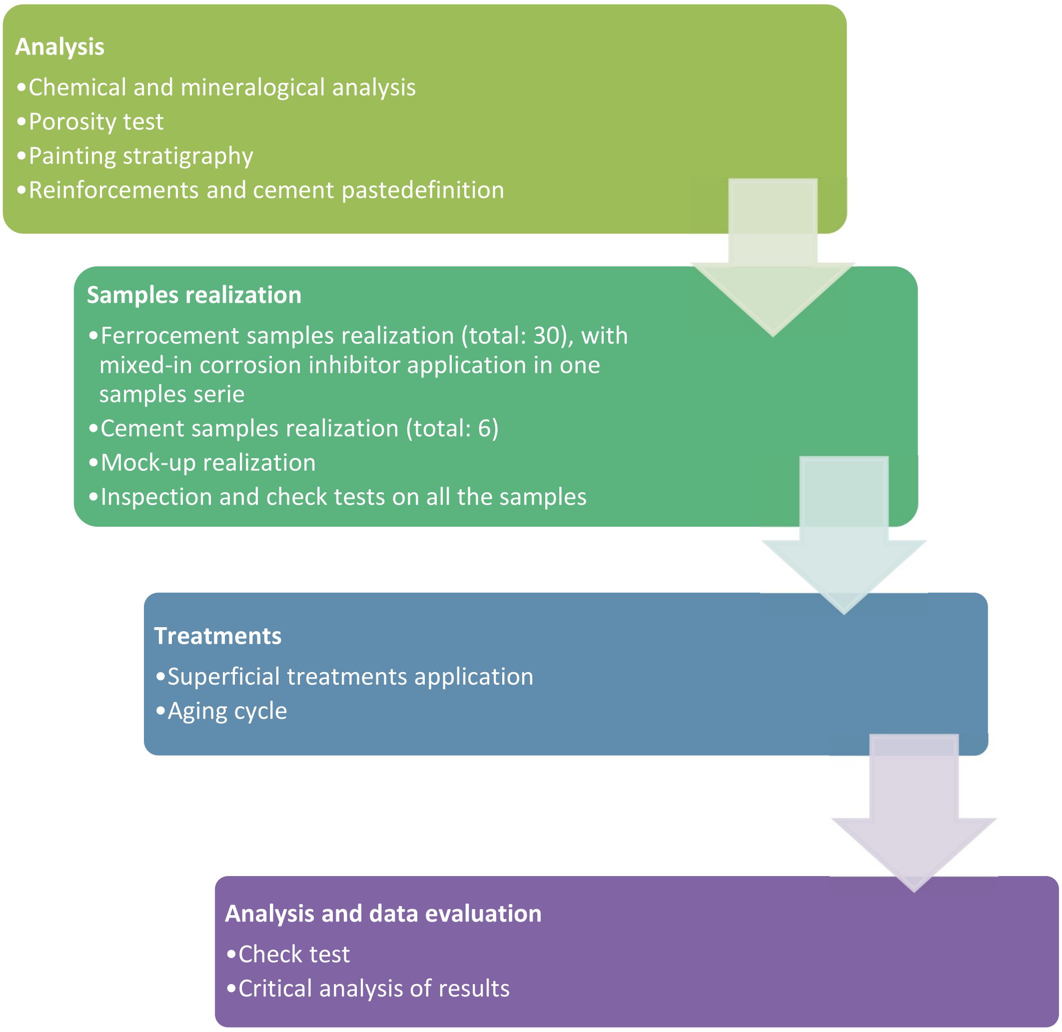
The analysis step involves all the procedures aimed to the definition to physical, chemical, and mineralogical characteristics of the inspected material, and the selection of specific materials for the reproduction of samples in laboratory.

The samples realization involves all the steps followed to realize the samples and the mock-ups. The procedure is made up to realize samples as much regular as possible, avoiding all the possible causes of irregularities.

Treatments applied to the samples differs to test the different possibilities in protecting the samples. Aging is performed to check the effective utility of the treatments.

At the end the differences in corrosion potential and bending resistance are measured by testing the samples, and the results are evaluated to provide the output of the analysis.

The methodology followed realize the ferrocement samples is described in the following scheme.



Analysis
- Chemical and mineralogical analysis
- Porosity test
- Painting stratigraphy
- Reinforcements and cement pastedefinition

Samples realization
- Ferrocement samples realization (total: 30), with mixed-in corrosion inhibitor application in one samples serie
- Cement samples realization (total: 6)
- Mock-up realization
- Inspection and check tests on all the samples

Treatments
- Superficial treatments application
- Aging cycle

Analysis and data evaluation
- Check test
- Critical analysis of results

6.3 MATERIAL ANALYSIS AND SELECTION

The cement paste composition is analysed by picking up a sample from a ferrocement beam located in the west area of the Hall C, from a corrugated floor consisting in ferrocement wave-shaped beams in the lower part and a reinforced concrete slab in the higher part, with a wood table in between them, the length of the inspected elements is about 9 m with a variable section.

Two samples are extracted, one is analysed in the Buzzi laboratory by chemical and mineralogical analysis and a second one is analysed in the Polito Mastlab laboratory.

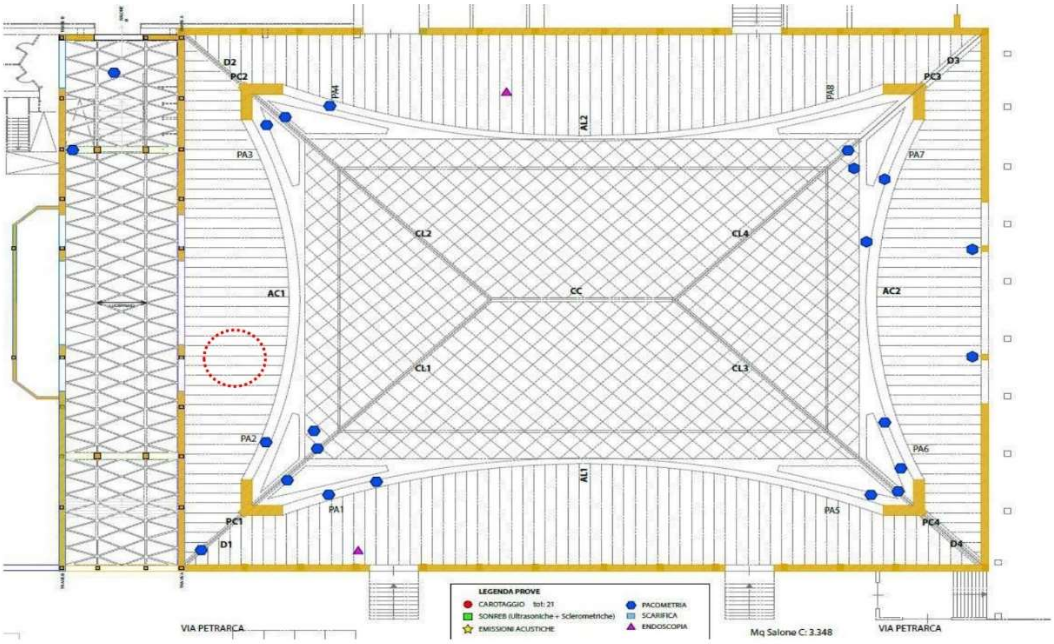


Figure 38 Ferrocement sample position map

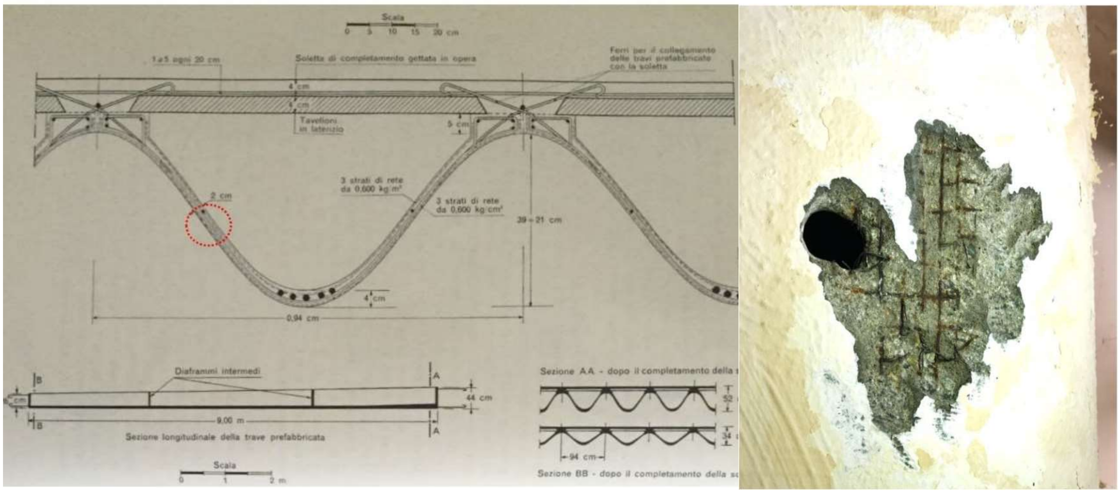


Figure 39 Ferrocement sample position section (on the left), beam after the sample extraction (on the right)

Chemical and mineralogical analysis

The sample of dimensions about 12x6 cm is broken in smaller fragments, with diameter lower than 1 mm. A chemical analysis is performed by using an X-ray fluorescence spectrometer, the results of the chemical analysis are the following.

*Table 14 Chemical composition of the original material (*weight loss is determined calcining the sample at 950°C)*

Element (oxide)	Amount (%)	Element (oxide)	Amount (%)
Weight loss*	17,72	TiO_2	0,32
SiO_2	41,28	P_2O_5	0,12
CaO	22,73	MnO	0,11
Fe_2O_3	6,30	BaO	0,09
Al_2O_3	6,14	SrO	0,06
MgO	2,23	Cr_2O_3	0,03
K_2O	1,41	Cl	0,02
SO_3	0,73	NiO	0,02
Na_2O	0,66	CuO	0,02

A mineralogical analysis is carried using X-ray diffraction, the results are the following.

Table 15 Mineralogical composition of the original material

Phase name	Amount (%)
Portlandite	0,6
Calcite	18,4
Quartz	44,2
Anorthite	8,8
Albite	5,5
Microcline	7,8
Biotite	3,9
Montmorillonite	3,0
Chlorite	3,5
Kaolinite	4,3

From the analysis it comes out that (Material selection: cement, activities report regarding To-expo analysis for Getty foundation) “Portlandite and, partially, calcite, can be ascribed to the binder component of the mortar, they are phases typically developed during the hydration of Portland cement. Quartz and feldspar (anorthite, albite and microcline) comes from the aggregates, namely sand and gravel. The presence of clay minerals (montmorillonite, chlorite, and kaolinite) suggests the addition of clay to the mortars to make it slightly sticky. As a matter of fact, according to the patent 429331, Nervi used to add fossil minerals or bentonite to the mortar to adjust its consistency."

From this analysis a compatible material to be used for the mock-ups realization is chosen from the Buzzi Unicem mixing plant.

Polito analysis

From the sample the steel nets are gradually extracted by using an electric abrasor. Four layers of steel net are identified, with a discrepancy respect the three layers of the original drawing.

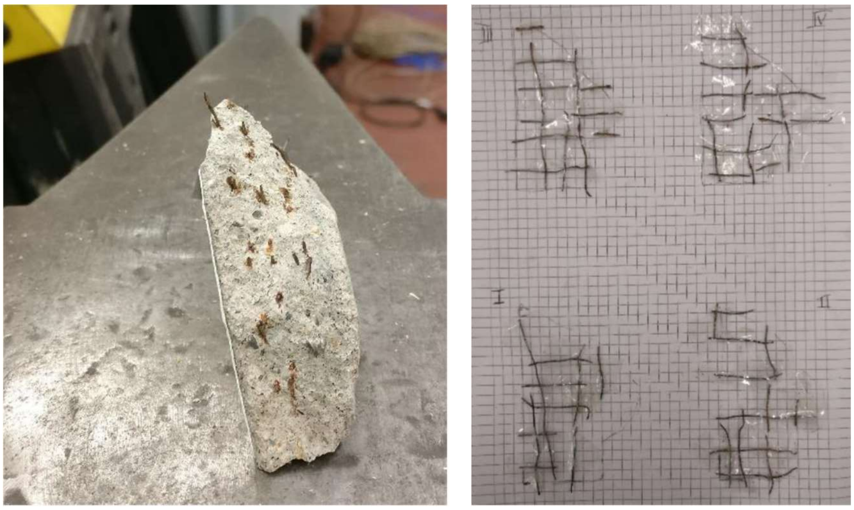


Figure 40 on the left: ferrocement sample, on the right: ferrocement wire meshes extracted from the sample [39]

From this analysis the reinforcements for the mock-ups are chosen, smooth steel bars and woven meshes with 1mm diameter and 10x10 mm spacing are selected.

The smooth steel bars diameters selected for the beam's construction, basing on the original drawings, are:

- Φ 5 for transversal and longitudinal reinforcement
- Φ 10 for longitudinal reinforcement
- Φ 12 for longitudinal reinforcement

6.4 FERROCEMENT SAMPLES REALIZATION

6.4.1 Samples planning description

30 ferrocement samples and 6 pure concrete mix ones are casted. The 6 pure concrete mix samples are realized to perform tests on the concrete mix and determine the typical resistance of the mix, the 30 ferrocement samples are realized to study the ferrocement corrosion process and test different solution for protecting the material from corrosion.

The samples are divided into seven series, each sample is identified in a unique way with the following code system.

S1 -SA-PA- 01

S1 is referred to the series number (S1, S2, S3, S4, S5, S6, S7).

SA is referred to the application of corrosion inhibitor on the sample (SA for surface applied, MI for mixed-in inhibitors).

PA is referred to the application of painting on the sample (if written VF refers to the application of glass-based compound).

01 is referred to the sample number, the number 01 is always the control one.

Table 16 selected material for mock-ups

Material selected:		
Cement mix	premixed mortar based on pozzolanic cement	
Steel bars	mild smooth rebar	Φ 5
	semi-hard steel rebars	Φ 10 and Φ12
Steel mesh	Woven steel net	Φ1
	10 mm spacing	

The samples realized are divided in 7 series as:

- 7 samples with mixed-in corrosion inhibitor (S1-MI)

  6 of those samples (from 02 up to 07) are realized by mixing the concrete paste with a mixed-in corrosion inhibitor, one of them (01) is realized without any addiction, so it can be used as comparison test.

- 7 samples with surface applied corrosion inhibitor (S2-SA)

  Six of the seven samples of this series are treated with a migrating corrosion inhibitor, with different application techniques:

  - In three of them (02, 03, 04) the corrosion inhibitor is spread of one face of the sample by two brush applications
  - In one of them (05) the corrosion inhibitor is spread of one face of the sample by three brush applications.
  - In one of them (06) the corrosion inhibitor is spread of one face of the sample by one spray application and by one brush application.
  - In one other of them (07) the corrosion inhibitor is spread of one face of the sample by three spray applications
  - Then one of the samples is not treated (01)
- 4 samples painted and then treated with surface applied corrosion inhibitor (S3-PA-SA)
  - Three of them (02, 03, 04) are painted and treated with migrating corrosion inhibitor
  - One of them, as it is the control one (01) is only painted
- 3 samples treated with surface applied corrosion inhibitor and glass-based compound (S4-SA-VF)
  - Two of those samples (02, 03) are both treated on one face of the samples with a surface inhibitor of corrosion applied by brush (two hands, waiting for the drying

    of the first application before the next one, and with the glass-based compound, applied in the same way.
    - One sample (01) is not treated to have a comparison in aging.

- 3 samples treated with glass-based compound (S5-VF)

    - On two of the samples (02, 03) of this series a layer of vetrofluid in spread on one face using a brush, with two applications, waiting for the drying of the first one and then the second one.
    - Here as well one sample (01) is not treated to have a comparison in aging.
- 6 samples for the mechanical tests (S6-M)

    - All those samples are not treated with any kind of superficial treatment for countering corrosion, all of them will be tested in bending without being aged to have a reference for the comparison between the resistance values in the aged case and in the not aged one.

- 6 cement paste samples (S7 – CP)
    - Those samples are realized for mechanical test on the concrete mix and planned to be tested in compression to define the mechanical characteristics of the concrete paste.

6.4.2 Treatments description

A short description of the used treatments is here provided.

SERIE 01: Mixed in corrosion inhibitor

The mixed in corrosion inhibitor used is a water-based, organic, corrosion inhibiting admixture

of mixed type, it means it influences both anodic and cathodic reaction. It is based on amine salts of carboxylic acids. It acts by forming a protective layer on embedded reinforcement, reduces the corrosion rate and delays the onset of corrosion. It appears like a dark brown liquid; it is mixed in low quantity with water and then with concrete when it is casted, at the rate of 1.5 pts/ yd3 (1l/m3). The PH of the mixed in corrosion inhibitor is about 11-12. The corrosion inhibitor does not affect slump, air content, density, set time, flexural strength, compressive strength.

SERIE 02, SERIE 03, SERIE 04: Migrating corrosion inhibitor

The surface-applied migrating corrosion inhibitor used is a blend of amino-alcohols and salts of carboxylic acids. It is a mixed type of corrosion inhibitor which appears like a yellow fluid. It acts by both delaying the corrosion onset and reducing corrosion rates. It is applied by brush or spray directly on concrete surface, then capable to migrate in any direction inside the concrete specimen, up to seven cm in 30 days. Its PH is about 9-10. It is capable to work between 2°C and 50°C.

SERIE 04, SERIE 05: Glass-based compound

Is a glass- based compound called VetroFluid, with specific modifying adding which penetrates in to concrete and locks porosity and acts as a barrier to protect it. It appears like a colourless and odourless fluid. It can be applied directly on concrete surface by brush or spray. The glass-based compound is completely maturated in 36 days. The compound is capable to work for temperatures higher that 5°C. It damages glass and aluminium.

SERIE 03: Painting

The selected painting used the samples is selected basing on the one used in Nervi's Hall analysed by paint analysis (Leonardo laboratory). It is a water-based paint, used to paint walls in internal and external environments. The paint is white coloured. It is applied by brush application directly on concrete's surface twice, the first time with a mix of 10-15% with water, the second one with a mix of 20-25% with water. When applied the temperature needs to be between 8 °C and 35 °C.

Epoxydic resin

Is a lightly yellow resin, waterproof. Is composed by two components, which are mixed when the resin must be applied, then mixed for three min, and re-potted to guarantee a good mix. The resin is applied by brush application. The application must be done in an environment with a temperature higher than 5°C.

Epoxydic resin has been applied on both sides of each sample to avoid contamination during the aging.

A synthetic description of the treatments of each sample is provided in the following tables.

Table 17 samples identification and preparation date

Series	Sample ID	Casting Date	Series	Sample ID	Casting Date
S1	S1-MI-01	17/12/2021	**S4**	S4-SA-VF-01	17/12/2021
	S1-MI-02	16/12/21		S4-SA-VF-02	17/12/2021
	S1-MI-03	16/12/21		S4-SA-VF-03	17/12/2021
	S1-MI-04	16/12/21	**S5**	S5-VF-01	14/12/21
	S1-MI-05	16/12/21		S5-VF-02	14/12/21
	S1-MI-06	16/12/21		S5-VF-03	14/12/21
	S1-MI-07	16/12/21	**S6**	S6-M-01	14/12/21
S2	S2-SA-01	14/12/21		S6-M-02	14/12/21
	S2-SA-02	14/12/21		S6-M-03	14/12/21
	S2-SA-03	17/12/2021		S6-M-04	14/12/21
	S2-SA-04	17/12/2021		S6-M-05	14/12/21
	S2-SA-05	17/12/2021		S6-M-06	17/12/2021
	S2-SA-06	17/12/2021	**S7**	S7-CP-01	16/12/21
	S2-SA-07	17/12/2021		S7-CP-02	16/12/21
S3	S3-PA-SA-01	16/12/2021		S7-CP-03	16/12/21
	S3-PA-SA-02	16/12/2021		S7-CP-04	16/12/21
	S3-PA-SA-03	16/12/2021		S7-CP-05	16/12/21
	S3-PA-SA-04	16/12/2021		S7-CP-06	16/12/21

Table 18 Samples treatments description

Series	Sample ID	Treatment Type - Date	Resin application	Aging
S1	S1-MI-01	No Inhibitor mixed in	Borders	Yes
	S1-MI-02	Inhibitor Mixed in	Borders	Yes
	S1-MI-03	Inhibitor Mixed in	Borders	Yes
	S1-MI-04	Inhibitor Mixed in	Borders	Yes
	S1-MI-05	Inhibitor Mixed in	Borders	Yes
	S1-MI-06	Inhibitor Mixed in	Borders	Yes
	S1-MI-07	Inhibitor Mixed in	Borders	Yes
S2	S2-SA-01	No treatment	Borders	Yes
	S2-SA-02	S. A. Inhibitor [2 Appl. By brush]	Borders	Yes
	S2-SA-03	S. A. Inhibitor [2 Appl. By brush]	Borders	Yes

	S2-SA-04	S. A. Inhibitor[2 Appl. By brush]	Borders	Yes
	S2-SA-05	S. A. Inhibitor [3 Appl. By brush]	Borders	Yes
	S2-SA-06	S. A. Inhibitor [2 Appl. 1 brush + 1 spray]	Borders	Yes
	S2-SA-07	S. A. Inhibitor [3 appl. By spray]	Borders	Yes
S3	S3-PA-SA-01	Painted	Borders	Yes
	S3-PA-SA-02	Painted+S.A. Inhibitor	Borders	Yes
	S3-PA-SA-03	Painted+S.A. Inhibitor	Borders	Yes
	S3-PA-SA-04	Painted+S.A. Inhibitor	Borders	Yes
S4	S4-SA-VF-01	No treatment	Borders	Yes
	S4-SA-VF-02	S.A. Inhibitor+Glass based comp. 2H	Borders	Yes
	S4-SA-VF-03	S.A. Inhibitor+ Glass based comp. 2H	Borders	Yes
S5	S5-VF-01	No treatment	Borders	Yes
	S5-VF-02	Glass-based compound	Borders	Yes
	S5-VF-03	Glass-based compound	Borders	Yes
S6	S6-M-01	No treatment	No	No
	S6-M-02	No treatment	No	No
	S6-M-03	No treatment	No	No
	S6-M-04	No treatment	No	No
	S6-M-05	No treatment	No	No
	S6-M-06	No treatment	No	No
S7	S7-CP-01	No treatment	No	No
	S7-CP-02	No treatment	No	No
	S7-CP-03	No treatment	No	No
	S7-CP-04	No treatment	No	No
	S7-CP-05	No treatment	No	No
	S7-CP-06	No treatment	No	No

6.4.3 **Realization**

A total of thirty-six samples were prepared for this case study: thirty samples were prepared to be treated and aged to study the durability and their performance, while six were solely prepared to study the mechanical properties of the cementitious material (these samples did not include the metal mesh layers). The sample dimensions are of 300x30x75 (h) mm, and include seven layers of metal mesh 270x55 mm. The six samples' dimensions used to test concrete mechanical property are 160x35x35(h) mm.

Figure 41 (on the left) ferrocement sample, (on the right) cement sample

The ferrocement samples have been realized following Pier Luigi Nervi's design and in accordance with ACI Standard PRC-549-18. The first step in the preparation of the samples consisted of cutting the layers of metal mesh to size. The process started by cutting small steel sheets from a large steel bundle; each piece was then straightened, bending by hand-pushing to reduce the curvature effect of the metal bundle.

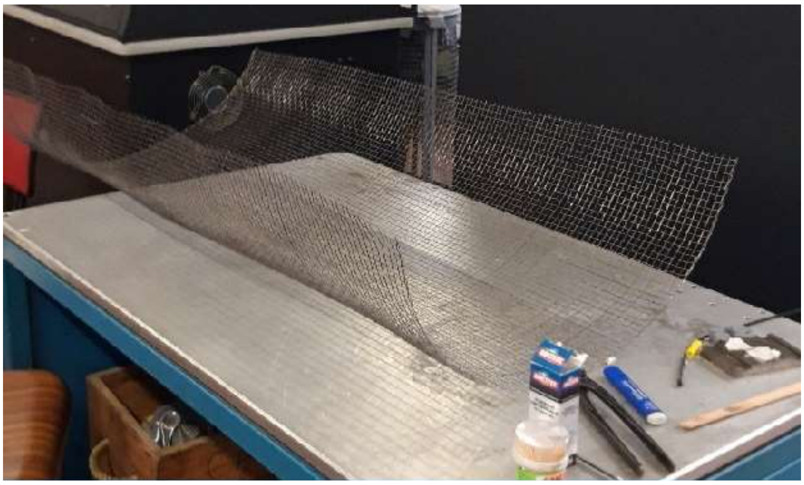


Figure 42 Steel sheet before bending

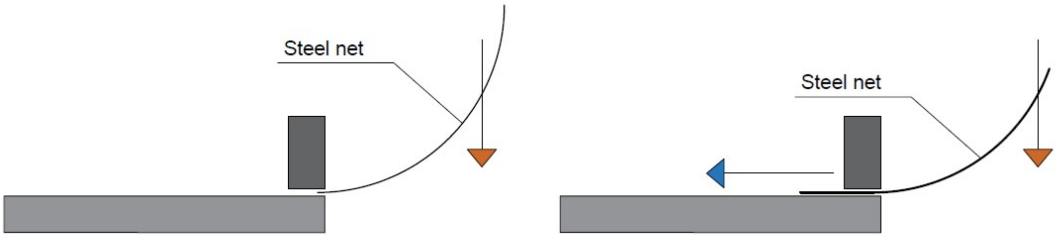


Figure 43 Steel sheet bending scheme

Once the large steel sheets curvature was fixed, smaller sheets were cut with a dimension of 240 mm x 50 mm. Each sample included seven metal sheets.

Clay was used to assemble the seven metal layers of each sample. A clay bed was prepared to allow for the correct positioning of each metal layers. Each metal sheet was placed with a 2 mm distance to the next providing a 2 mm concrete. By leaning the steel mesh on the clay layer, the position of the mesh did not change. This was a laborious step. After completing this step, seven wood sticks were glued within the metal layers to provide additional stiffness. The location of the wood sticks is shown in the following figures: three of them were placed on the side, and one in the middle to reduce deformation during the concrete pour.

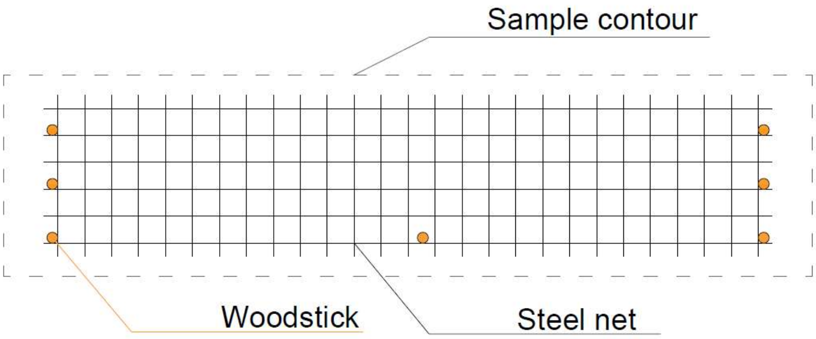


Figure 44 Steel net and wood sticks positioning

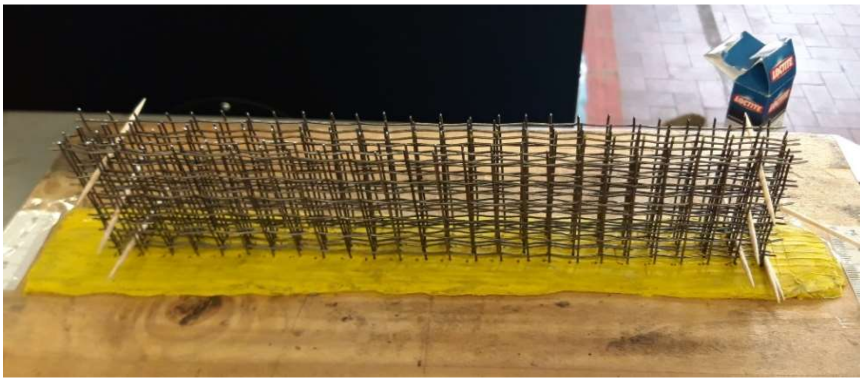


Figure 45 Steel net with positioned wood sticks

This solution provided stability to the metal frame and ensured the correct distance between each mesh layer. After positioning the mesh layers, electrical connections were done by using faston terminal, which allowed to make a stable connection between each mesh layers to carry out electrochemical testing. A faston was placed on each net from where a steel wire was connected to it, on both short sides of the steel mesh package, in the lower and in the top.

Once the electrical connections were completed, the samples were then placed in a plexiglass formwork in preparation for casting. The plexiglass formwork (A type: 130x320x85 (h) mm, B type: 90x320x85 (h) mm) has been realized by cutting plexiglass rectangles and by boring them to create holes for screws. Two different formworks were created: Type A for three samples to be cast at the same time and Type B for two samples to be cast at the same time.

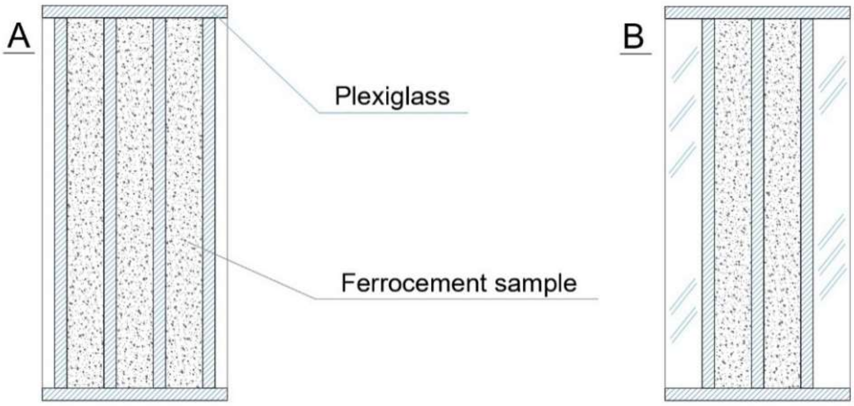


Figure 46 Plexiglass formworks type A and B

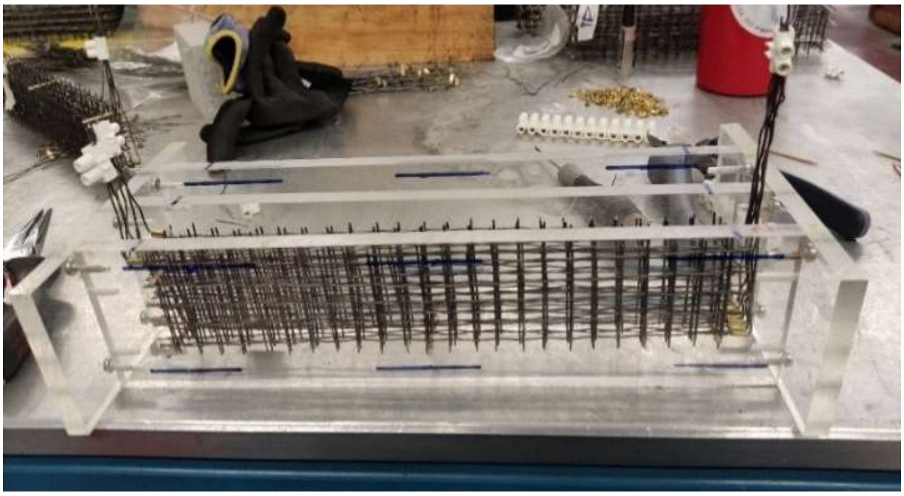


Figure 47 Steel net formwork positioning

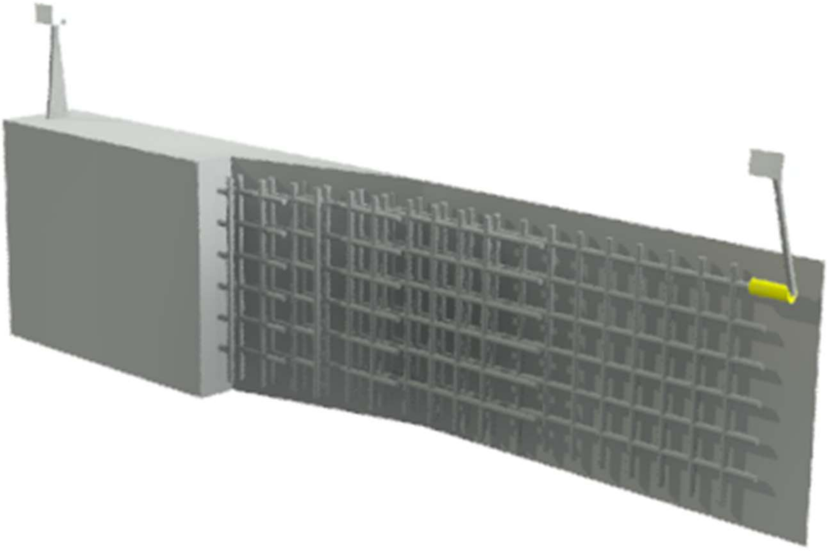


Figure 48 Concrete sample model

The samples were poured during the week of December 2021. Two different water/cement (w/c) ratios had been previously tested to achieve the best consistency for this application: WC 0.15 and 0.18.

All the samples have been casted using w/c ratio equal to 0.18, which provided the best workability for this application. The following steps were taken for the pouring:

- The plexiglass formwork is assembled, and an Oil-Based Release Agents was applied to all the surface to prevent concrete to stick to the sides of the formwork.
- 1.458 kg of concrete mix powder is weighted and placed in the kneader machine's jar.
- 0.292 kg of water is added into the jar.
- The kneader machine is switched on at speed one (low speed) for 60 seconds, then at speed two (high speed) for other 30 seconds.
- When the concrete mix is ready to pour, half of the mix is placed in the formwork and compacted by handshaking and a hand electric vibration tool.
- The steel mesh package is inserted in the formwork and placed in position.
- The remaining part of the concrete mix is then poured in the formwork.
- The mix is again compacted by handshaking and a hand electric vibration tool.
- The samples are then covered with a plastic polyethylene covering and left for 24 h in a humidity-controlled room.
- The samples are left to cure for 28 days underwater.

Figure 49 Ferrocement samples casting procedure, from up left to down right: (i) oil-based release agent application on formwork, (ii) concrete mix weighting (iii) water weighting (iv)compacting concrete

Figure 50 Ferrocement samples casting steps: from up left to down right: (i) steel net package inserting, (ii) concrete final compacting procedure, (iii) concrete samples covering, (iv) de-assembling formwork, (v) underwater curing

The samples were cured underwater in a humidity-controlled environment for 28 days. The curing of the samples started on the 20th of December 2021 and terminated on 20th of January 2022.

6.4.4 Treatments application

Superficial treatments application differs for each type of product applied. Series 02, surface applied corrosion inhibitor, has been divided into different types of applications, to then check the effective result of each type. So, as described before, the numbers 02, 03 and 04 of the series 02 (SA) have been subjected to a first application by brush of corrosion inhibitor and then, after the first layer dried, a second application identical to the first one. The only difference of the sample 06 of the series 02 (SA) is that the process is repeated three times. In series 05 the first layer of corrosion inhibitor in applied by brush application, and after the drying of the layer, a second application by spray has been done. In the last sample of the series 02 (SA) the surface inhibitor is applied by three spray applications, always after the drying of the previous one. By measuring the samples weight before and after the product application, it has been noticed that the spray application is spreading an higher quantity of material (150 % respect the brush one).

Series 03 is painted with a specific type of paint, of white colour that reproduces the painting applied in Nervi's Hall ferrocement elements. The painting is applied by two brush applications divided by a drying time of 30 min. After that, three samples of the series, from 02 to 04, are treated by applying migrating corrosion inhibitor by two brush applications, waiting for drying a time of 30 min.

Series 04 (SA-VF) is treated both with surface applied inhibitor and vetrofluid. Only two samples 02 and 03 are subjected to the treatment, as the sample 01 of each series from 01 to 05 is used as control sample, and so is not treated with any product. The application of the products is so performed by applying the migrating corrosion inhibitor as in the samples 02-SA-02, 02-SA-03 and 02-SA-04, which means two hands applied by brush. Then as well by brush the vetrofluid has been applied, the application was supposed to be done twice, the first one two hours after the surface applied inhibitor application to simulate on-site timing, but due to an unknown reaction that brought up white crystals to the surface of the samples, it has been stopped after the first one and only one layer of vetrofluid has been applied.

Series 05 (VF) samples number 02 and 03 have been covered on one face by two brush applications of vetrofluid, still waiting the drying of the first layer for the application of the second one.

After that, in exception for the series 03 (PA-SA) where the procedure is inverted, epoxydic resin has been applied on the samples to protect some areas of them from the unfavourable environmental conditions which will be subjected to during the aging process. Due to an error, in all the samples of the series 01 (MI) and 02 (SA), the resin has been first applied to all the faces of the sample, in exception of one that will be directly hit by the aging (which coincides with the one treated with migrating corrosion inhibitor in series 02). This condition would simulate a sample infinitely thick, where the humidity flow entrance façade would be the same of the exit one, that's not representing the conditions of the Nervi's halls. So, the resin has been scratched away from the face opposite to the one directly hit from the aging flow by the use of sand paper, and the resin applied on both the bigger faces only on the borders, in order to concentrate the aging process in the middle of the sample.

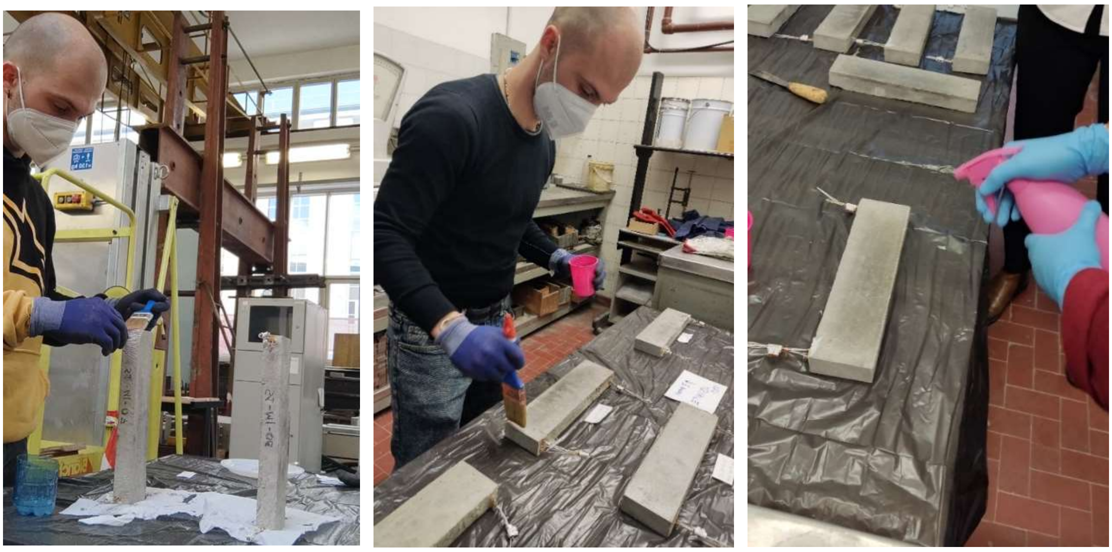


Figure 51 From left: epoxydic resin application, migrant corrosion inhibitor brush application, migrant corrosion inhibitor spray application

6.5 ASSESSMENT TESTING – PRE, DURING AND AFTER

A series of testing is conducted to assess the effectiveness of the treatment and condition of the samples as follows:

Table 19 Ferrocement samples tests definition

Test type	Pre aging	During aging	After aging
Photographic documentation	X	Every two weeks	X
Half-cell Corrosion Potential (ASTM C856)	X	Every two weeks	X
Porosity test	X	-	X

Table 20 Ferrocement samples – mechanical tests

Test type	#Samples
Compressive Strength Testing	Cement samples
Bending	Ferrocement samples

6.5.1 Photographic documentation

Photographic documentation is carried out by using a mobile phone camera (model POCO X3 Pro). Each sample is photographed using artificial lighting (neon lights 58 W) to maintain the same condition. A colorimeter is used to successively compare the photos.

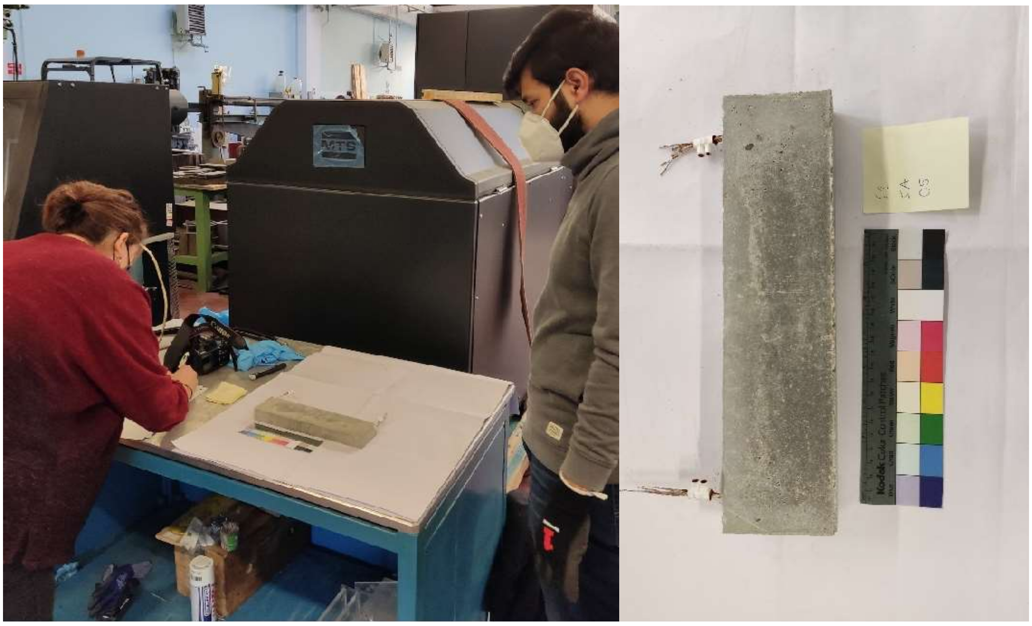


Figure 52 Photographic documentation

6.5.2 Corrosion potential measurement

Half-cell corrosion potential measurements are carried out with a Cu/Cu SO4 reference electrode. Half-cell Corrosion potential is measured before starting the aging cycle, every two weeks during, and at the end.

All the data collected are evaluated in accordance *ASTM C876 Guidelines for corrosion potential of reinforcement steel without cover in concrete*.

The values are evaluated as follows:

- If corrosion potential is higher than -200V (with reference to Cu/CuSO4), the probability of corrosion activity of the steel reinforcement is less than 10%.
- If corrosion potential is between -200 and -350V (with reference to Cu/CuSO4), there is uncertain probability of the probability of corrosion activity of the steel reinforcement in the tested area.
- If corrosion potential is lower than -350V (with reference to Cu/CuSO4), the probability of corrosion activity of the steel reinforcement is higher than 90%.

Twenty measurements are collected based on a 25 mm equally spaced grid on the treated surface of the sample as shown in

Figure 53. Before completing the measurements, the treated surface is wetted by spraying water.

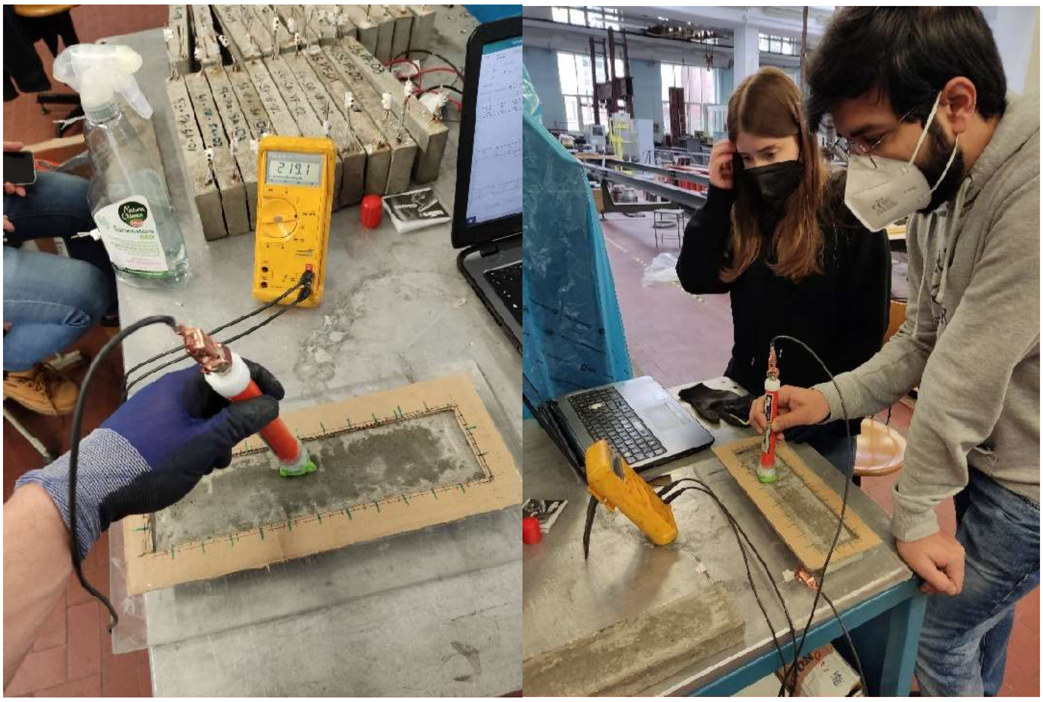


Figure 53 Corrosion Potential Measurement

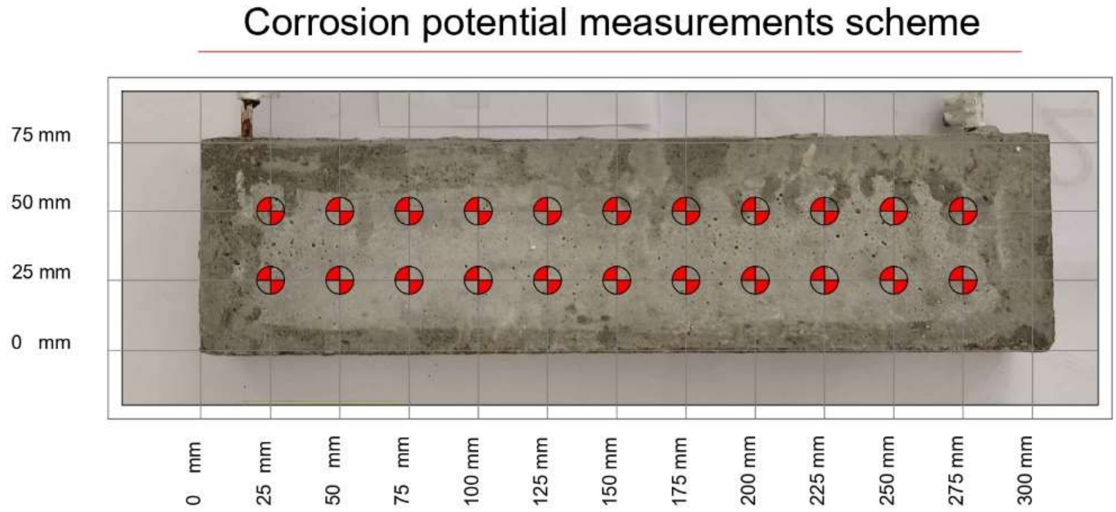


Figure 54 corrosion potential sampling scheme

6.5.3 Aging

All the samples are subjected to an accelerated weathering cycle to verify the effectiveness of the treatments and the durability of the sample. A solution with 3.5% NaCl solved in water is used to accelerate the corrosion process. The aging cycles run for a three-month period alternating wet and dry cycles as follows:

- Wet day: One day of salt spray, where the samples are sprayed continuously for a period of three hours.
- Dry day: the samples are drying in natural conditions

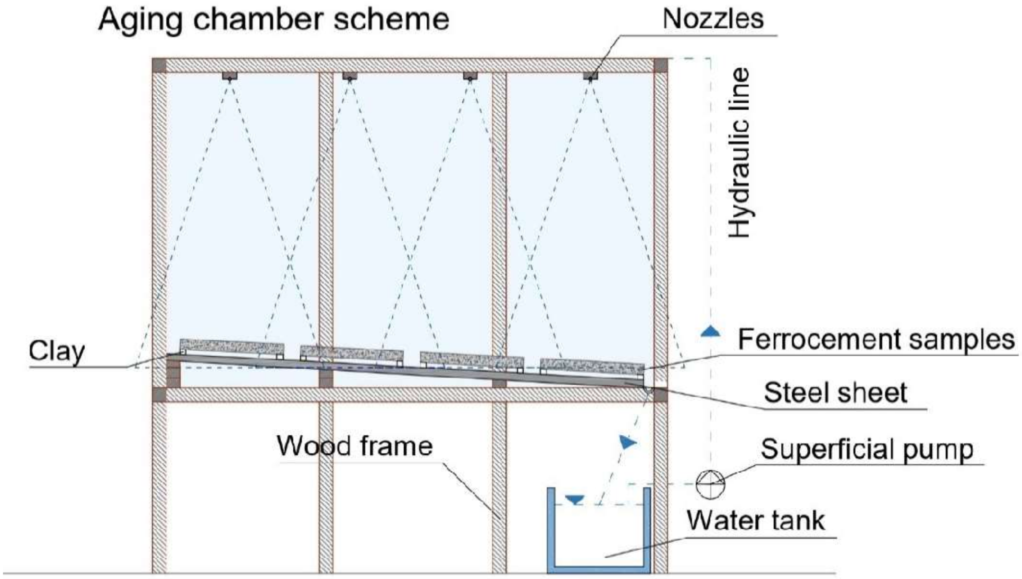


Figure 55 Aging chamber scheme

Figure 56 aging chamber

The accelerated weathering will be conducted in a chamber of 1500x1000x1000 (h) mm containing eight nozzles uniformly spaced located at the top. The platform, where the samples are displayed, is a steel plate placed at an angle of 15°. To prevent direct contact between the samples and the water running off, each sample will be lifted by using a 20 mm clay layer. The solution is sprayed from the eight nozzles, the solution is then collected by a water tank located underneath the table. The solution is then recirculated by using an electric surface pump with a 2-bar pressure.

6.5.4 Mechanical tests

Mechanical testing is planned to be performed on the samples. The output of the bending test provides a quantitative data for the definition of the resistance decrease of the samples after aging.

Bending tests

Bending test is planned to be carried out on some samples of the different series and all the samples of the S6. The test is carried out once the aging of the samples is completed, so the results of the differences between the once aged and the once not aged will be evident. The test is be performed on three points, so a constant bending moment is applied at the middle of the sample, in this way as an output the exact value of the cracking and maximum resistance of the material is measured.

On S7 bending test of three points is planned to be carried out up to failure. The two parts of the broken samples is planned to be used for compression test.

Compression test

Compression test is planned to be carried out on S7 concrete samples to have data about the concrete's resistance. UNI EN 197-1 standard is followed for the test.

The samples area tested is about 35x35 cm, from each test the concrete mix maximum compression resistance is provided.

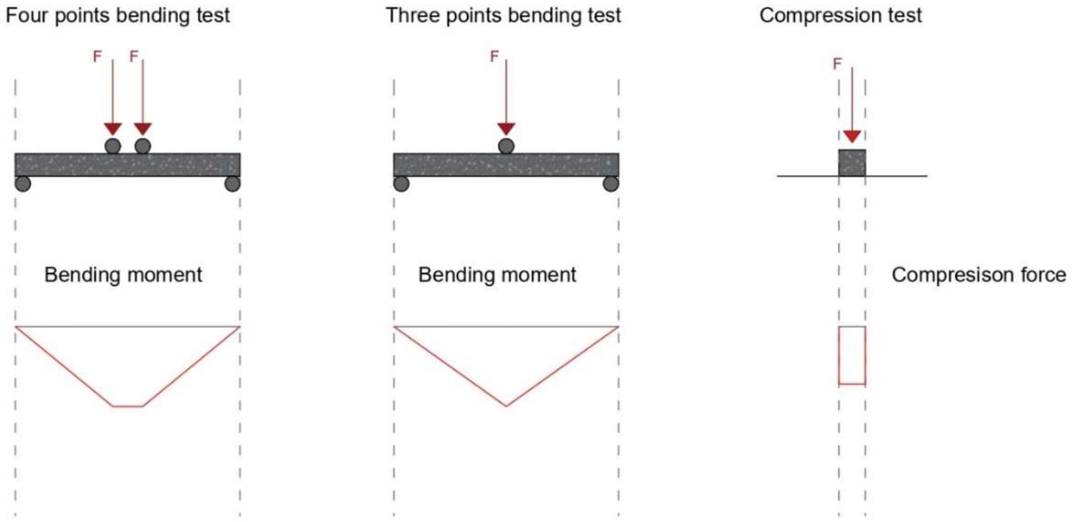


Figure 57 different tests configuration

6.6 MOCK-UP REALIZATION

The large mock-ups are a reproduction scale 1:1 of the internal beams of Hall C of Turin Exhibition Halls as shown in the following figure.

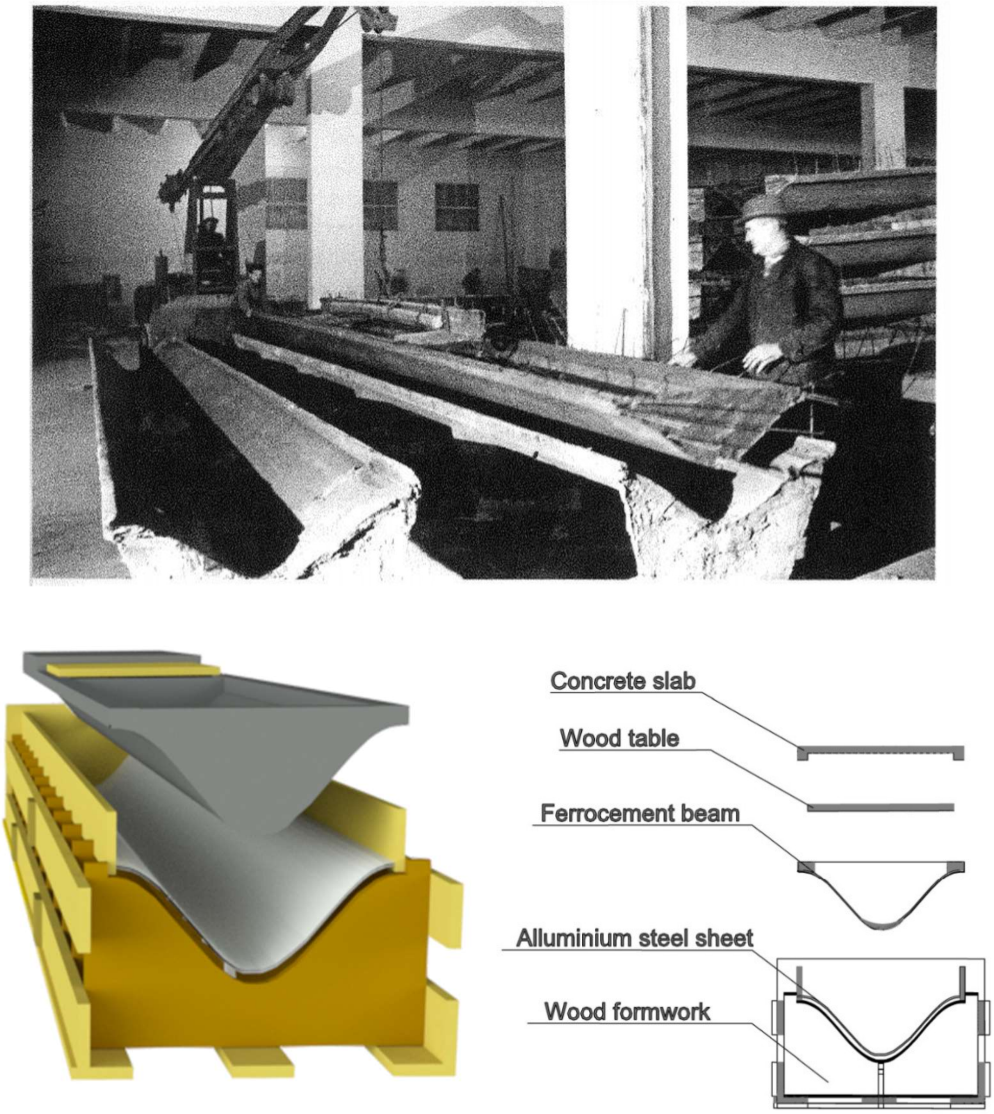


Figure 58 up: ferrocement beam realization, low: ferrocement formwork model and section

These are the steps followed for the realization of the large-scale mock-up:

- Wood formwork structure realization
- Steel sheet placing
- Steel nets cutting, positioning, and shaping (two layers)
- Transversal and longitudinal pre-shaped reinforcement positioning
- Steel nets cutting, positioning, and shaping (two layers)
- Diaphragms positioning (two external ones and one in the middle)
- Concrete casting
- Wooden boards positioning
- Concrete floor slab casting

6.6.1 Formwork realization

The formwork is realized by cutting 13 MDF sections of 30 mm of thickness following the shape of the beam which gets flatter in shape from the beginning of the beam (0 meters) up to the end (6 meters). The panels are placed on three horizontal longitudinal wood beams, then placed on six pairs of horizontal transversal wood beams, so a thickness under the formwork can provide a space for inserting any device for the movement.

Figure 59 Formwork realization

6.6.2 Aluminium plate application

An aluminium steel plate of 600 cm length and large on one side 106 cm and on the other one 120 cm is placed on the wood formwork.

To provide the curved shape a procedure is followed:

- The steel sheet is distended on the formwork
- Gravel bags are placed in the middle of the steel sheet through all the formwork length
- The steel sheet is nailed to the formwork diaphragms starting from the middle line, and continuing symmetrically to the formwork side
- Once the side curvature needs to be forced on the steel sheet, a heavy steel bar is placed on the side and pushed down
- The sides of the steel sheet are nailed to the formwork diaphragms
- The side and the middle weight are removed

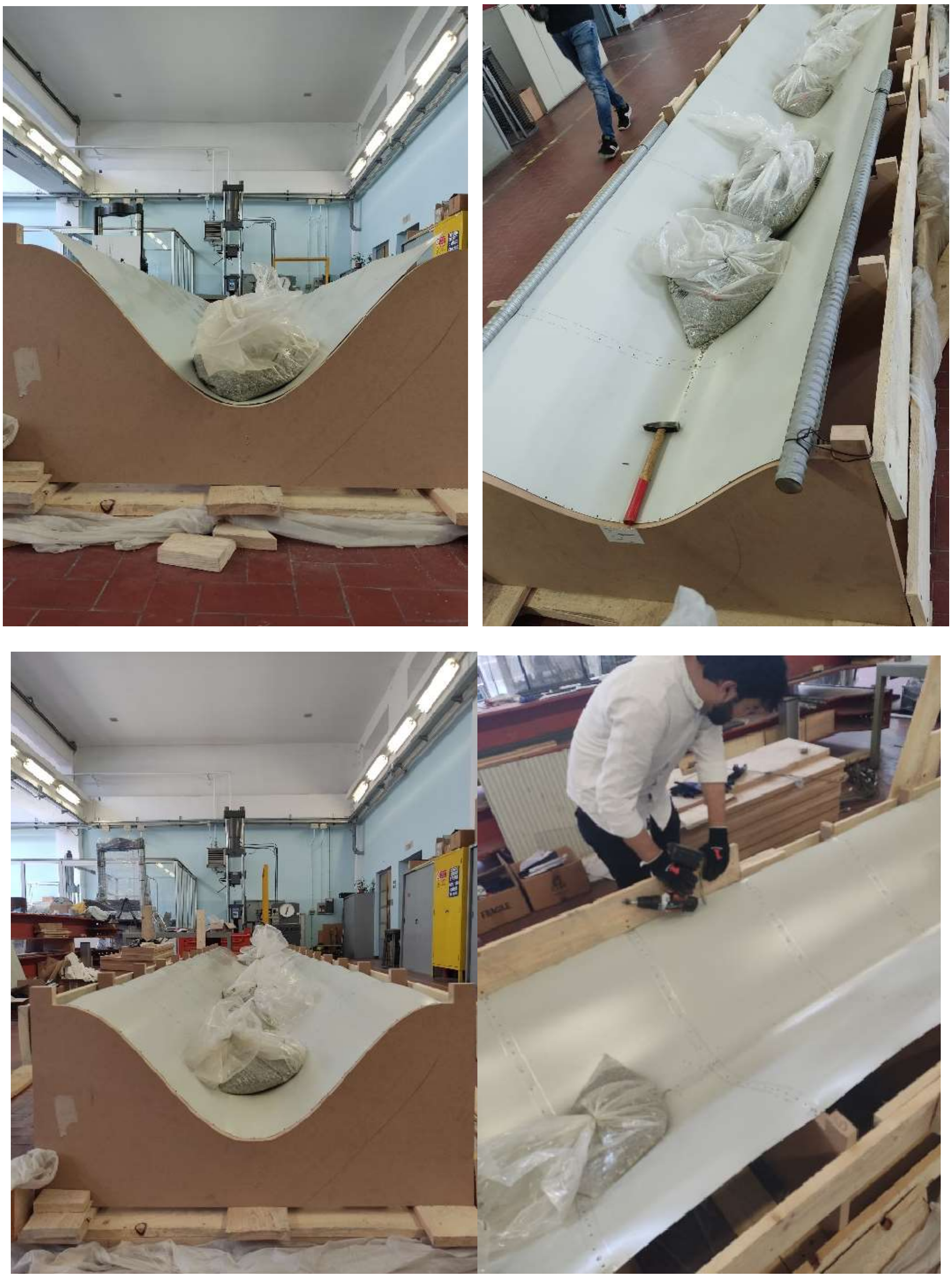


Figure 60 from up on the left: Fixing in the middle point of the middle of the plate, side fixing of the plate by using steel bars, final shape, side wood boards positioning

6.6.3 Reinforcement shaping

The steel reinforcement used follows the wave section of the beam; a specialized tool is used to perform the bending operation of the steel bars. The bending operation is performed following the shape of the beam. For each beam, thirty steel rebars and sixty anchorage bars are prepared.

Figure 61 Steel bending procedure

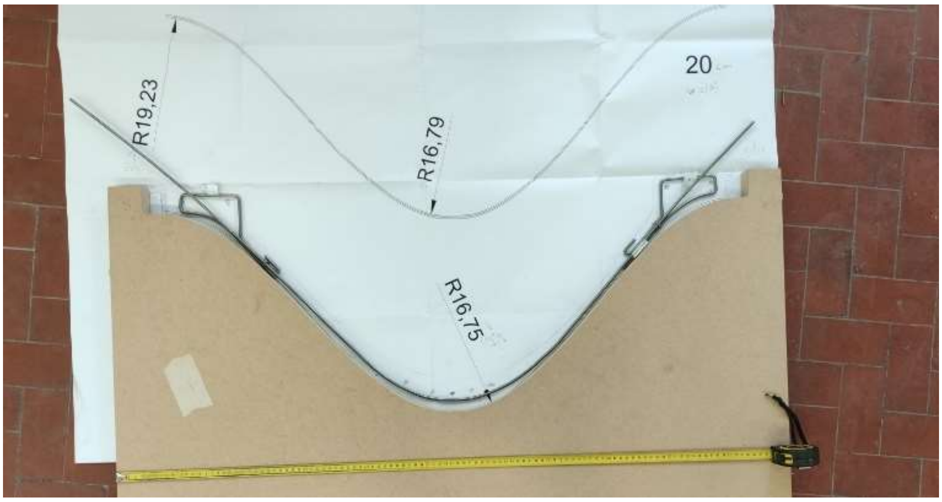


Figure 62 Steel bending shape

6.6.4 Reinforcement positioning

The reinforcements for the lower beam are composed of four layers of steel mesh and different longitudinal and transversal steel bars.

The procedure for the positioning and the shaping of the reinforcements is the following:

- Two steel layers of 6 m length are cut
- The two steel layers are placed on the upper part of the formwork and the deformation is corrected
- The two steel layers are positioned inside the formwork and cut to fit the exact size of the beam
- Transversal reinforcement, pre-shaped, is placed in position each 0.2 m and fixed to the steel nets
- Longitudinal reinforcement is welded to reach 6 m length and placed in position
- Two more layers of steel net are cut, deformations corrected, placed in position, and cut again to fit the beam
- The diaphragms reinforcements are positioned, and the formwork closed on the sides
- All the steel reinforcements are connected

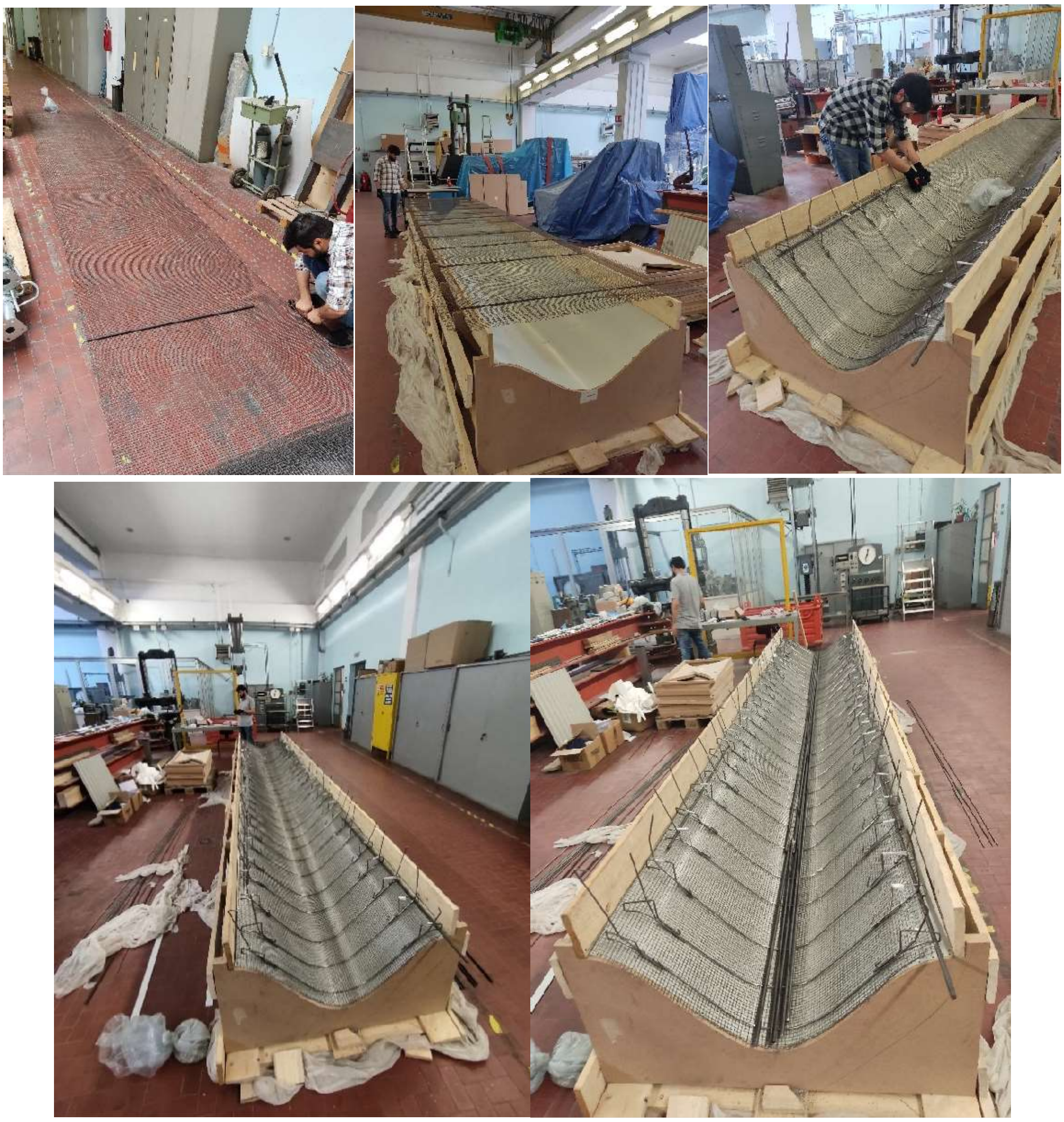


Figure 63 Reinforcement application procedure, from high on the left side: Steel nets cutting, Steel nets straightening an positioning, transversal reinforcement positioning and fixing, transversal reinforcement positioned, longitudinal lower reinforcement application

6.6.5 **Casting**

The casting is divided into two parts, the casting of the lower beam and the casting of the upper slab.

- The steel package is uplifted to spread the oil on the steel sheet
- The steel package is placed back in position
- The lower beam is casted by applying the concrete directly on the steel package and vibrated by hitting with a hammer the formwork.
- Once the concrete lower slab hardened, a wood table is positioned on the upper part of the beam
- Upper slab reinforcement positioning
- Upper slab casting

7 RESULTS ANALYSIS AND DISCUSSION

Corrosion potential is measured and reported following the scheme plotted below.

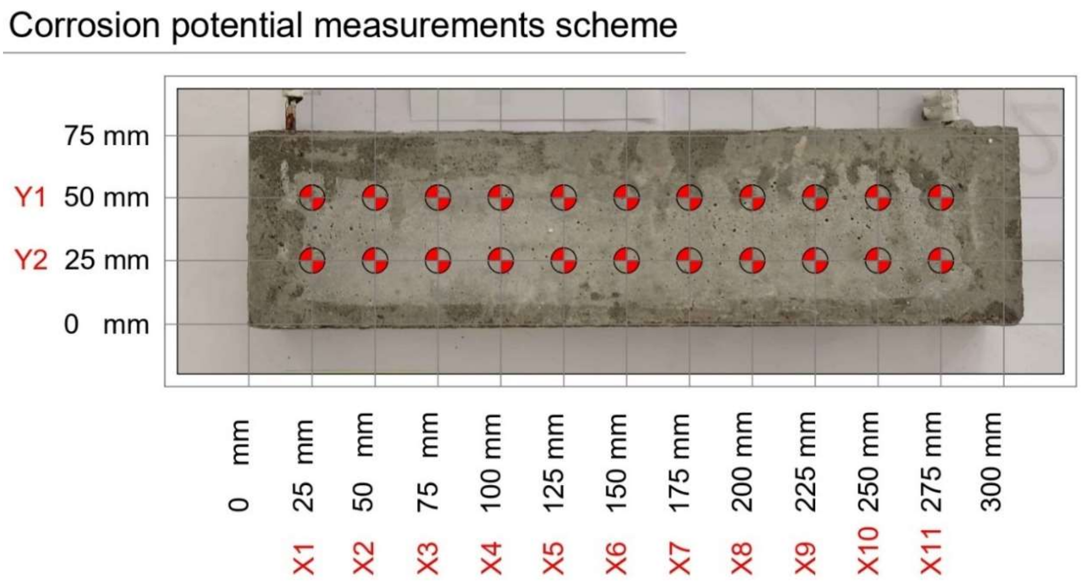


Figure 64 corrosion potential measurements scheme

For each series the graphs about the mean corrosion values are plotted and the main results discussed and deeper analysed. All the acquired data can be found in the attachment A.

Some considerations must be done before analysing the results.

As first the aging is still in the middle of the process, so the corrosion potential values might still have some evolutions in the long period which might deteriorate or not the samples.

The results are analysed on the basis of the corrosion potential and the photographic campaign, those two data are not enough to have a full understanding of the corrosion process happening, more complete considerations can be done once the aging is finished and the sample mechanical tested.

The results discussion is divided for each series.

7.1 S1-MI RESULTS

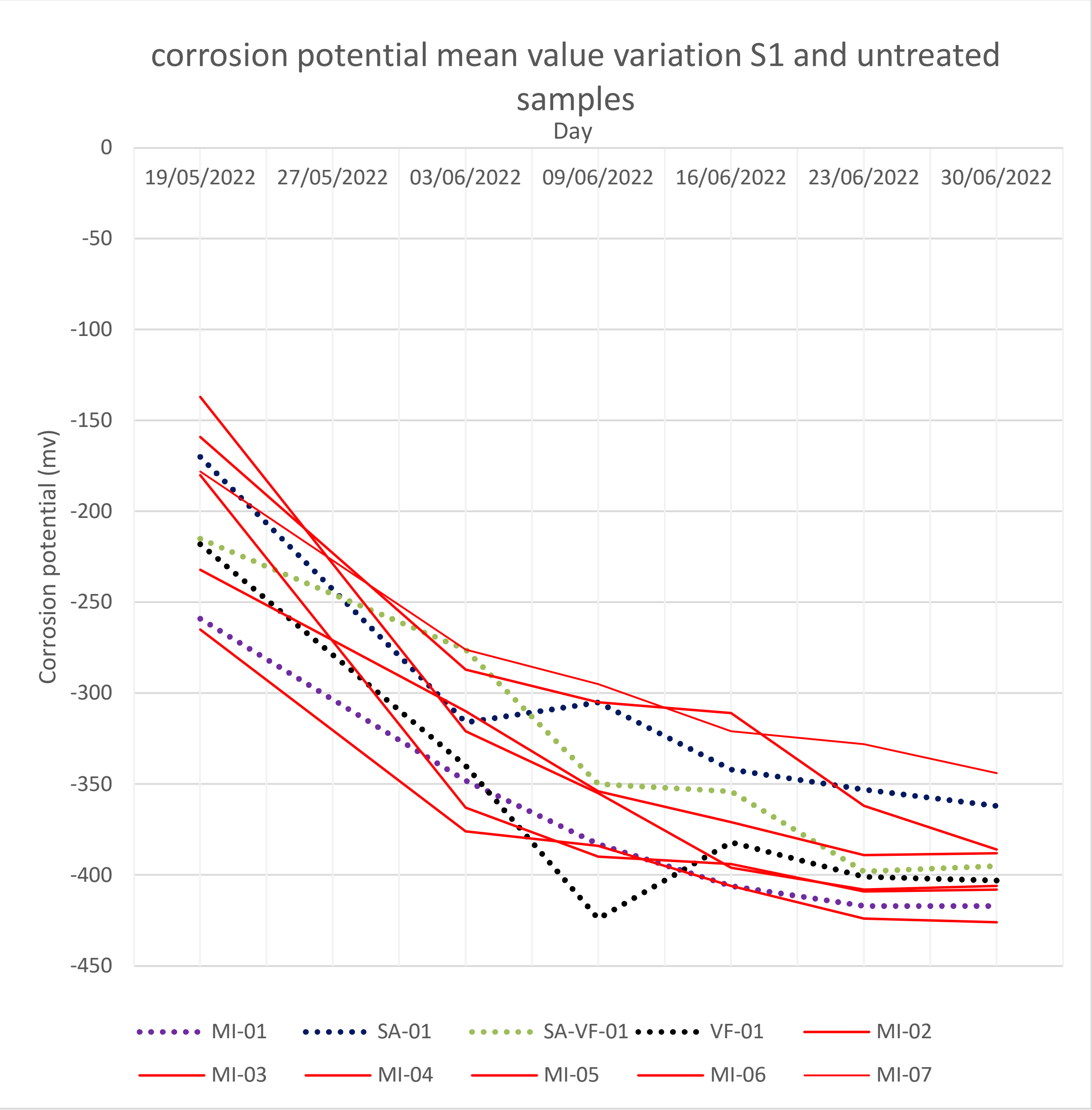


Figure 65 S1 and not treated samples mean corrosion potential values variation

The Mixed-in corrosion inhibitor samples (MI-02, MI-03, MI-04, MI-05, MI-06, MI-07) corrosion potential loss is like the one of the not treated samples (MI-01, SA-01, SA-VF-01, VF-01).

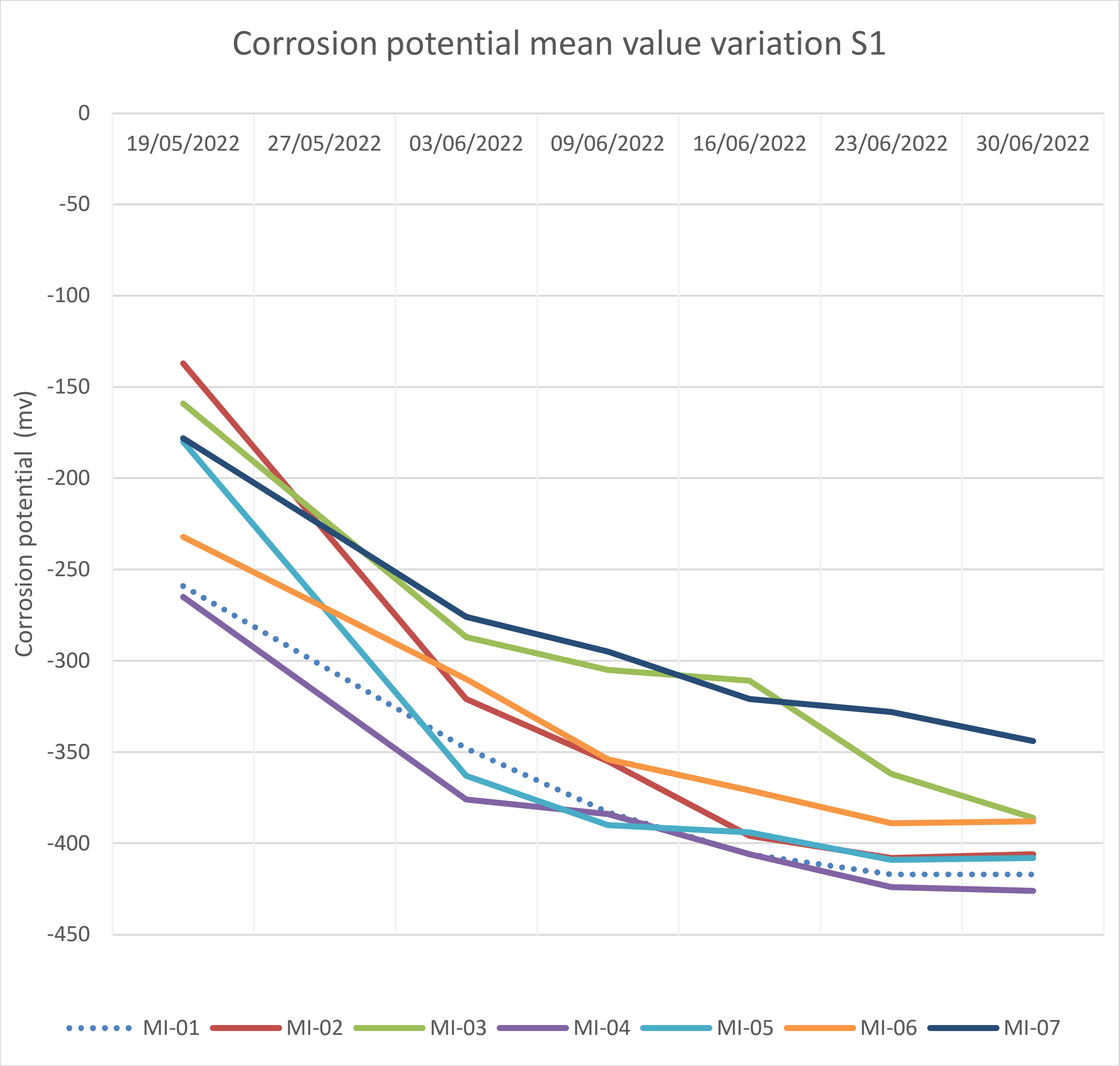


Figure 66 S1 mean corrosion potential values variation

The mean corrosion potential value of MI-01 is lower than the mean values of all the rest of the series samples, unless MI-04.

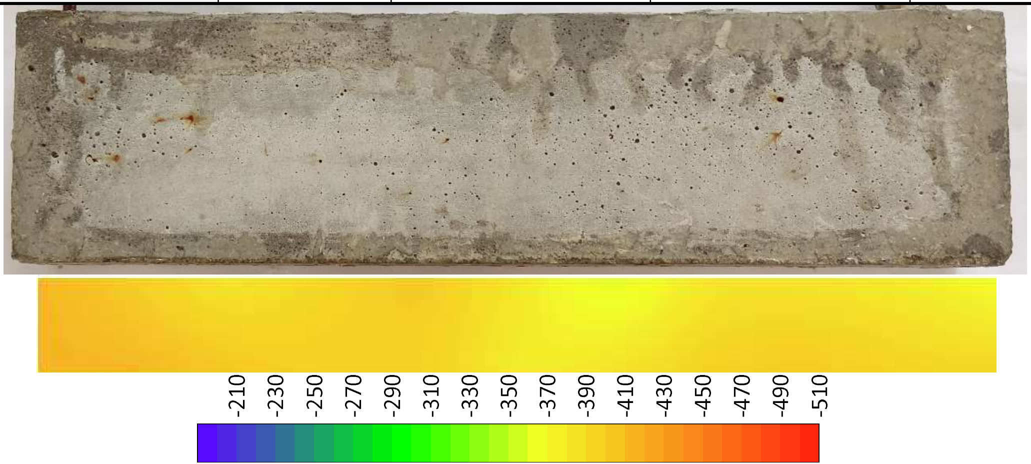
The corrosion potential in the time variable is getting more negative in less time at the aging beginning, then in all the samples the tendency to get more negative is decreasing.

The corrosion potential values tend to get more stable around -400 mv.

The sample MI-07 trend is about 50 mv higher than all the rest of the samples on 30/06, this sample might be an out layer.

Table 21 S1-MI-01 Corrosion potential analysis 30-06

Sample ID	S1-M1-01			
Description	Control sample, no treatments			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-392	-433	-417	11

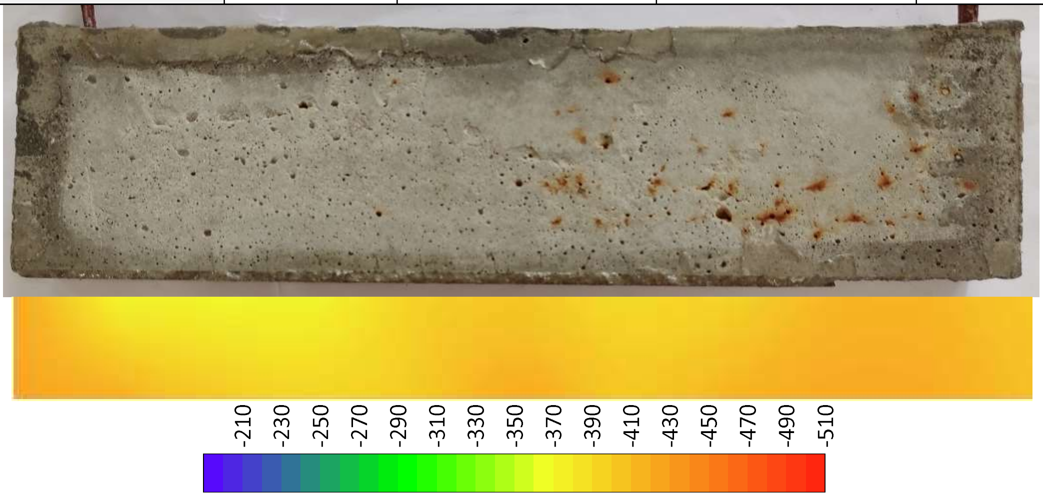


[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-433	-433	-425	-422	-420	-407	-412	-421	-424	-420	-418
Y2	-433	-421	-410	-417	-424	-410	-392	-410	-410	-407	-399

This sample shows a uniform corrosion behaviour. The corrosion potential values in the middle part of the sample are slightly higher than the ones on the sample’s side.

Table 22 S1-MI-04 Corrosion potential analysis 30-06

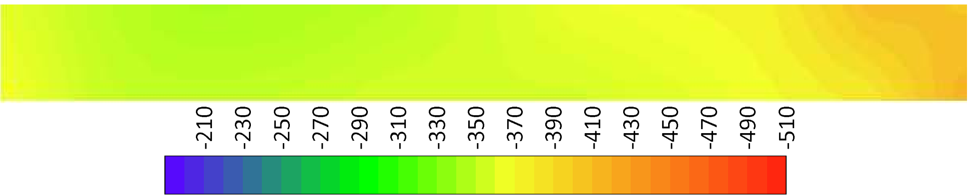
Sample ID	S1-M1-04			
Description	Mixed-in corrosion inhibitor			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-403	-442	-426	12



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-441	-404	-403	-404	-421	-425	-416	-420	-432	-433	-424
y2	-442	-438	-426	-419	-425	-439	-425	-434	-440	-439	-429

The sample presents high porosity. Corrosion in clearly happening as can be seen from the sample’s surface.

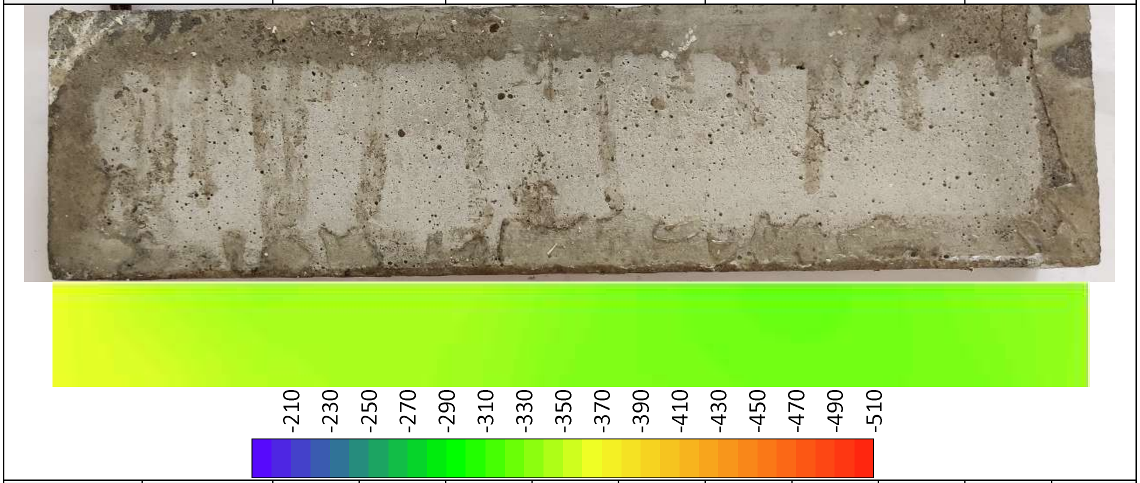
Table 23 S1-MI-06 corrosion potential analysis 30-06

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S1-M1-06</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Mixed-in corrosion inhibitor</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">30-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-354</td><td colspan="3">-434</td><td colspan="3">-388</td><td colspan="2">22</td></tr>
<tr><td colspan="12">

</td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-389</td><td>-367</td><td>-354</td><td>-355</td><td>-364</td><td>-378</td><td>-395</td><td>-400</td><td>-405</td><td>-428</td><td>-424</td></tr>
<tr><td>y2</td><td>-402</td><td>-373</td><td>-368</td><td>-372</td><td>-380</td><td>-379</td><td>-378</td><td>-388</td><td>-399</td><td>-406</td><td>-434</td></tr>
</table>

The sample is behaving in good conditions, the lower values of the corrosion potential can be found on the sides of the sample. This can be due to the influence of the electric connections on the sides and to the presence of wood sticks, which represents weak points for the water infiltration.

Table 24 S1-MI-07 Corrosion potential values analysis 30-06

Sample ID	S1-M1-07			
Description	Mixed-in corrosion inhibitor			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-311	-394	-344	24



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-344	-324	-319	-319	-325	-327	-347	-353	-361	-384	-392
y2	-341	-332	-317	-311	-320	-335	-353	-354	-347	-363	-394

The sample is interested by epoxydic resin flow on the aged face, this might have partially protected the sample from the aging process.

7.2 S2-SA RESULTS

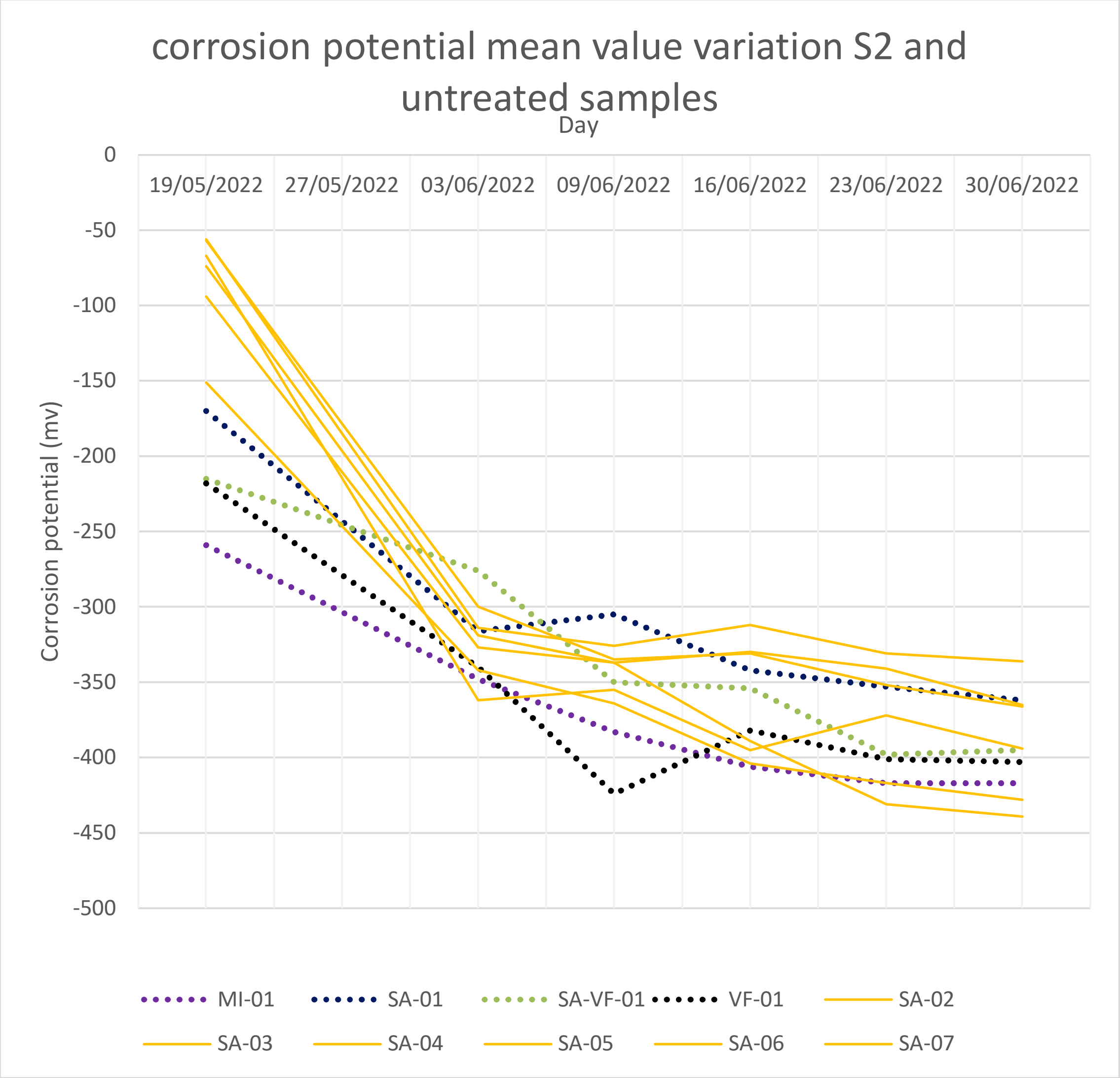


Figure 67 S2 and not treated samples mean corrosion potential variation

The mean corrosion potential loss in the not treated samples is lower than the corrosion potential loss in the surface applied corrosion inhibitor samples (SA-01, SA-02, SA-03, SA-04, SA-05, SA-06, SA-07).

The mean values of the corrosion potential in the surface applied corrosion inhibitor samples are more variable than the same values in the not treated samples.

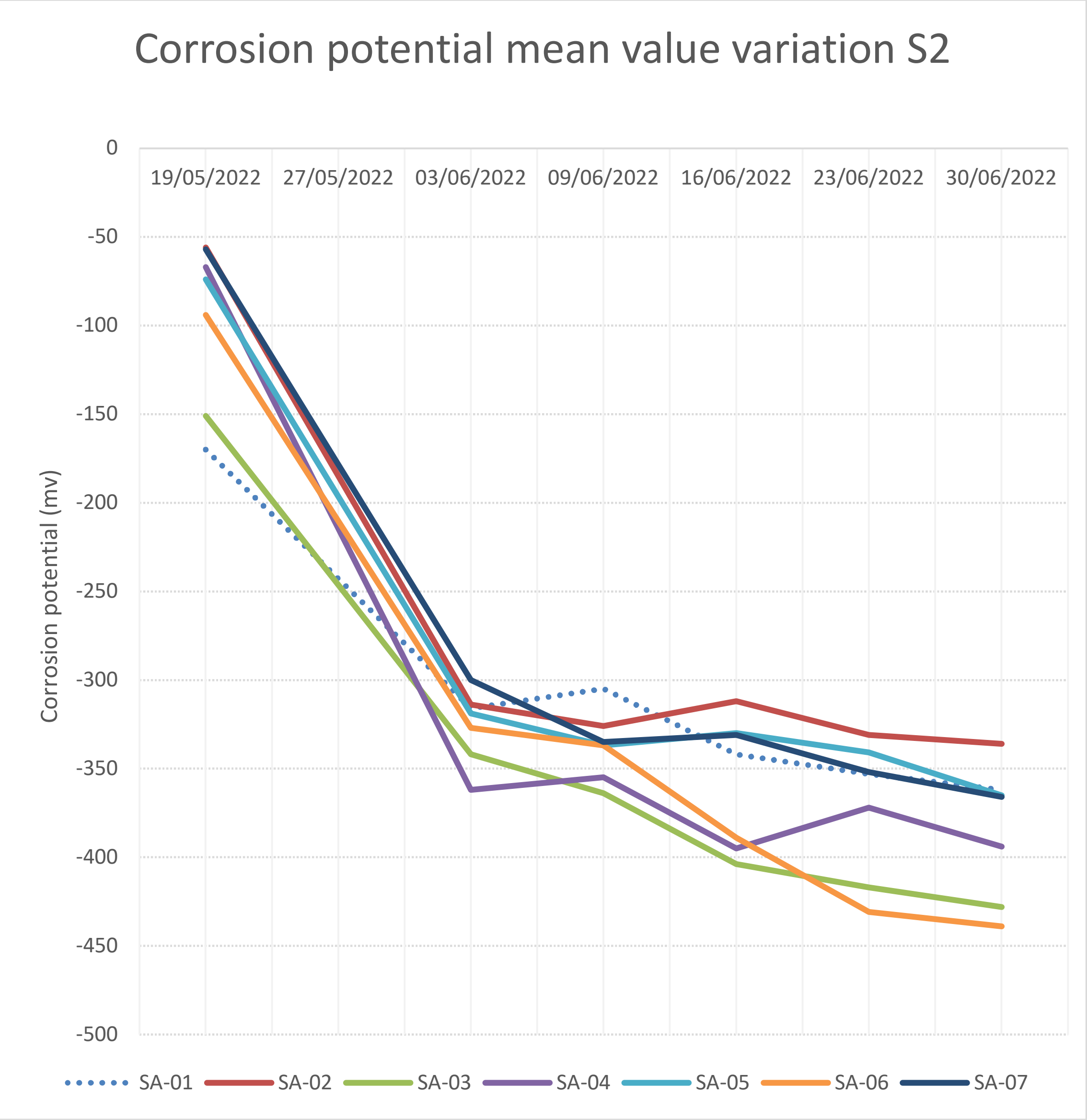


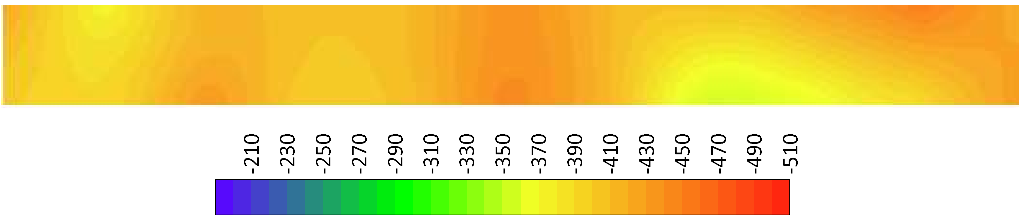
Figure 68 S2 mean corrosion potential variation

The mean corrosion potential difference is measured between the SA-02 and the SA-06 is about 103 mv.

SA-03, SA-04 and SA-06 are the samples with the lower corrosion potential values on 30/06.

Table 25 S2-SA-03 corrosion potential analysis 30-06

Sample ID	S2-SA-03			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-374	-459	-428	20

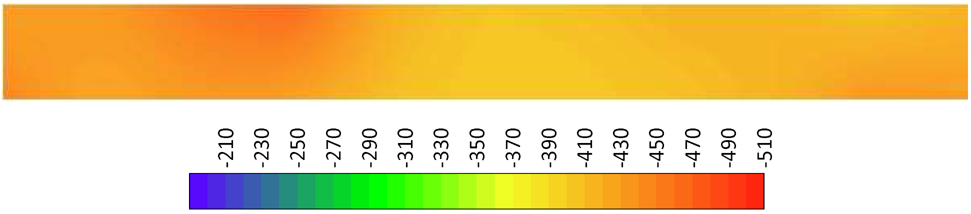


[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-438	-401	-433	-426	-430	-448	-430	-428	-443	-459	-437
y2	-421	-416	-446	-420	-427	-454	-430	-374	-392	-411	-444

The sample is clearly subjected to uniform corrosion process. The corrosion can be spot from the photographic documentation on the sides, where the wood sticks represent a weak point for water infiltration, and in the middle part, where the steel net configuration is followed from the corrosion.

Table 26 S2-SA-06 corrosion potential analysis 30-06

Sample ID	S2-SA-06			
Description	Migrating corrosion inhibitor applied, two brush applications + one spray application			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-424	-469	-439	12



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-444	-446	-460	-469	-437	-426	-429	-435	-434	-427	-434
y2	-455	-440	-446	-443	-428	-425	-424	-428	-434	-448	-445

Uniform corrosion is shown by corrosion potential measurements.

Corrosion potential values does not highly differs from the middle and the sides of the sample.

Photographic documentation shows only small corrosion traces.

7.3 S3-PA SA TEST RESULTS

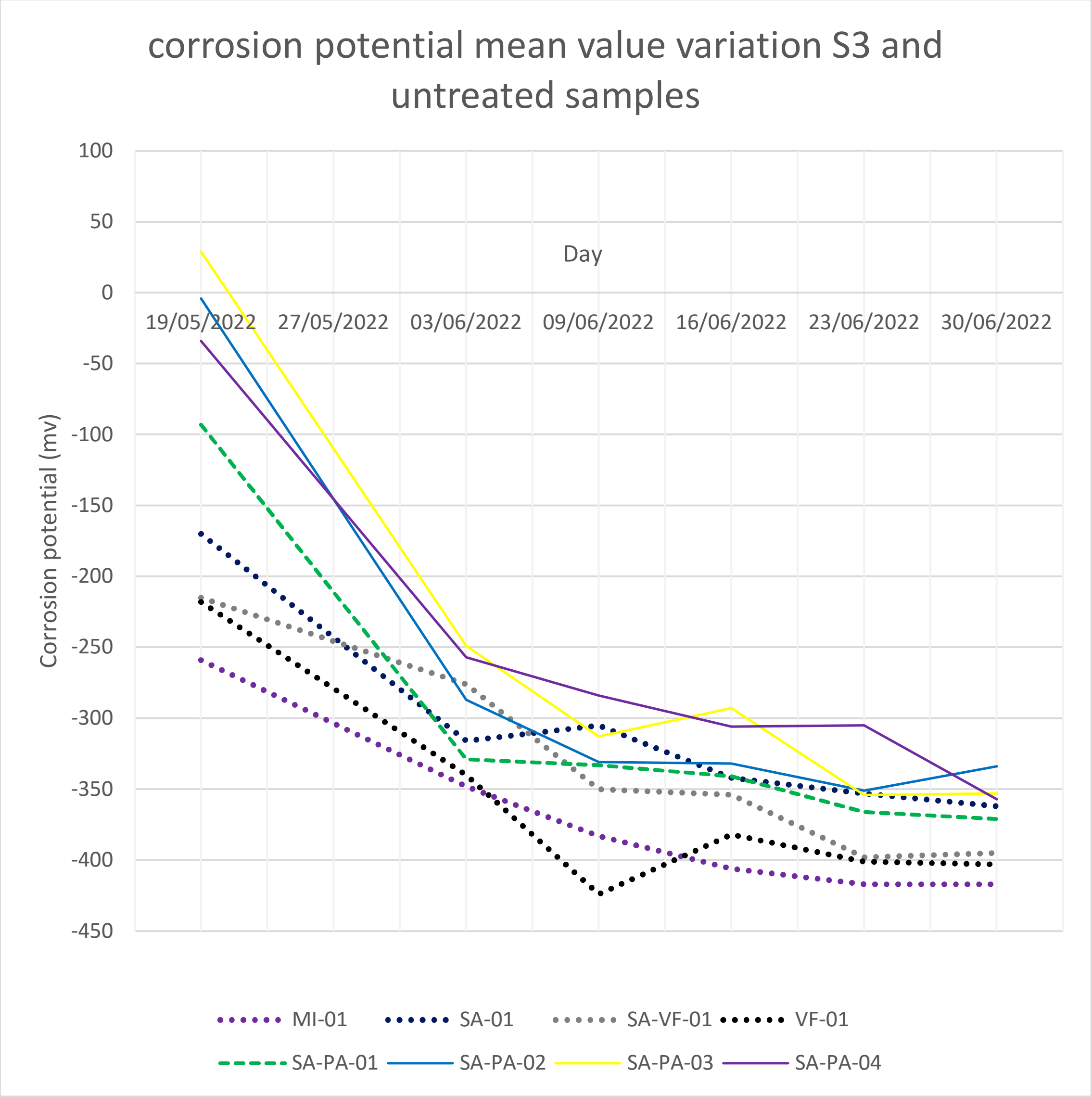


Figure 69 S3 and untreated samples corrosion potential mean values variation

The SA-PA series (in blue and green) presents higher values of the mean corrosion potential during all the aging. The corrosion potential loss in the SA-PA series is higher than the untreated samples.

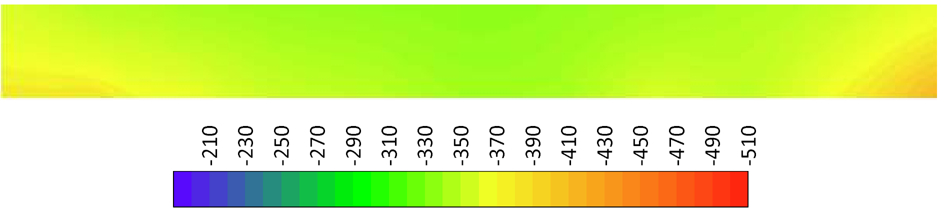
The sample SA-PA-01 shows a behaviour similar to the rest of the samples during the first step of the aging process.

After 03/06 the SA-PA-01 shows a tendency to highly reduce rate of lowering of the mean corrosion potential. In the SA-PA-02 and SA-PA-03 the corrosion potential lowering rate reduces after the 09/06.

In SA-PA-04 the mean corrosion potential is higher than the rest of the samples, and the rate of lowering is slowed after 03706 but keeps being important up to 30/06.

Table 27 S3-PA SA-01 corrosion potential analysis 30-06

Sample ID	S3- PA SA - 01			
Description	Control sample, painted by two brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-336	-433	-371	27

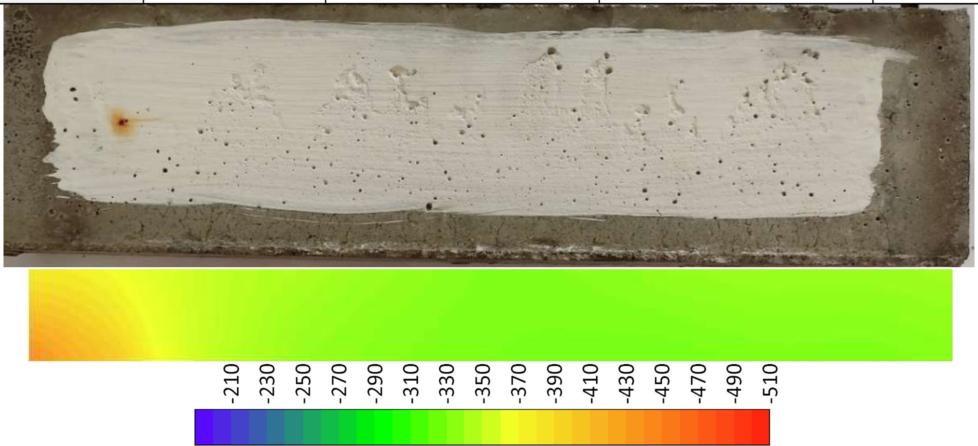


[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-383	-361	-351	-344	-340	-336	-341	-348	-358	-370	-391
y2	-409	-411	-394	-372	-365	-349	-353	-383	-369	-403	-433

Corrosion potential values are smoothly lower in some areas in the sample, where macroscopic defects are present. Corrosion can be spotted where the corrosion potential value is lower.

Table 28 S3- PA SA - 03 corrosion potential analysis 30-06

Sample ID	S3- PA SA - 03			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-320	-452	-353	35



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-404	-396	-369	-355	-341	-329	-331	-341	-345	-343	-348
y2	-452	-421	-366	-340	-330	-325	-323	-320	-327	-325	-331

The sample shows uniform corrosion potential in the middle part.

On the left side and weak points corrosion potential is lowered. The sample shows high porosity but low corrosion influence.

7.4 S4- SA VF TEST RESULTS

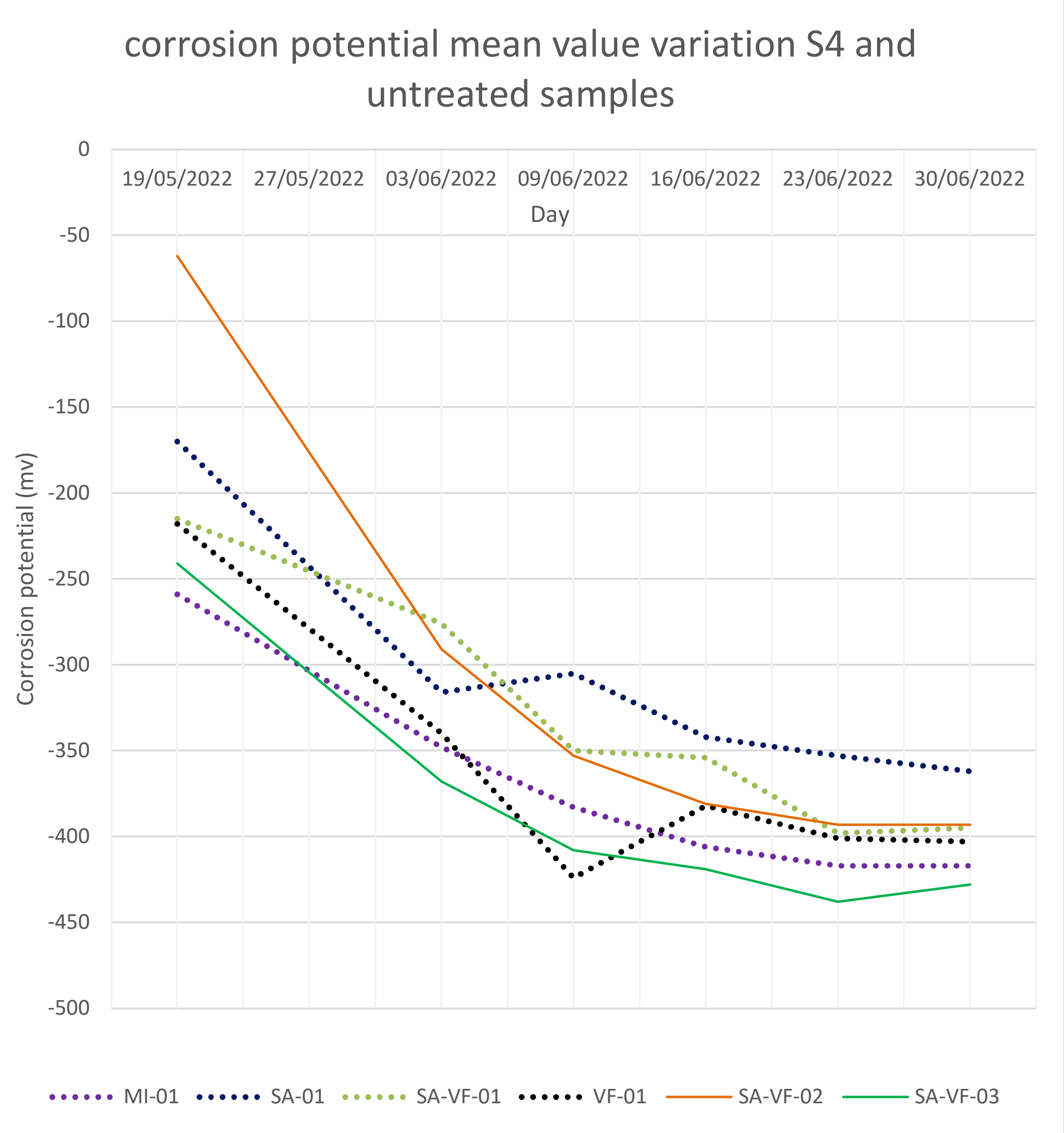


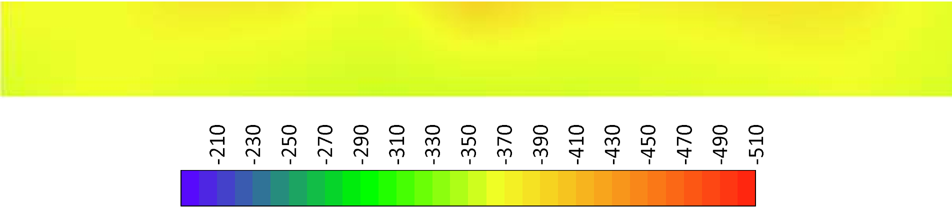
Figure 70 S4 and untreated samples corrosion potential mean values variation

The SA-VF-02 and SA-VF-03 samples shows a behaviour mostly similar to the not treated samples. The SA-VF-02 initial value is higher than the all the other values in the plot, after 03/06 the values become similar to all the rest of the samples.

The samples mean corrosion potential shows the tendency to converge around -400 mv and -450 mv range.

Table 29 S4- SA VF- 01 corrosion potential analysis 30-06

Sample ID	S4-SA VF - 01			
Description	Control sample, no treatments			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-376	-421	-395	13



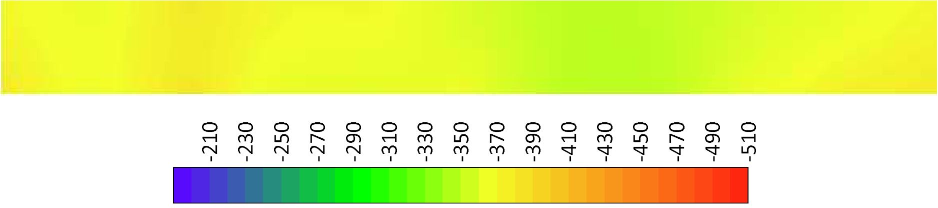
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-402	-396	-408	-407	-395	-421	-406	-405	-411	-408	-393
y2	-381	-399	-389	-381	-376	-379	-379	-385	-389	-395	-381

The sample shows corrosion tendency higher in the upper part than in the lower one. Superficial defects from the photographic documentation are low and mainly irrelevant.

The sample is not showing clear corrosion effects.

Table 30 S4- SA VF- 02 corrosion potential analysis 30-06

Sample ID	S4-SA VF - 02			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-366	-410	-393	14



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-401	-394	-409	-401	-402	-383	-367	-369	-382	-392	-401
y2	-409	-396	-410	-392	-391	-395	-367	-366	-395	-405	-408

The sample is clearly subjected to alteration. This alteration is due to the reaction between the two applied superficial treatments: the surface applied corrosion inhibitor and the glass-based compound.

The sample shows corrosion in a weak spot on the right side.

7.5 S5-VF TEST RESULTS

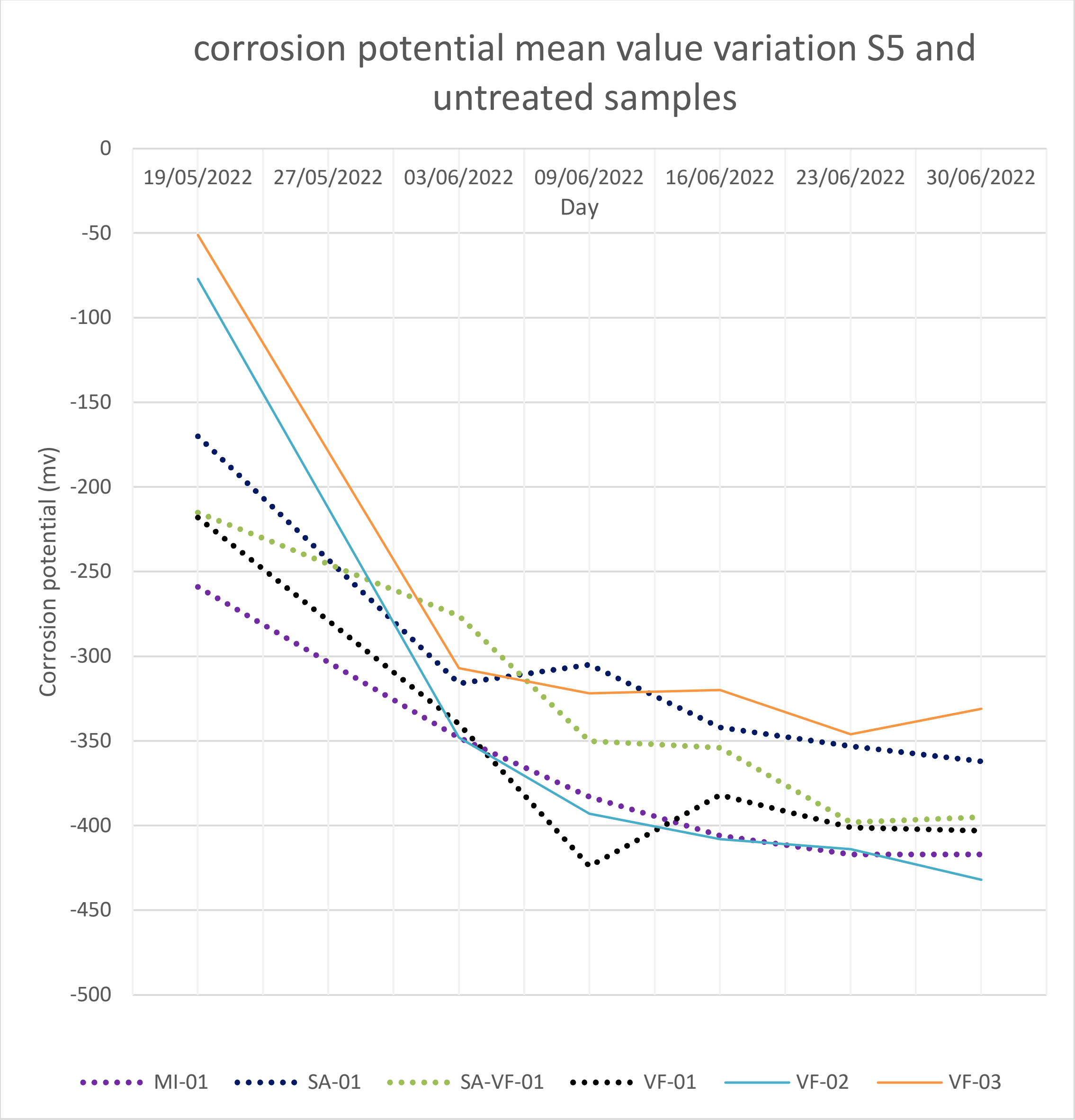


Figure 71 S5 and untreated samples corrosion potential mean values variation

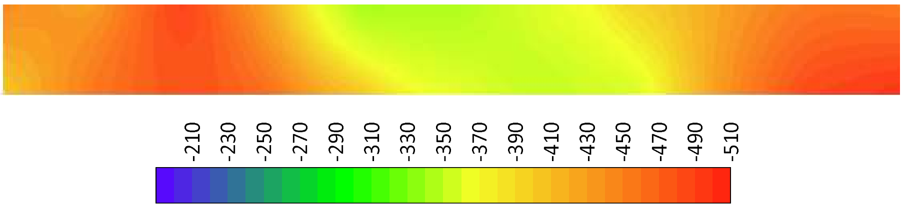
The glass-based compound treated samples shows high loss in corrosion potential up to 03/06 and then VF-02 shows a tendency to lowering the mean corrosion potential similar to the not treated samples and higher than the one showed by VF-03.

The corrosion potential values of the Serie:

- VF-02 shows the tendency to converge to -450 mv,
- VF-03 shows the tendency to converge around -350 mv.

Table 31 S5-VF-02 corrosion potential analysis 30-06

Sample ID	S5-VF-02			
Description	2 glass-based compounds brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-351	-494	-432	43



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-453	-442	-487	-435	-351	-356	-385	-418	-440	-461	-459
y2	-422	-461	-478	-465	-426	-393	-369	-380	-447	-485	-494

The sample shows high tendency to corrosion from corrosion potential. The middle part of the sample is protected from corrosion agents. Corrosion mainly regards the sides measurements.

Photographic documentation shows the sample is highly influenced by corrosion on the left side.

8 PLANNED STEPS

The planned activities regard the laboratory tests.

The Ferrocement samples aging is planned to be carried out until the end of august, to complete three months of aging. After this, in September 2022, the following test are planned to be performed:

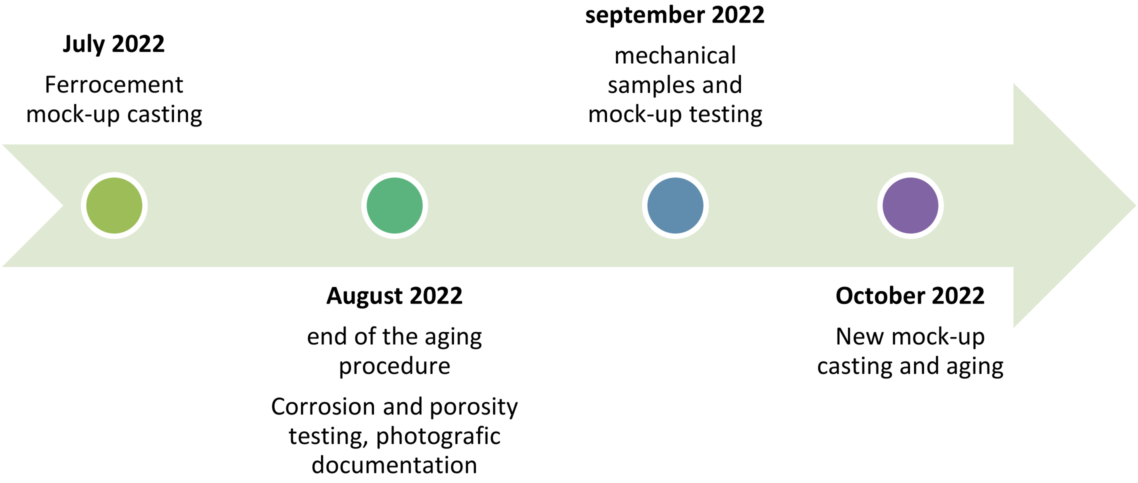
- Photographic documentation
- Corrosion potential test
- Porosity test
- Bending test

Bending test is planned to be performed also on S6-M series, to provide a comparison between aged samples and unaged ones.

Bending and compression tests are planned to be carried out on S7-CP series samples in the same period.

The first ferrocement beam mock-up is planned to be casted in July, harden in august and be tested in September by three points bending test.

A second ferrocement beam mock-up is planned to be casted, aged, and tested after the first one, in October.



9 CONCLUSIONS

The on-site analysis of Hall B of To-expo has been completed. The inspection showed that the structure behaves in a good state of preservation, the construction techniques employed, and the thick concrete cover allowed the concrete to reach the present day in a good conservation state. In addition, the pillars, essential load-bearing elements in the structure, were protected by the structure itself, as they are located within it.

The few exceptions that have damaged the structure consist of subsequent additions to the Nervi's design, as in the case of the water leak from the emergency system located on the P12N pillar.

On the other hand, inspections on ferrocement elements have been very difficult, as the elements themselves are very delicate. Laboratory activities, aimed at reproducing the original material, help to obtain an objective criterion on the deterioration and corrosion dynamics in ferrocement.

However, the results achieved in laboratory activities still represent only a partial view of the progression of aging, which at the moment is clearly still in development. In addition, many variables could influence the value of the corrosion potential, such as thickness variability in the concrete cover or moisture in the specimens at the time of measurement. At the end of the aging process with the subsequent mechanical tests, it will be possible to completely understand the treatment effects.

Mock-ups are an important part of laboratory analysis; once casted and tested, a large volume of data can be retrieved and exploited.

Lastly, the treatments might later be tested in situ to verify how useful they might then be in situations that differ from those in the laboratory.

10 ATTACHMENT A – CORROSION POTENTIAL TEST RESULTS

10.1 CORROSION POTENTIAL TESTING RESULTS

Corrosion potential testing results are here provided, the results are shown in form of a table, for each measurement statistical analysis is performed and a photographic documentation provided.

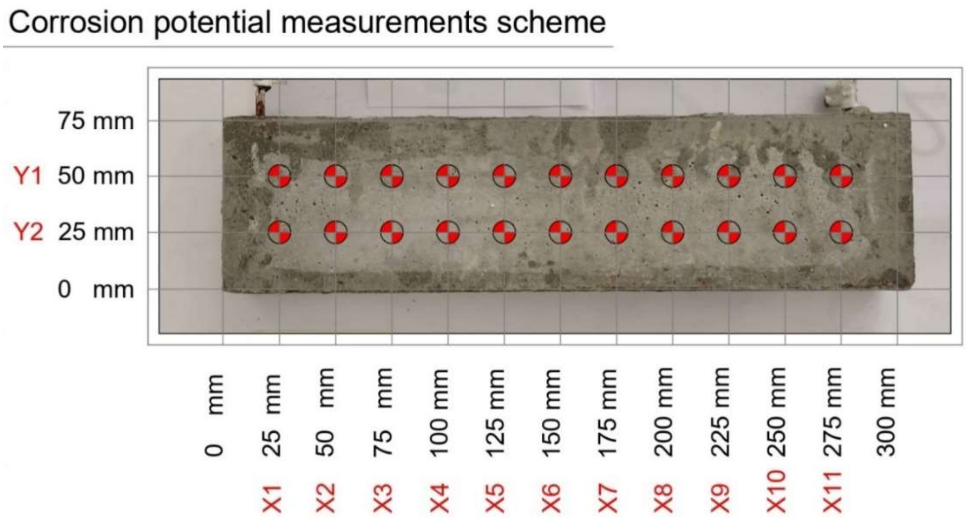


Figure 72 corrosion potential measurements scheme

Table 32 S1-MI-01 - corrosion potential analysis on 18/05

Sample ID	S1-M1-01			
Description	Control sample, no treatments			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-219	-312	-261	32

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-303	-309	-270	-271	-296	-256	-229	-230	-260	-252	-289
y2	-312	-311	-286	-251	-262	-239	-223	-219	-220	-230	-233

Table 33 S1-MI-01 - 03/06 corrosion potential analysis

Sample ID	S1-M1-01			
Description	Control sample, no treatments			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-303	-400	-348	28

[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-380	-368	-377	-372	-355	-336	-312	-326	-353	-363	-400
Y2	-389	-369	-353	-347	-347	-323	-305	-303	-325	-326	-325

Table 34 S1-MI-01 - 09/06 corrosion potential analysis

Sample ID	S1-M1-01			
Description	Control sample, no treatments			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-329	-428	-383	31

[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-428	-425	-408	-397	-386	-360	-347	-380	-409	-410	-401
Y2	-427	-424	-389	-370	-374	-330	-329	-362	-380	-354	-346

Table 35 S1-M1-01 - 16/06 corrosion potential analysis

<table>
<tr><th colspan="2">Sample ID</th><td colspan="10">S1-M1-01</td></tr>
<tr><th colspan="2">Description</th><td colspan="10">Control sample, no treatments</td></tr>
<tr><th colspan="2">Date</th><td colspan="10">16-giu</td></tr>
<tr><th colspan="2" rowspan="2">Measurements [mv]</th><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-354</td><td colspan="3">-437</td><td colspan="3">-406</td><td colspan="2">21</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>X1</td><td>X2</td><td>X3</td><td>X4</td><td>X5</td><td>X6</td><td>X7</td><td>X8</td><td>X9</td><td>X10</td><td>X11</td></tr>
<tr><td>Y1</td><td>-424</td><td>-429</td><td>-406</td><td>-408</td><td>-414</td><td>-406</td><td>-388</td><td>-376</td><td>-402</td><td>-416</td><td>-418</td></tr>
<tr><td>Y2</td><td>-437</td><td>-407</td><td>-402</td><td>-420</td><td>-411</td><td>-354</td><td>-362</td><td>-405</td><td>-427</td><td>-425</td><td>-398</td></tr>
</table>

Table 36 S1-M1-01 - 23/06 corrosino potential analysis

<table>
<tr><th colspan="2">Sample ID</th><td colspan="10">S1-M1-01</td></tr>
<tr><th colspan="2">Description</th><td colspan="10">Control sample, no treatments</td></tr>
<tr><th colspan="2">Date</th><td colspan="10">23-giu</td></tr>
<tr><th colspan="2" rowspan="2">Measurements [mv]</th><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-379</td><td colspan="3">-450</td><td colspan="3">-417</td><td colspan="2">16</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>X1</td><td>X2</td><td>X3</td><td>X4</td><td>X5</td><td>X6</td><td>X7</td><td>X8</td><td>X9</td><td>X10</td><td>X11</td></tr>
<tr><td>Y1</td><td>-450</td><td>-432</td><td>-420</td><td>-420</td><td>-401</td><td>-399</td><td>-415</td><td>-430</td><td>-426</td><td>-417</td><td>-422</td></tr>
<tr><td>Y2</td><td>-433</td><td>-428</td><td>-417</td><td>-433</td><td>-426</td><td>-389</td><td>-379</td><td>-409</td><td>-415</td><td>-407</td><td>-399</td></tr>
</table>

Table 37 S1-M1-01 - 30/06 corrosion potential analysis

Sample ID	S1-M1-01			
Description	Control sample, no treatments			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-392	-433	-417	11

[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-433	-433	-425	-422	-420	-407	-412	-421	-424	-420	-418
Y2	-433	-421	-410	-417	-424	-410	-392	-410	-410	-407	-399

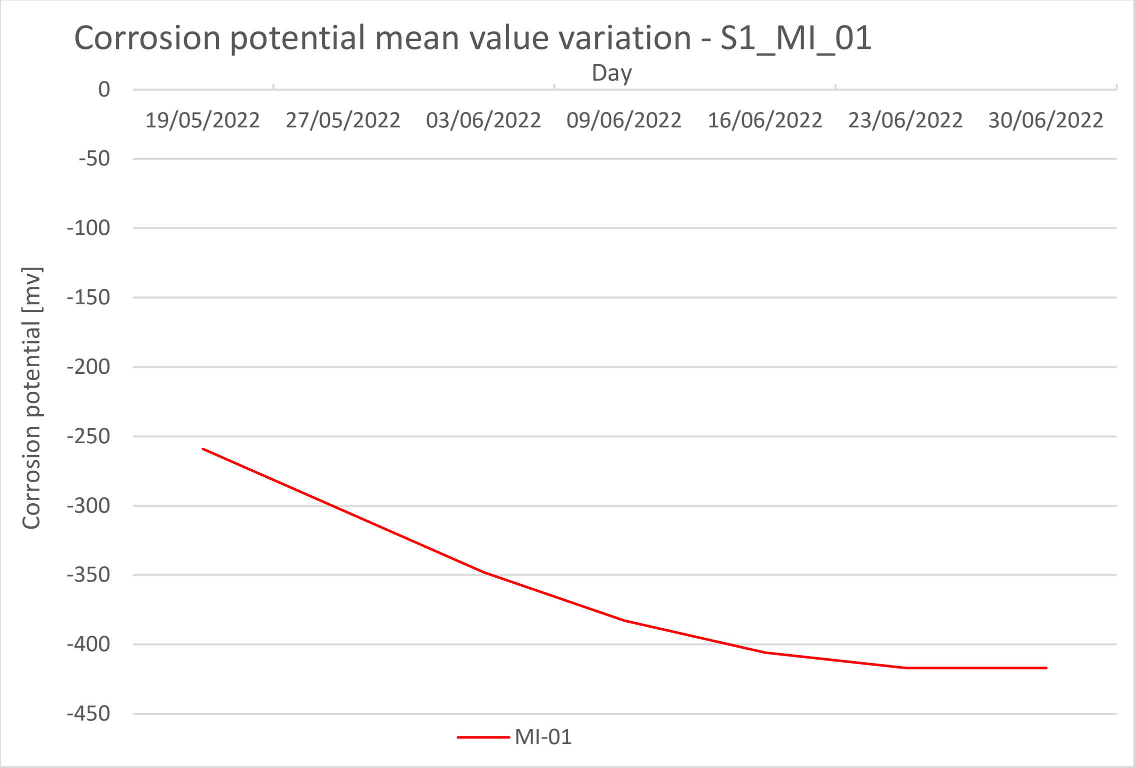


Figure 73 corrosion potential mean value variation, S1-MI-01

Table 38 S1-M1-02 18/06 corrosion potential analysis

Sample ID	S1-M1-02			
Description	Mixed-in corrosion inhibitor			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	310	85	137	55

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-232	-155	-136	-90	-92	-96	-94	-114	-112	-116	-85
y2	-310	-212	-195	-152	-115	-105	-113	-125	-128	-128	-110

Table 39 S1-M1-02 - 03/09 corrosion potential analysis

Sample ID	S1-M1-02			
Description	Mixed-in corrosion inhibitor			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-275	-436	-321	49

[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-436	-394	-347	-310	-293	-290	-275	-282	-297	-312	-367
Y2	-429	-380	-311	-285	-285	-280	-282	-284	-307	-310	-313

Table 40 S1-M1-02 - 09/06 corrosion potential analysis

Sample ID	S1-M1-02			
Description	Mixed-in corrosion inhibitor			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-311	-436	-355	32
				

[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-425	-377	-346	-325	-311	-341	-381	-353	-341	-335	-387
Y2	-436	-378	-337	-320	-324	-345	-370	-341	-339	-344	-354

Table 41 S1-M1-02 -16/06 corrosion potential analysis

Sample ID	S1-M1-02			
Description	Mixed-in corrosion inhibitor			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-335	-489	-396	36
				

[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-421	-412	-377	-348	-353	-386	-426	-423	-421	-430	-489
Y2	-423	-398	-377	-335	-341	-364	-400	-404	-394	-398	-400

Table 42 S1-M1-02 - 23/06 - corrosion potential analysis

Sample ID	S1-M1-02			
Description	Mixed-in corrosion inhibitor			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-352	-462	-408	28

[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-413	-414	-392	-352	-366	-407	-437	-448	-422	-424	-462
Y2	-412	-406	-399	-358	-364	-393	-416	-421	-406	-416	-437

Table 43 S1-M1-02 - 30/06 - corrosion potential analysis

Sample ID	S1-M1-02			
Description	Mixed-in corrosion inhibitor			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-367	-440	-406	21

[mv]	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11
Y1	-409	-430	-398	-380	-367	-398	-409	-435	-423	-423	-440
Y2	-412	-400	-402	-371	-367	-396	-402	-409	-402	-421	-431

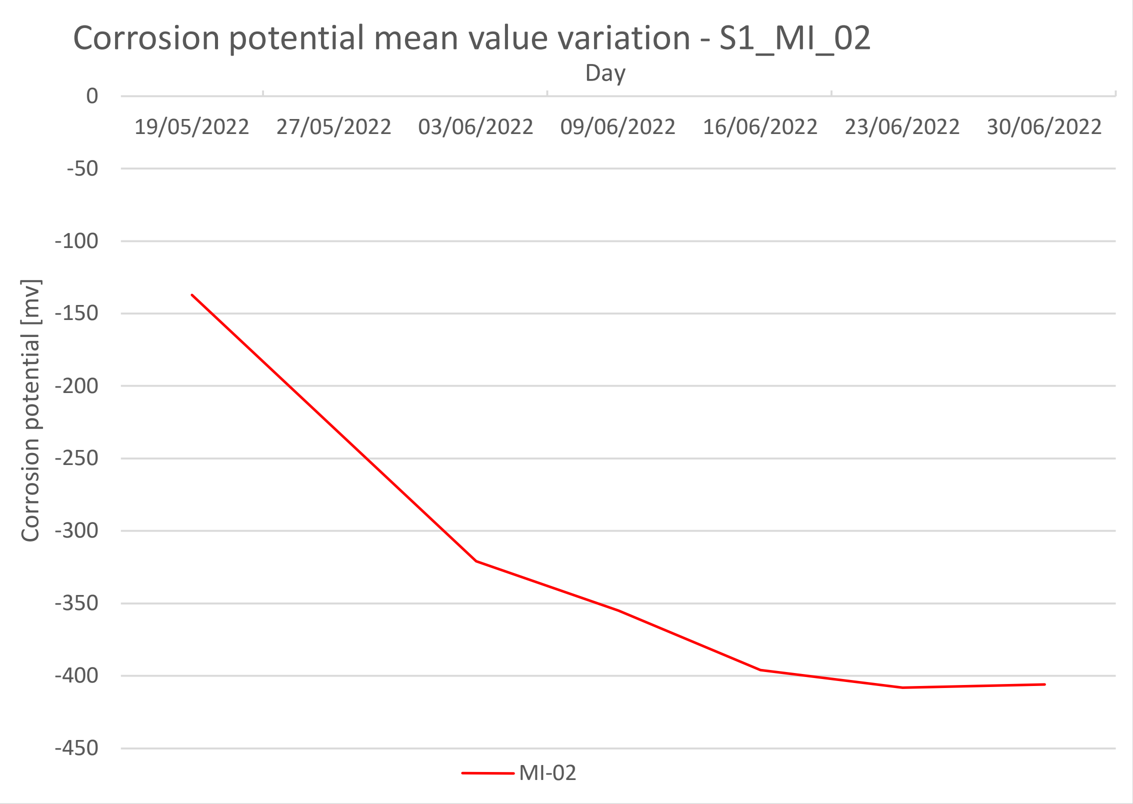


Figure 74 S1-M1-02 - corrosion potential mean value variation

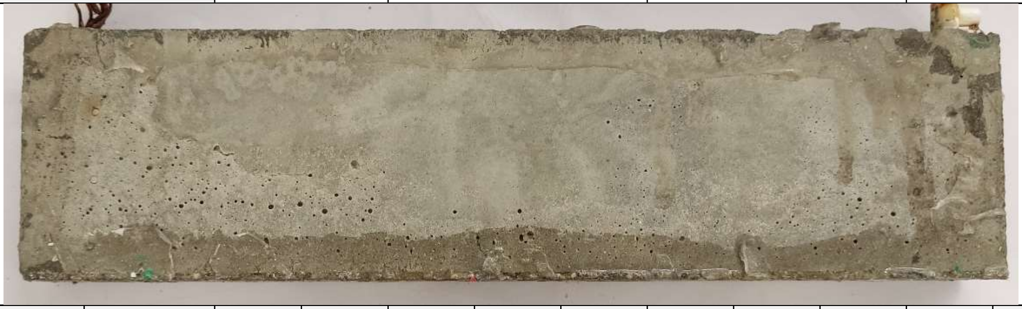
Table 44 S1-M1-03 - 18/06 - corrosion potential analysis

Sample ID	S1-M1-03			
Description	Mixed-in corrosion inhibitor			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	250	114	159	38

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-232	-190	-181	-157	-131	-126	-132	-131	-115	-125	-114
y2	-250	-216	-190	-179	-162	-148	-155	-150	-145	-148	-118

Table 45 S1-M1-03 - 03/06 - corrosion potential analysis

Sample ID	S1-M1-03			
Description	Mixed-in corrosion inhibitor			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-240	-356	-287	38



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-356	-322	-300	-287	-284	-275	-264	-255	-249	-244	-242
y2	-356	-337	-322	-326	-315	-311	-284	-263	-251	-241	-240

Table 46 S1-M1-03 - 09/06 - corrosion potential analysis

Sample ID	S1-M1-03			
Description	Mixed-in corrosion inhibitor			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-260	-393	-305	40

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-393	-330	-306	-300	-296	-293	-280	-267	-262	-260	-264
y2	-379	-346	-329	-349	-330	-341	-305	-280	-269	-263	-267

Table 47 S1-M1-03 - 16/06 - corrosion potential analysis

Sample ID	S1-M1-03			
Description	Mixed-in corrosion inhibitor			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-260	-398	-311	42

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-398	-357	-328	-312	-301	-290	-285	-288	-268	-264	-265
y2	-367	-369	-357	-342	-330	-348	-302	-275	-265	-260	-263

Table 48 S1-M1-03 - 23/06 - corrosion potential analysis

Sample ID	S1-M1-03			
Description	Mixed-in corrosion inhibitor			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-305	-471	-362	48

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-471	-410	-386	-368	-357	-341	-336	-346	-320	-311	-307
y2	-435	-433	-421	-393	-371	-368	-342	-328	-312	-305	-307

Table 49 S1-M1-03 -30/06 - corrosion potential analysis

Sample ID	S1-M1-03			
Description	Mixed-in corrosion inhibitor			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-321	-474	-386	38

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-474	-431	-412	-398	-386	-381	-373	-374	-375	-344	-341
y2	-442	-433	-410	-400	-396	-390	-370	-358	-349	-329	-321

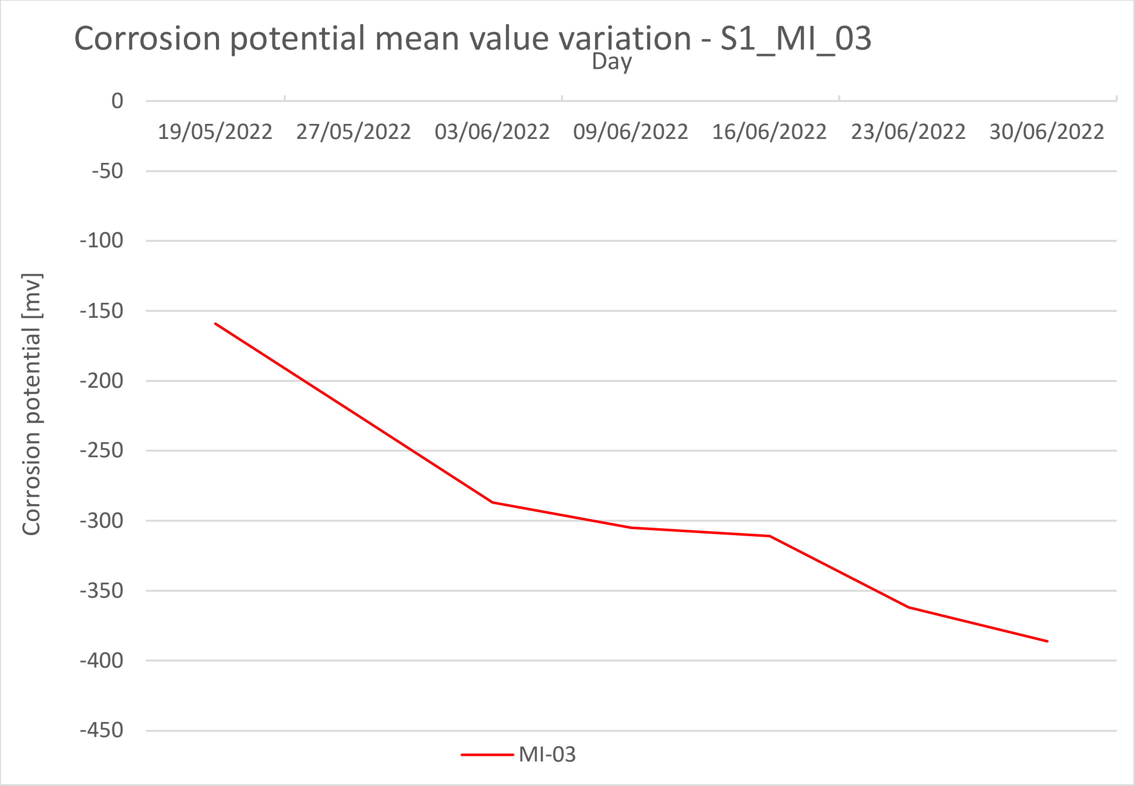


Figure 75 S1-M1-03 corrosion potential mean values

Table 50 S1-M1-04 -18/05 - corrosion potential analysis

Sample ID	S1-M1-04			
Description	Mixed-in corrosion inhibitor			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-197	-360	-291	41

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-197	-222	-245	-295	-316	-311	-290	-300	-301	-302	-350
y2	-253	-247	-246	-270	-292	-302	-320	-320	-316	-340	-360

Table 51 S1-M1-04 - 03/06 -corrosion potential analysis

Sample ID	S1-M1-04			
Description	Mixed-in corrosion inhibitor			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-334	-442	-376	35

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-350	-348	-334	-337	-355	-375	-392	-375	-366	-369	-415
y2	-400	-351	-336	-338	-342	-368	-395	-425	-442	-425	-440

Table 52 S1-M1-04 - 09/06 - corrosion potential analysis

Sample ID	S1-M1-04			
Description	Mixed-in corrosion inhibitor			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-326	-444	-384	34

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-394	-367	-326	-337	-346	-380	-409	-401	-381	-379	-433
y2	-388	-343	-338	-351	-375	-389	-423	-444	-417	-401	-427

Table 53 S1-M1-04 - 16/06 - corrosion potential analysis

Sample ID	S1-M1-04			
Description	Mixed-in corrosion inhibitor			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-381	-428	-406	13

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-416	-381	-388	-395	-395	-410	-406	-407	-397	-428	-425
y2	-405	-412	-385	-400	-412	-419	-418	-425	-404	-407	-394

Table 54 S1-M1-04 -16/06- corrosion potential analysis

Sample ID	S1-M1-04			
Description	Mixed-in corrosion inhibitor			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-328	-453	-424	25

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-435	-405	-399	-399	-432	-429	-426	-421	-426	-440	-435
y2	-420	-441	-429	-328	-431	-440	-430	-436	-435	-443	-453

Table 55 S1-M1-04 - 30/06- corrosion potential analysis

Sample ID	S1-M1-04			
Description	Mixed-in corrosion inhibitor			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-403	-442	-426	12

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-441	-404	-403	-404	-421	-425	-416	-420	-432	-433	-424
y2	-442	-438	-426	-419	-425	-439	-425	-434	-440	-439	-429

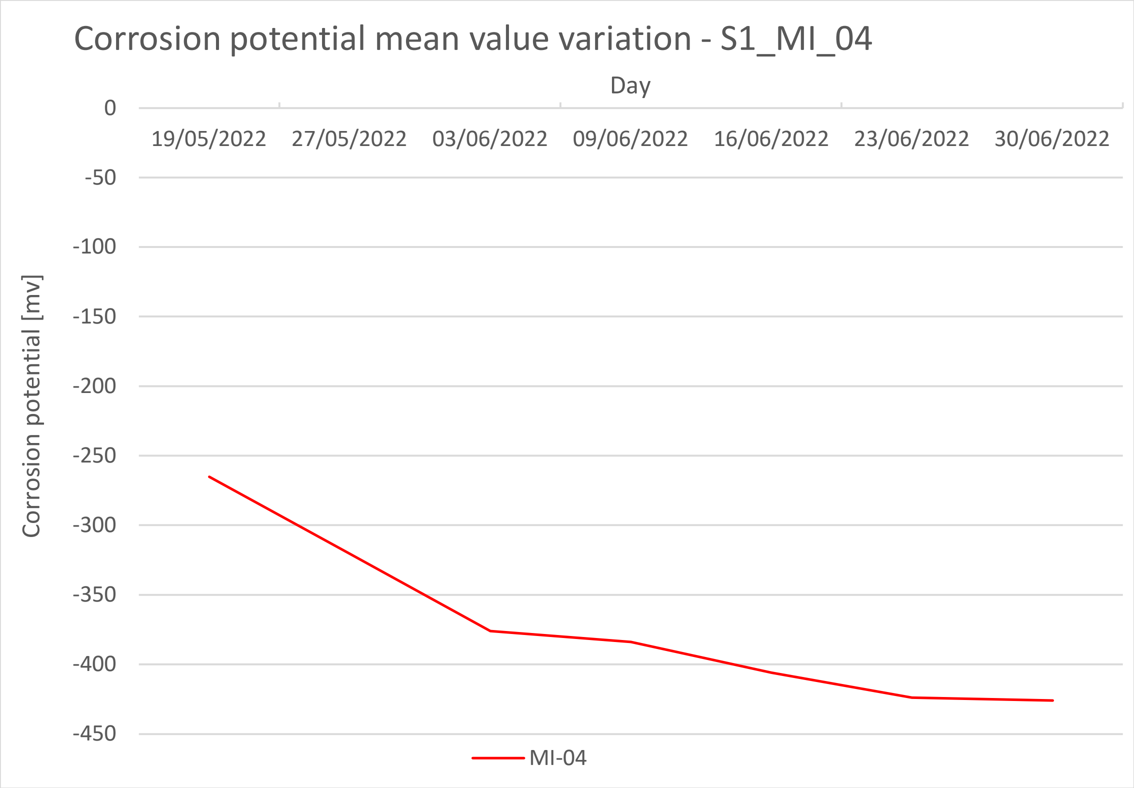


Figure 76 S1-M1-04 corrosion potential mean values

Table 56 S1-M1-05 -18/05- corrosion potential analysis

Sample ID	S1-M1-05			
Description	Mixed-in corrosion inhibitor			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	303	84	191	68
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-143	-132	-104	-84	-105	-156	-198	-222	-228	-283	-301
y2	-194	-153	-141	-144	-151	-182	-187	-222	-280	-294	-303

Table 57 S1-M1-05 - 03/06- corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S1-M1-05</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Mixed-in corrosion inhibitor</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">03-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-310</td><td colspan="3">-429</td><td colspan="3">-363</td><td colspan="2">37</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-417</td><td>-372</td><td>-352</td><td>-337</td><td>-326</td><td>-310</td><td>-323</td><td>-328</td><td>-310</td><td>-326</td><td>-429</td></tr>
<tr><td>y2</td><td>-400</td><td>-381</td><td>-380</td><td>-348</td><td>-383</td><td>-418</td><td>-402</td><td>-354</td><td>-338</td><td>-362</td><td>-392</td></tr>
</table>

Table 58 S1-M1-05 -09/06- corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S1-M1-05</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Mixed-in corrosion inhibitor</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">09-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-327</td><td colspan="3">-448</td><td colspan="3">-390</td><td colspan="2">30</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-448</td><td>-437</td><td>-384</td><td>-336</td><td>-327</td><td>-403</td><td>-428</td><td>-390</td><td>-407</td><td>-384</td><td>-414</td></tr>
<tr><td>y2</td><td>-381</td><td>-407</td><td>-365</td><td>-358</td><td>-402</td><td>-408</td><td>-407</td><td>-361</td><td>-366</td><td>-381</td><td>-393</td></tr>
</table>

Table 59 S1-M1-05 - 09/06- corrosion potential analysis

<table>
<tr><td>Sample ID</td><td colspan="11">S1-M1-05</td></tr>
<tr><td>Description</td><td colspan="11">Mixed-in corrosion inhibitor</td></tr>
<tr><td>Date</td><td colspan="11">16-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="3">St. dev</td></tr>
<tr><td colspan="2">-349</td><td colspan="3">-446</td><td colspan="3">-394</td><td colspan="3">28</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-427</td><td>-425</td><td>-371</td><td>-350</td><td>-349</td><td>-387</td><td>-414</td><td>-400</td><td>-415</td><td>-380</td><td>-446</td></tr>
<tr><td>y2</td><td>-418</td><td>-395</td><td>-355</td><td>-357</td><td>-412</td><td>-414</td><td>-430</td><td>-387</td><td>-379</td><td>-378</td><td>-385</td></tr>
</table>

Table 60 S1-M1-05 -23/06- corrosion potential analysis

<table>
<tr><td>Sample ID</td><td colspan="11">S1-M1-05</td></tr>
<tr><td>Description</td><td colspan="11">Mixed-in corrosion inhibitor</td></tr>
<tr><td>Date</td><td colspan="11">23-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="3">St. dev</td></tr>
<tr><td colspan="2">-367</td><td colspan="3">-453</td><td colspan="3">-409</td><td colspan="3">23</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-453</td><td>-430</td><td>-380</td><td>-367</td><td>-399</td><td>-389</td><td>-405</td><td>-405</td><td>-411</td><td>-415</td><td>-437</td></tr>
<tr><td>y2</td><td>-430</td><td>-416</td><td>-378</td><td>-384</td><td>-419</td><td>-429</td><td>-448</td><td>-394</td><td>-391</td><td>-407</td><td>-405</td></tr>
</table>

Table 61 S1-M1-05 -30/06- corrosion potential analysis

Sample ID	S1-M1-05			
Description	Mixed-in corrosion inhibitor			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-371	-454	-408	20

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
\y1	-454	-423	-381	-371	-396	-396	-406	-417	-416	-418	-421
y2	-409	-407	-396	-425	-411	-409	-446	-407	-387	-385	-386

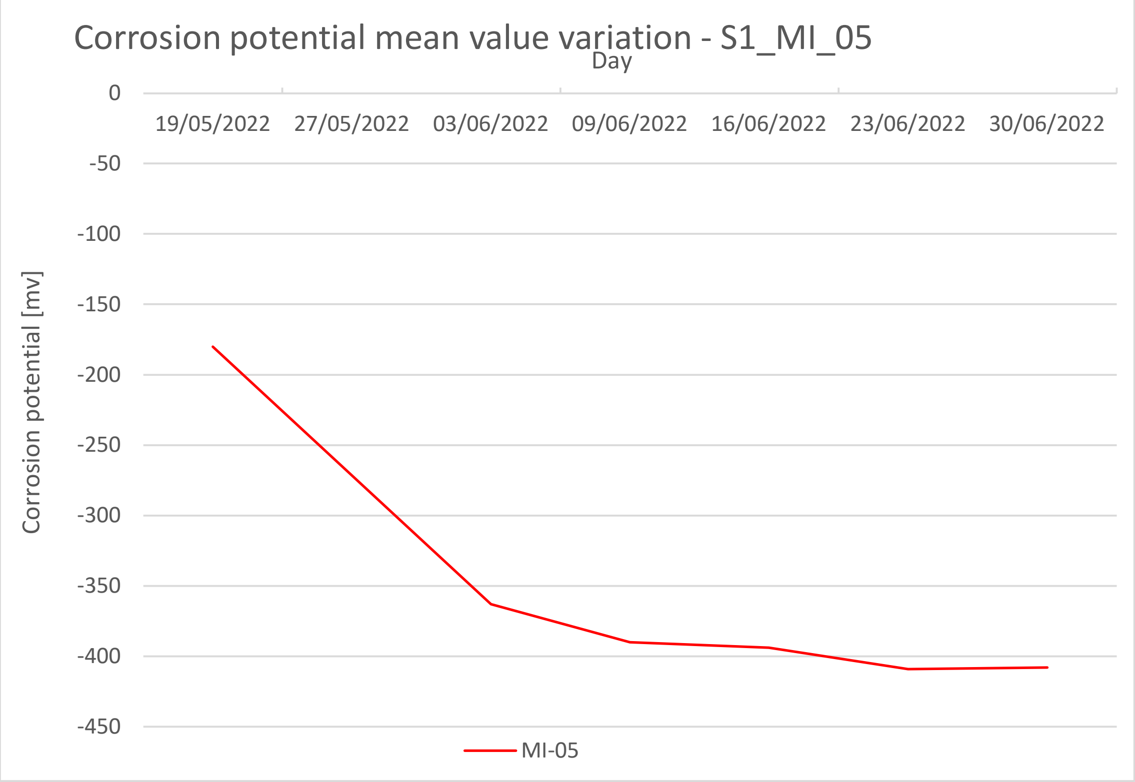


Figure 77 S1-M1-05 corrosion potential mean values

Table 62 S1-M1-06 -18/06- corrosion potential analysis

Sample ID	S1-M1-06			
Description	Mixed-in corrosion inhibitor			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	290	210	232	18

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-249	-243	-220	-210	-212	-215	-222	-220	-236	-242	-290
y2	-242	-234	-223	-216	-216	-230	-230	-227	-231	-236	-263

Table 63 S1-M1-06 - 03/06- corrosion potential analysis

Sample ID	S1-M1-06			
Description	Mixed-in corrosion inhibitor			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-280	-399	-310	28

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-328	-301	-289	-280	-282	-285	-300	-323	-326	-341	-399
y2	-330	-315	-297	-285	-281	-287	-299	-307	-309	-316	-340

Table 64 S1-M1-06 -09/06- corrosion potential analysis

Sample ID	S1-M1-06			
Description	Mixed-in corrosion inhibitor			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-305	-446	-354	38

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-389	-342	-320	-317	-320	-337	-363	-377	-353	-388	-441
y2	-446	-345	-318	-305	-315	-383	-339	-328	-333	-352	-366

Table 65 S1-M1-06 -16/06- corrosion potential analysis

Sample ID	S1-M1-06			
Description	Mixed-in corrosion inhibitor			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-328	-427	-371	27

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-387	-351	-333	-349	-360	-366	-382	-386	-390	-427	-419
y2	-388	-345	-328	-339	-347	-358	-359	-376	-386	-399	-397

Table 66 S1-M1-06 -23/06- corrosion potential analysis

Sample ID	S1-M1-06			
Description	Mixed-in corrosion inhibitor			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-355	-448	-389	26
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-386	-365	-356	-358	-366	-384	-394	-393	-414	-448	-426
y2	-403	-363	-355	-370	-367	-374	-377	-403	-415	-420	-417

Table 67 S1-M1-06 -30/06- corrosion potential analysis

Sample ID	S1-M1-06			
Description	Mixed-in corrosion inhibitor			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-354	-434	-388	22
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-389	-367	-354	-355	-364	-378	-395	-400	-405	-428	-424
y2	-402	-373	-368	-372	-380	-379	-378	-388	-399	-406	-434

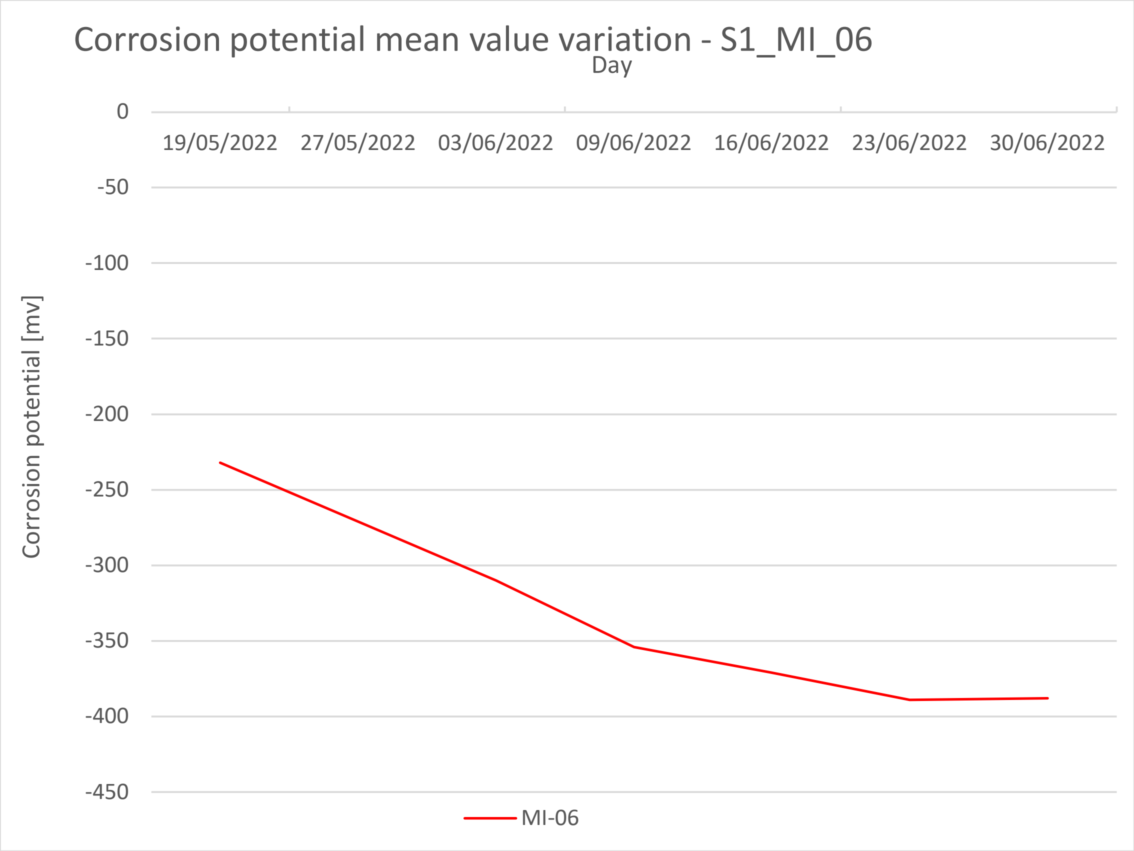


Figure 78 S1-M1-06 corrosion potential analysis mean value

Table 68 S1-M1-07 -18/06- corrosion potential analysis

<table>
<tr><th colspan="2">Sample ID</th><td colspan="10">S1-M1-07</td></tr>
<tr><th colspan="2">Description</th><td colspan="10">Mixed-in corrosion inhibitor</td></tr>
<tr><th colspan="2">Date</th><td colspan="10">18-mag</td></tr>
<tr><th colspan="2" rowspan="2">Measurements [mv]</th><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">317</td><td colspan="3">138</td><td colspan="3">178</td><td colspan="2">46</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-260</td><td>-181</td><td>-160</td><td>-151</td><td>-145</td><td>-143</td><td>-140</td><td>-138</td><td>-142</td><td>-162</td><td>-192</td></tr>
<tr><td>y2</td><td>-317</td><td>-233</td><td>-176</td><td>-160</td><td>-150</td><td>-147</td><td>-148</td><td>-154</td><td>-174</td><td>-206</td><td>-228</td></tr>
</table>

Table 69 S1-M1-07-03/06 - corrosion potential analysis

Sample ID	S1-M1-07			
Description	Mixed-in corrosion inhibitor			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-241	-332	-276	32

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-331	-315	-301	-276	-255	-246	-245	-246	-257	-279	-332
y2	-328	-314	-284	-262	-250	-241	-241	-245	-256	-276	-293

Table 70 S1-M1-07 -09/06- corrosion potential analysis

Sample ID	S1-M1-07			
Description	Mixed-in corrosion inhibitor			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-264	-362	-295	27

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-345	-312	-290	-284	-288	-269	-266	-275	-289	-305	-362
y2	-347	-307	-285	-277	-279	-269	-264	-273	-298	-289	-307

Table 71 S1-M1-07 -16/06- corrosion potential analysis

Sample ID	S1-M1-07			
Description	Mixed-in corrosion inhibitor			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-299	-351	-321	14

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-342	-318	-304	-300	-304	-314	-329	-324	-322	-336	-351
y2	-339	-322	-307	-299	-307	-317	-338	-325	-320	-316	-323

Table 72 S1-M1-07 -23/06- corrosion potential analysis

Sample ID	S1-M1-07			
Description	Mixed-in corrosion inhibitor			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-299	-373	-328	19

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-344	-324	-309	-311	-317	-321	-332	-330	-344	-369	-373
y2	-345	-317	-304	-299	-309	-321	-337	-329	-322	-328	-341

Table 73 S1-M1-07 -30/06- corrosion potential analysis

Sample ID	S1-M1-07			
Description	Mixed-in corrosion inhibitor			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-311	-394	-344	24

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-344	-324	-319	-319	-325	-327	-347	-353	-361	-384	-392
y2	-341	-332	-317	-311	-320	-335	-353	-354	-347	-363	-394

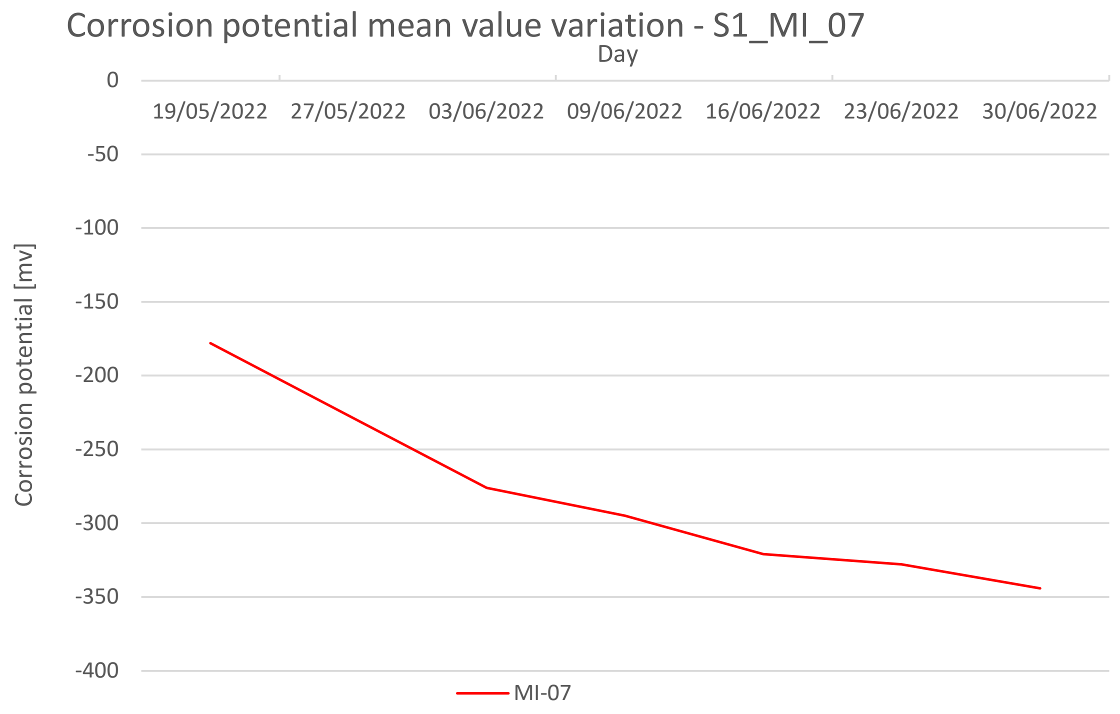


Figure 79 S1-M1-07 corrosion potential mean value

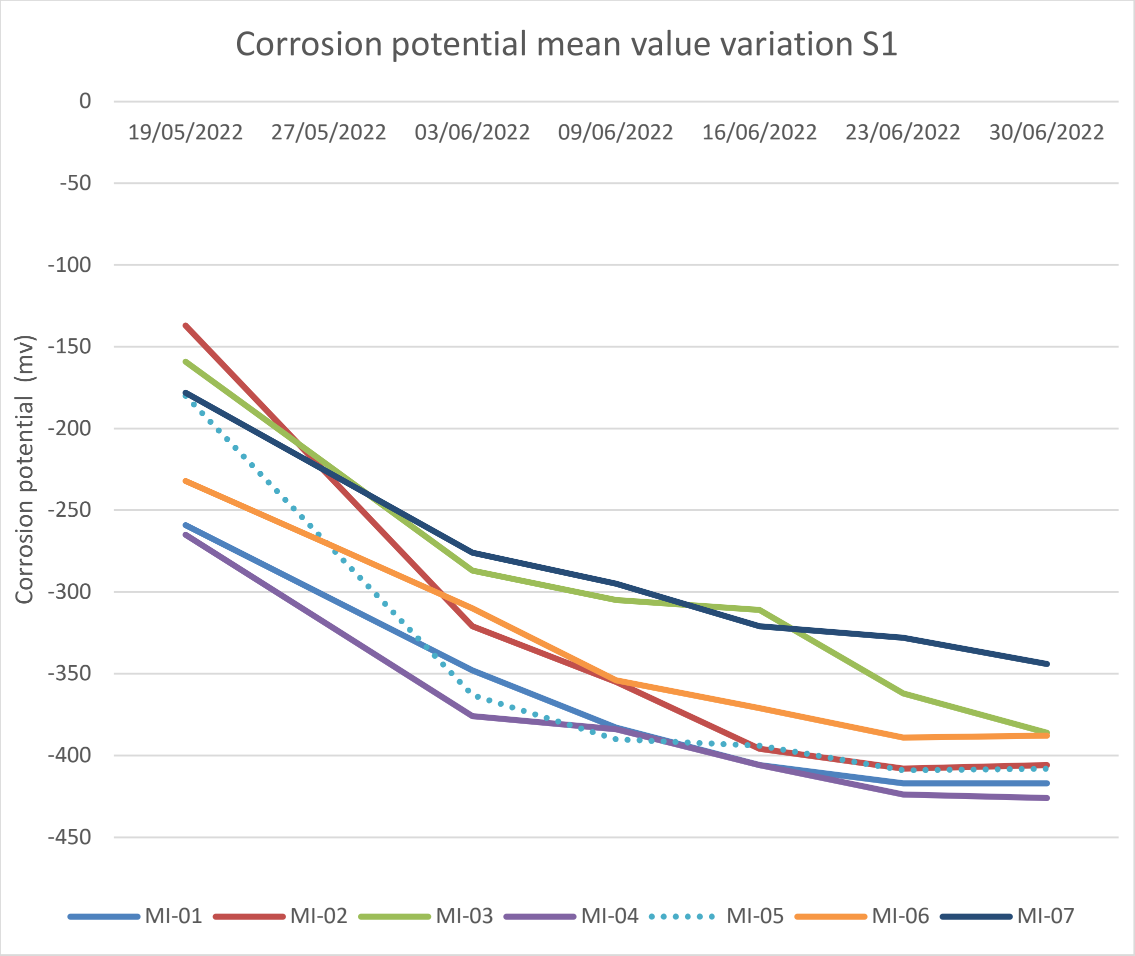


Figure 80 S1-M1 corrosion potential mean values

Table 74 S2-SA-01-18/05- corrosion potential analysis

Sample ID	S2-SA-01			
Description	Control sample, no treatments			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-110	-299	-170	45
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-180	-150	-137	-137	-132	-132	-148	-155	-110	-172	-290
y2	-168	-168	-160	-157	-159	-160	-163	-173	-187	-206	-299

Table 75 S2-SA-01-03/06- corrosion potential analysis

Sample ID	S2-SA-01			
Description	Control sample, no treatments			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-272	-399	-316	40
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-394	-350	-331	-306	-318	-291	-280	-285	-304	-317	-399
y2	-384	-338	-299	-280	-278	-296	-272	-272	-278	-320	-354

Table 76 S2-SA-01-09/06- corrosion potential analysis

<table>
<tr><th colspan="2">Sample ID</th><td colspan="10">S2-SA-01</td></tr>
<tr><th colspan="2">Description</th><td colspan="10">Control sample, no treatments</td></tr>
<tr><th colspan="2">Date</th><td colspan="10">09-giu</td></tr>
<tr><th colspan="2" rowspan="2">Measurements [mv]</th><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-237</td><td colspan="3">-421</td><td colspan="3">-305</td><td colspan="2">44</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-370</td><td>-306</td><td>-297</td><td>-292</td><td>-278</td><td>-272</td><td>-268</td><td>-274</td><td>-293</td><td>-312</td><td>-394</td></tr>
<tr><td>y2</td><td>-421</td><td>-331</td><td>-290</td><td>-284</td><td>-288</td><td>-237</td><td>-275</td><td>-277</td><td>-283</td><td>-302</td><td>-358</td></tr>
</table>

Table 77 S2-SA-01-16/06- corrosion potential analysis

<table>
<tr><th colspan="2">Sample ID</th><td colspan="10">S2-SA-01</td></tr>
<tr><th colspan="2">Description</th><td colspan="10">Control sample, no treatments</td></tr>
<tr><th colspan="2">Date</th><td colspan="10">16-giu</td></tr>
<tr><th colspan="2" rowspan="2">Measurements [mv]</th><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-281</td><td colspan="3">-441</td><td colspan="3">-342</td><td colspan="2">46</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-436</td><td>-345</td><td>-357</td><td>-339</td><td>-304</td><td>-281</td><td>-285</td><td>-295</td><td>-305</td><td>-335</td><td>-394</td></tr>
<tr><td>y2</td><td>-441</td><td>-369</td><td>-360</td><td>-342</td><td>-320</td><td>-305</td><td>-301</td><td>-302</td><td>-326</td><td>-381</td><td>-400</td></tr>
</table>

Table 78 S2-SA-01-23/06-corrosion potential analysis

Sample ID	S2-SA-01			
Description	Control sample, no treatments			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-299	-454	-353	44

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-433	-395	-390	-350	-320	-299	-311	-313	-325	-370	-383
y2	-454	-378	-375	-355	-335	-312	-301	-299	-323	-380	-371

Table 79 S2-SA-01-30/06-corrosion potential analysis

Sample ID	S2-SA-01			
Description	Control sample, no treatments			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-306	-450	-362	41

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-436	-400	-380	-369	-347	-317	-306	-325	-328	-353	-385
y2	-450	-399	-397	-371	-348	-320	-308	-311	-333	-390	-390

Table 80 S2-SA-01corrosion potential mean value variation

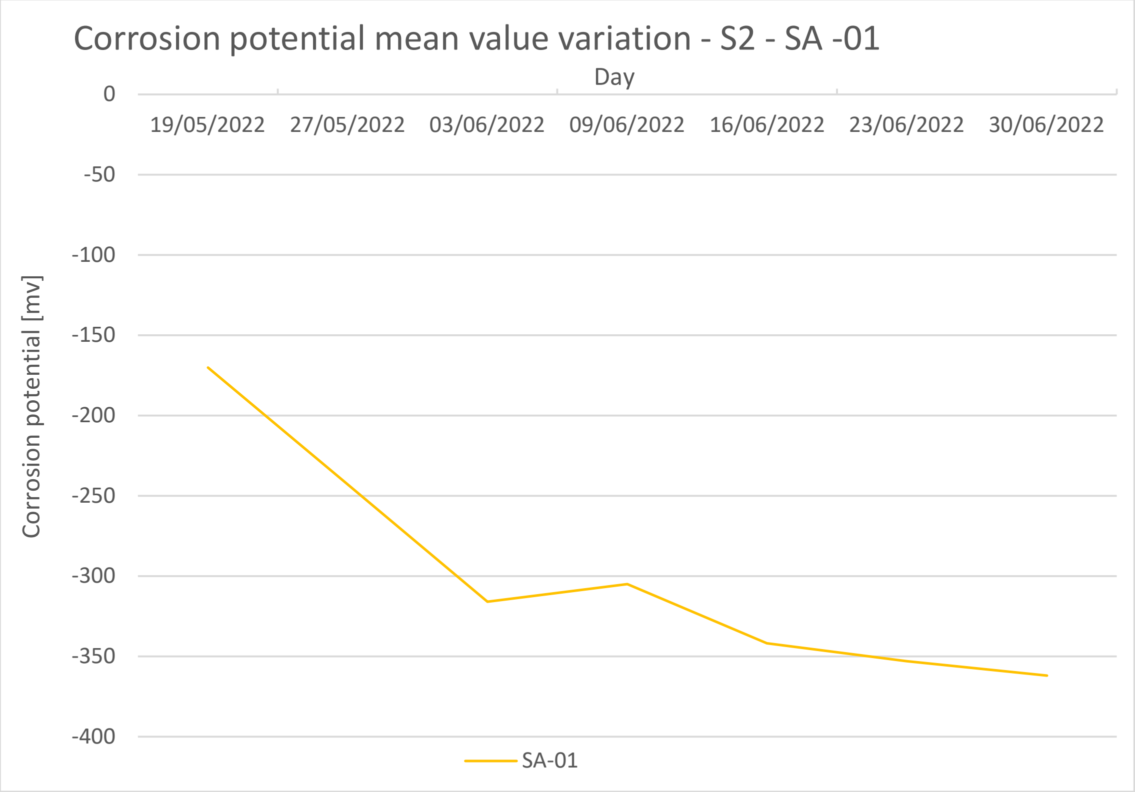


Table 81 S2-SA-02-18/05-corrosion potential analysis

Sample ID	S2-SA-02			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-33	-72	-56	10

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-36	-47	-52	-64	-72	-70	-53	-48	-55	-58	-64
y2	-33	-48	-51	-51	-57	-65	-63	-56	-61	-63	-65

Table 82 S2-SA-02-03/06-corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-02</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, two brush applications</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">03-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-262</td><td colspan="3">-451</td><td colspan="3">-314</td><td colspan="2">51</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-451</td><td>-415</td><td>-312</td><td>-265</td><td>-272</td><td>-286</td><td>-281</td><td>-287</td><td>-272</td><td>-287</td><td>-341</td></tr>
<tr><td>y2</td><td>-385</td><td>-366</td><td>-324</td><td>-285</td><td>-280</td><td>-319</td><td>-333</td><td>-290</td><td>-262</td><td>-265</td><td>-319</td></tr>
</table>

Table 83 S2-SA-02-09/06-corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-02</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, two brush applications</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">09-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-294</td><td colspan="3">-434</td><td colspan="3">-326</td><td colspan="2">33</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-434</td><td>-336</td><td>-306</td><td>-294</td><td>-298</td><td>-310</td><td>-321</td><td>-311</td><td>-312</td><td>-330</td><td>-369</td></tr>
<tr><td>y2</td><td>-389</td><td>-338</td><td>-309</td><td>-299</td><td>-302</td><td>-322</td><td>-330</td><td>-312</td><td>-302</td><td>-312</td><td>-338</td></tr>
</table>

Table 84 S2-SA-02 -16/06-corrosion potential analysis

Sample ID	S2-SA-02			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-285	-411	-312	32

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-411	-327	-290	-285	-287	-297	-286	-287	-293	-323	-354
y2	-377	-327	-300	-296	-311	-318	-306	-286	-289	-297	-310

Table 85 S2-SA-02-23/06-corrosion potential analysis

Sample ID	S2-SA-02			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-283	-417	-331	37

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-408	-340	-315	-324	-338	-325	-315	-325	-308	-359	-417
y2	-399	-348	-321	-310	-332	-321	-306	-287	-286	-283	-319

Table 86 S2-SA-02-30/06-corrosion potential analysis

Sample ID	S2-SA-02			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-291	-449	-336	41

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-420	-366	-328	-317	-325	-312	-317	-313	-330	-364	-449
y2	-405	-336	-311	-305	-319	-322	-307	-291	-304	-321	-328

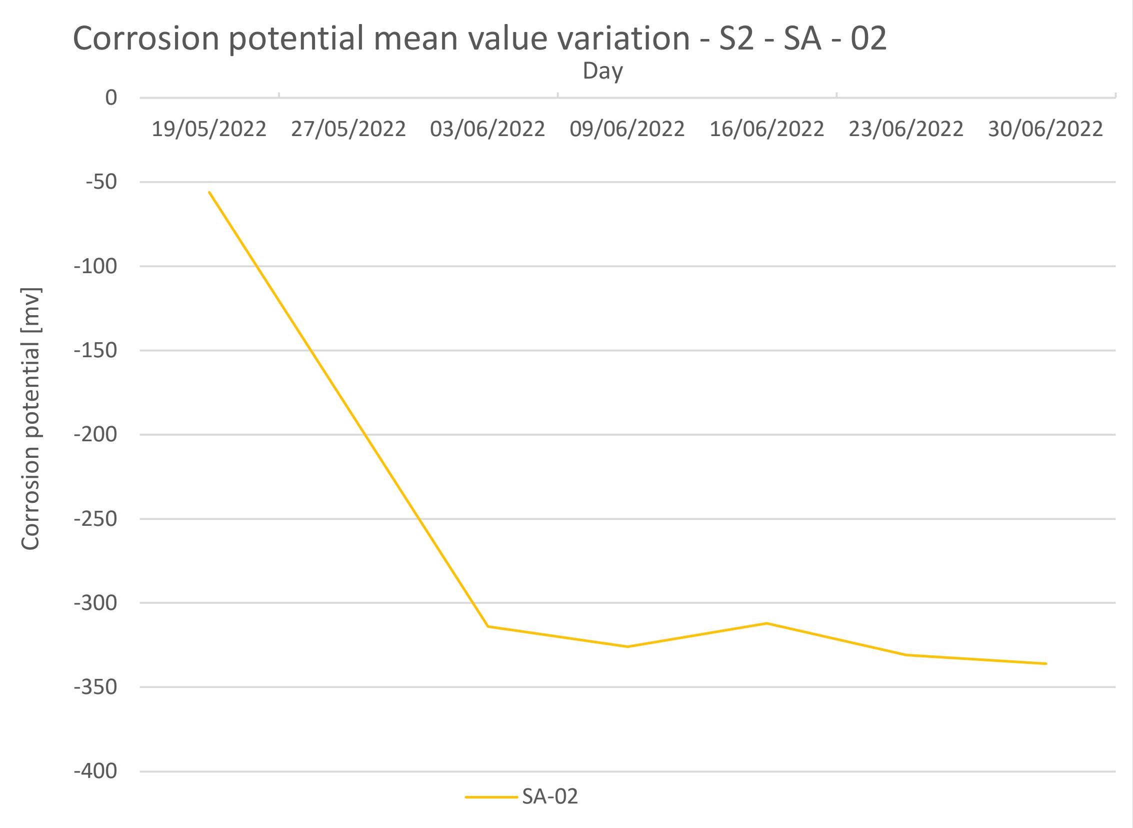


Figure 81 S2-SA-02-corrosion potential mean value variation

Table 87 S2-SA-03-18/05-corrosion potential analysis

Sample ID	S2-SA-03			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-73	-150	-92	16

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-150	-83	-84	-80	-84	-88	-73	-79	-86	-88	-80
y2	-111	-103	-102	-95	-90	-86	-84	-85	-93	-92	-98

Table 88 S2-SA-03-03/06-corrosion potential analysis

Sample ID	S2-SA-03			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-283	-434	-342	42

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-408	-360	-338	-398	-357	-351	-329	-300	-321	-360	-434
y2	-377	-322	-329	-322	-305	-287	-284	-283	-305	-356	-400

Table 89 S2-SA-03-09/06-corrosion potential analysis

Sample ID	S2-SA-03			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-308	-440	-364	38

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-440	-352	-389	-397	-370	-350	-324	-308	-323	-353	-436
y2	-394	-374	-372	-375	-341	-322	-316	-318	-355	-379	-419

Table 90 S2-SA-03-16/06-corrosion potential analysis

Sample ID	S2-SA-03			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-331	-455	-404	38

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-437	-428	-438	-442	-410	-391	-351	-347	-417	-424	-455
y2	-412	-452	-423	-413	-403	-370	-335	-331	-371	-409	-438

Table 91 S2-SA-03-23/06-corrosion potential analysis

Sample ID	S2-SA-03			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-349	-455	-417	30

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-430	-422	-448	-435	-446	-412	-369	-397	-404	-455	-435
y2	-438	-428	-435	-432	-433	-381	-349	-354	-422	-424	-429

Table 92 S2-SA-03-30/06-corrosion potential analysis

Sample ID	S2-SA-03			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-374	-459	-428	20

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-438	-401	-433	-426	-430	-448	-430	-428	-443	-459	-437
y2	-421	-416	-446	-420	-427	-454	-430	-374	-392	-411	-444

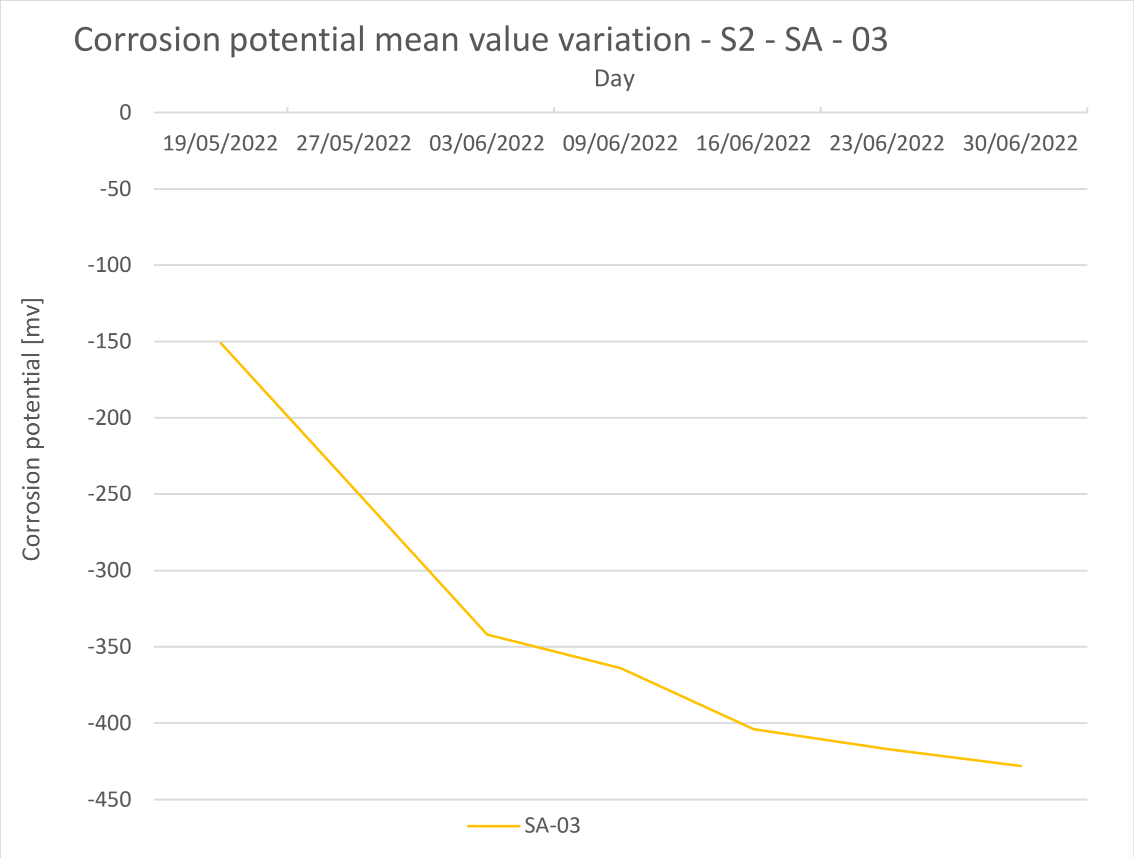


Figure 82 Table 81 S2-SA-03 corrosion potential mean value variation

Table 93 Table 81 S2-SA-04-18/05- corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-04</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, two brush applications</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">18-mag</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-32</td><td colspan="3">-99</td><td colspan="3">-67</td><td colspan="2">17</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-57</td><td>-60</td><td>-62</td><td>-56</td><td>-55</td><td>-36</td><td>-55</td><td>-57</td><td>-60</td><td>-57</td><td>-32</td></tr>
<tr><td>y2</td><td>-59</td><td>-79</td><td>-74</td><td>-80</td><td>-85</td><td>-86</td><td>-99</td><td>-95</td><td>-83</td><td>-75</td><td>-69</td></tr>
</table>

Table 94 S2-SA-04 -03/06- corrosion potential analysis

Sample ID	S2-SA-04			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-306	-473	-362	43

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-434	-390	-333	-335	-320	-333	-324	-309	-306	-318	-359
y2	-473	-394	-417	-359	-394	-395	-374	-357	-335	-339	-368

Table 95 S2-SA-04-09/06- corrosion potential analysis

Sample ID	S2-SA-04			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-294	-449	-355	45

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-449	-392	-324	-317	-301	-294	-304	-297	-302	-333	-407
y2	-410	-380	-339	-330	-373	-371	-375	-344	-358	-403	-408

Table 96 S2-SA-04 -16/06- corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-04</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, two brush applications</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">16-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-361</td><td colspan="3">-440</td><td colspan="3">-395</td><td colspan="2">19</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-440</td><td>-425</td><td>-385</td><td>-383</td><td>-380</td><td>-395</td><td>-366</td><td>-361</td><td>-383</td><td>-386</td><td>-395</td></tr>
<tr><td>y2</td><td>-418</td><td>-413</td><td>-404</td><td>-402</td><td>-389</td><td>-384</td><td>-405</td><td>-413</td><td>-397</td><td>-388</td><td>-383</td></tr>
</table>

Table 97 S2-SA-04-23/06- corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-04</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, two brush applications</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">23-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-332</td><td colspan="3">-416</td><td colspan="3">-372</td><td colspan="2">22</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-407</td><td>-370</td><td>-349</td><td>-341</td><td>-363</td><td>-350</td><td>-332</td><td>-377</td><td>-344</td><td>-372</td><td>-360</td></tr>
<tr><td>y2</td><td>-397</td><td>-374</td><td>-376</td><td>-360</td><td>-379</td><td>-375</td><td>-416</td><td>-407</td><td>-369</td><td>-382</td><td>-384</td></tr>
</table>

Table 98 S2-SA-04-30/06- corrosion potential analysis

Sample ID	S2-SA-04			
Description	Migrating corrosion inhibitor applied, two brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-374	-427	-394	13

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-407	-402	-384	-374	-385	-390	-378	-376	-393	-397	-388
y2	-396	-380	-403	-384	-390	-398	-427	-413	-406	-395	-392

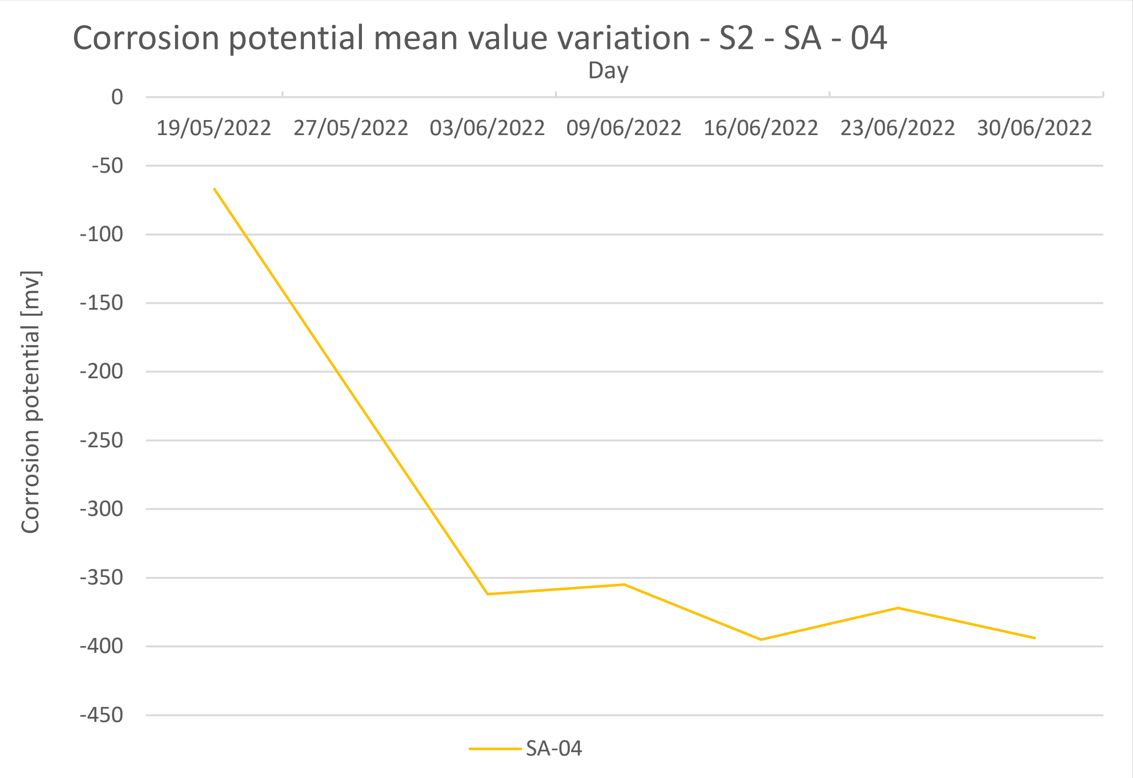


Figure 83 S2-SA-04- corrosion potential mean value variation

Table 99 S2-SA-05-18/06- corrosion potential analysis

Sample ID	S2-SA-05			
Description	Migrating corrosion inhibitor applied, three brush applications			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-32	-116	-74	22

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-51	-89	-75	-52	-80	-100	-99	-73	-68	-57	-39
y2	-32	-64	-86	-85	-98	-116	-101	-83	-75	-70	-41

Table 100 S2-SA-0503/06-- corrosion potential analysis

Sample ID	S2-SA-05			
Description	Migrating corrosion inhibitor applied, three brush applications			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-274	-425	-319	41

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-378	-344	-321	-304	-303	-288	-274	-281	-289	-309	-404
y2	-425	-333	-313	-298	-298	-305	-290	-287	-293	-315	-371

Table 101 S2-SA-05-09/06- corrosion potential analysis

Sample ID		S2-SA-05									
Description		Migrating corrosion inhibitor applied, three brush applications									
Date		09-giu									
Measurements [mv]		Min		Max			Mean			St. dev	
		-276		-420			-337			33	
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-374	-332	-322	-325	-314	-276	-290	-296	-306	-374	-355
y2	-420	-374	-340	-332	-331	-340	-342	-324	-322	-340	-377

Table 102 S2-SA-05-16/06- corrosion potential analysis

Sample ID		S2-SA-05									
Description		Migrating corrosion inhibitor applied, three brush applications									
Date		16-giu									
Measurements [mv]		Min		Max			Mean			St. dev	
		-296		-392			-330			26	
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-347	-329	-315	-320	-316	-311	-302	-307	-321	-355	-358
y2	-374	-320	-311	-303	-321	-321	-392	-296	-321	-354	-366

Table 103 S2-SA-05-23/06- corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-05</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, three brush applications</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">23-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-311</td><td colspan="3">-416</td><td colspan="3">-341</td><td colspan="2">28</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-350</td><td>-334</td><td>-331</td><td>-322</td><td>-322</td><td>-318</td><td>-320</td><td>-315</td><td>-329</td><td>-359</td><td>-390</td></tr>
<tr><td>y2</td><td>-416</td><td>-350</td><td>-347</td><td>-325</td><td>-340</td><td>-337</td><td>-311</td><td>-314</td><td>-325</td><td>-362</td><td>-394</td></tr>
</table>

Table 104 S2-SA-05-30/06- corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-05</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, three brush applications</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">30-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-317</td><td colspan="3">-411</td><td colspan="3">-365</td><td colspan="2">26</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-395</td><td>-372</td><td>-370</td><td>-361</td><td>-359</td><td>-369</td><td>-332</td><td>-324</td><td>-346</td><td>-384</td><td>-387</td></tr>
<tr><td>y2</td><td>-411</td><td>-385</td><td>-381</td><td>-367</td><td>-360</td><td>-379</td><td>-332</td><td>-317</td><td>-329</td><td>-374</td><td>-402</td></tr>
</table>

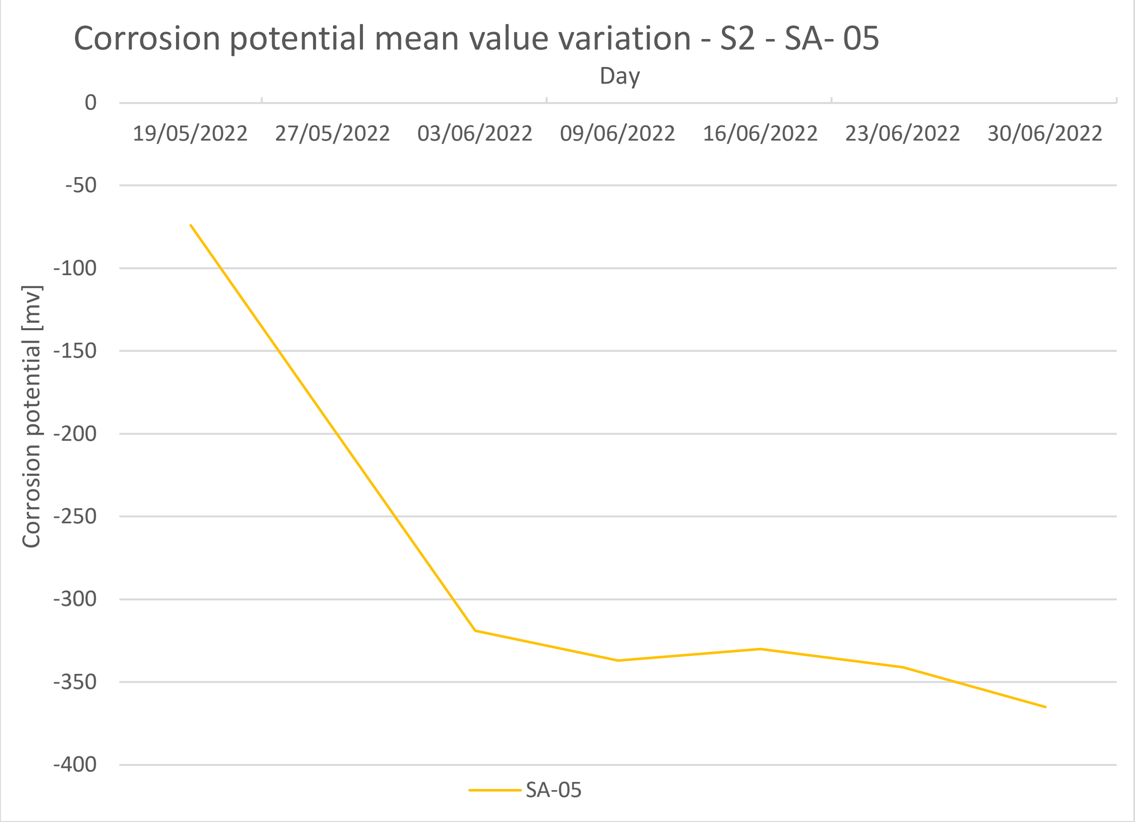


Figure 84 S2-SA-05- corrosion potential mean value variation

Table 105 S2-SA-06-18/05- corrosion potential analysis

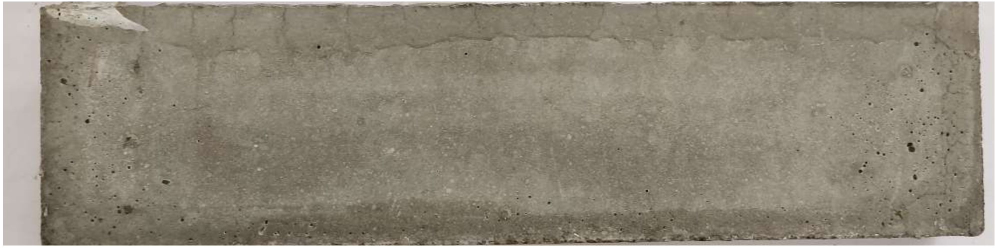
Sample ID	S2-SA-06										
Description	Migrating corrosion inhibitor applied, two brush applications + one spray application										
Date	18-mag										
Measurements [mv]	Min		Max			Mean			St. dev		
	-49		-120			-93			21		
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-79	-95	-106	-88	-62	-49	-63	-62	-88	-89	-66
y2	-110	-120	-120	-108	-105	-108	-113	-114	-107	-100	-92

Table 106 S2-SA-06-03/06- corrosion potential analysis

Sample ID	S2-SA-06										
Description	Migrating corrosion inhibitor applied, two brush applications + one spray application										
Date	03-giu										
Measurements [mv]	Min		Max			Mean			St. dev		
	-290		-398			-327			33		
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-371	-332	-311	-308	-297	-309	-315	-294	-290	-313	-392
y2	-373	-326	-308	-303	-312	-341	-398	-304	-296	-326	-370

Table 107 S2-SA-06-09/06- corrosion potential analysis

Sample ID	S2-SA-06										
Description	Migrating corrosion inhibitor applied, two brush applications + one spray application										
Date	09-giu										
Measurements [mv]	Min		Max			Mean			St. dev		
	-297		-404			-337			34		
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-381	-389	-334	-305	-310	-315	-333	-329	-317	-315	-404
y2	-401	-325	-301	-297	-323	-356	-374	-344	-307	-306	-358

Table 108 S2-SA-06-16/06- corrosion potential analysis

Sample ID	S2-SA-06			
Description	Migrating corrosion inhibitor applied, two brush applications + one spray application			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-354	-432	-389	20

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-404	-432	-410	-373	-364	-385	-398	-380	-377	-403	-398
y2	-427	-408	-375	-354	-389	-384	-408	-370	-373	-369	-379

Table 109 S2-SA-06-23/06- corrosion potential analysis

Sample ID	S2-SA-06			
Description	Migrating corrosion inhibitor applied, two brush applications + one spray application			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-399	-464	-431	14

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-450	-447	-464	-428	-426	-399	-417	-418	-410	-434	-435
y2	-439	-442	-443	-435	-430	-435	-428	-426	-427	-425	-427

Table 110 S2-SA-06-30/06- corrosion potential analysis

<table>
<tr><th>Sample ID</th><th colspan="4">S2-SA-06</th></tr>
<tr><td>Description</td><td colspan="4">Migrating corrosion inhibitor applied, two brush applications + one spray application</td></tr>
<tr><td>Date</td><td colspan="4">30-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td>Min</td><td>Max</td><td>Mean</td><td>St. dev</td></tr>
<tr><td>-424</td><td>-469</td><td>-439</td><td>12</td></tr>
<tr><td colspan="5"></td></tr>
</table>

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-444	-446	-460	-469	-437	-426	-429	-435	-434	-427	-434
y2	-455	-440	-446	-443	-428	-425	-424	-428	-434	-448	-445

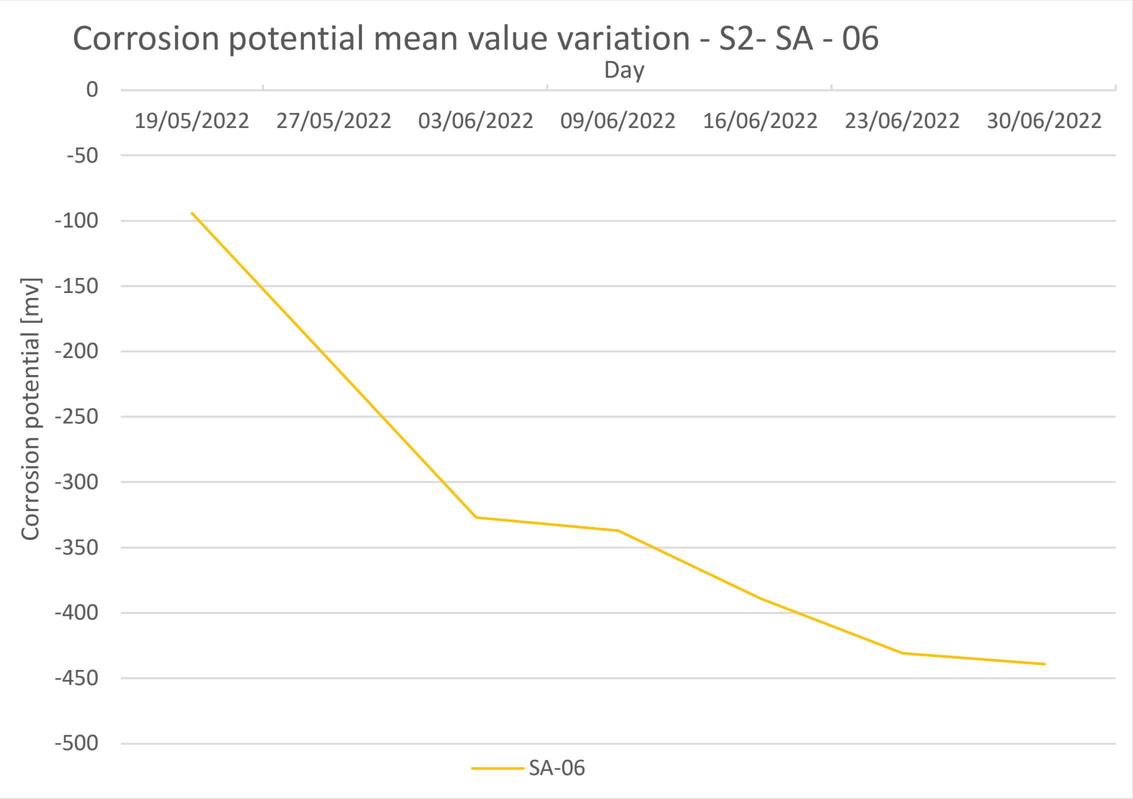
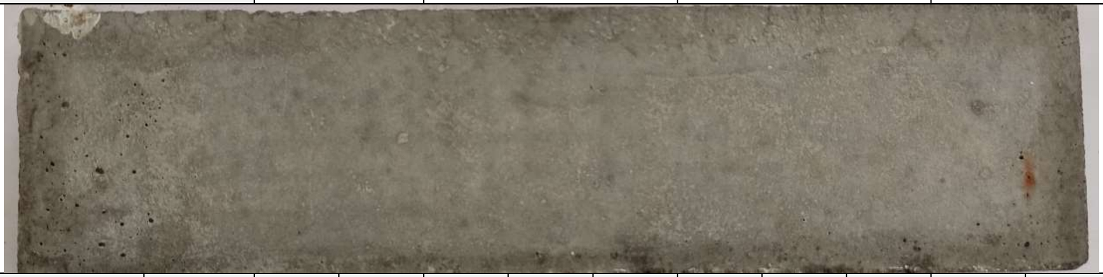


Figure 85 S2-SA-06- corrosion potential mean value variation

Table 111 S2-SA-07-18/05- corrosion potential analysis

Sample ID	S2-SA-07			
Description	Migrating corrosion inhibitor applied, three spray application			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-25	-76	-57	13



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-47	-63	-62	-64	-71	-59	-45	-50	-38	-50	-52
y2	-52	-60	-56	-56	-71	-76	-75	-76	-59	-51	-25

Table 112 S2-SA-07-03/06- corrosion potential analysis

Sample ID	S2-SA-07			
Description	Migrating corrosion inhibitor applied, three spray application			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-255	-382	-300	36

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-308	-339	-382	-302	-288	-276	-268	-255	-265	-282	-359
y2	-376	-323	-304	-292	-290	-297	-276	-264	-263	-278	-317

Table 113 S2-SA-07-09/06- corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-07</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, three spray application</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">09-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-289</td><td colspan="3">-421</td><td colspan="3">-335</td><td colspan="2">32</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-334</td><td>-357</td><td>-384</td><td>-330</td><td>-330</td><td>-313</td><td>-295</td><td>-289</td><td>-297</td><td>-308</td><td>-360</td></tr>
<tr><td>y2</td><td>-421</td><td>-377</td><td>-353</td><td>-338</td><td>-335</td><td>-338</td><td>-348</td><td>-315</td><td>-302</td><td>-307</td><td>-335</td></tr>
</table>

Table 114 S2-SA-07- 16/06-corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S2-SA-07</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Migrating corrosion inhibitor applied, three spray application</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">16-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-280</td><td colspan="3">-431</td><td colspan="3">-331</td><td colspan="2">47</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-364</td><td>-431</td><td>-404</td><td>-358</td><td>-319</td><td>-293</td><td>-286</td><td>-283</td><td>-297</td><td>-326</td><td>-348</td></tr>
<tr><td>y2</td><td>-391</td><td>-406</td><td>-376</td><td>-328</td><td>-309</td><td>-294</td><td>-284</td><td>-280</td><td>-287</td><td>-282</td><td>-332</td></tr>
</table>

Table 115 S2-SA-07-23/06- corrosion potential analysis

Sample ID	S2-SA-07			
Description	Migrating corrosion inhibitor applied, three spray application			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-300	-444	-352	42

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-383	-444	-421	-376	-347	-312	-302	-306	-324	-347	-367
y2	-394	-408	-398	-346	-337	-320	-304	-300	-313	-335	-369

Table 116 S2-SA-07-30/06- corrosion potential analysis

Sample ID	S2-SA-07			
Description	Migrating corrosion inhibitor applied, three spray application			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-308	-449	-366	43

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-391	-449	-428	-408	-357	-328	-322	-323	-339	-388	-405
y2	-403	-431	-397	-365	-352	-335	-320	-317	-325	-352	-308

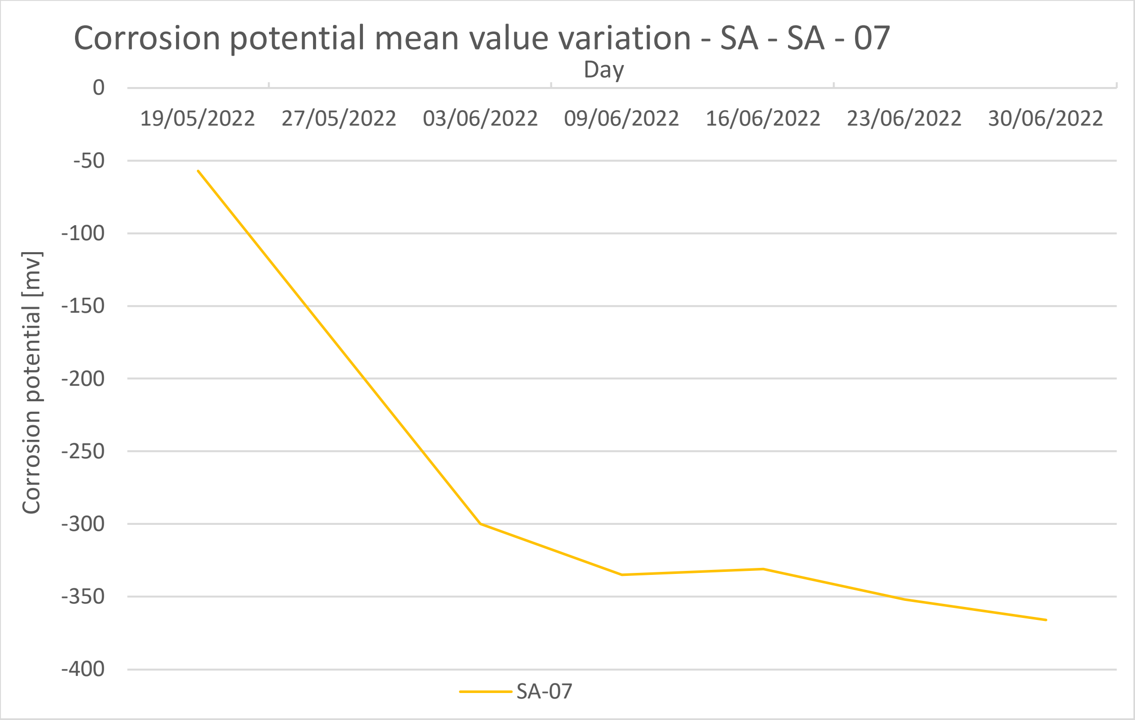


Figure 86 S2-SA-07- corrosion potential mean value variation

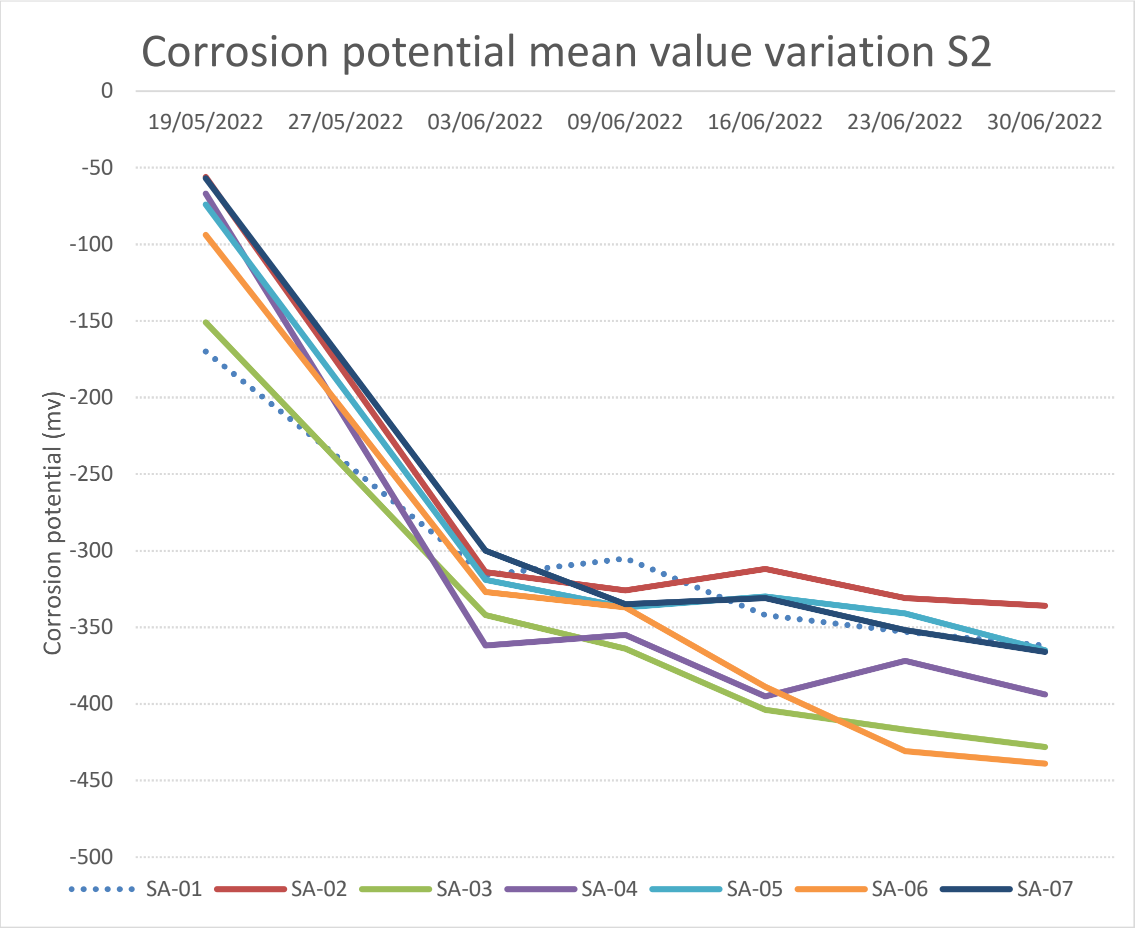
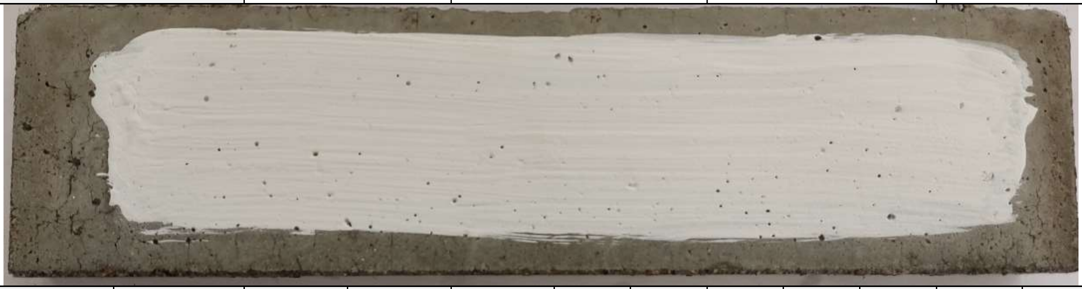


Figure 87 S2-SA- corrosion potential mean value variation

Table 117 S3-PA SA-01-18/05- corrosion potential analysis

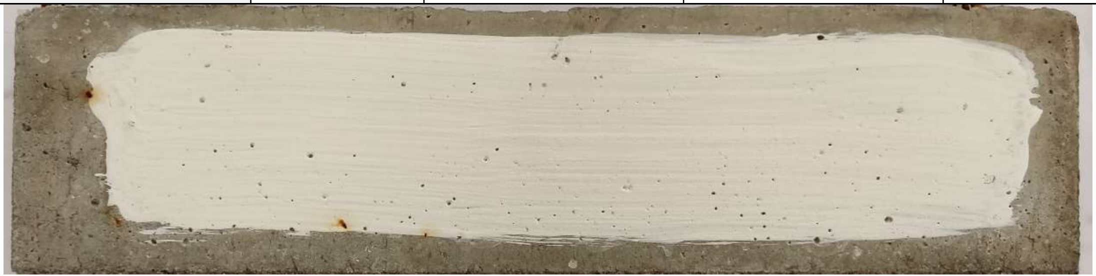
Sample ID	S3- PA SA - 01			
Description	Control sample, painted by two brush applications			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-18	-200	-93	54



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-148	-145	-128	-73	-45	-31	-18	-52	-56	-71	-65
y2	-200	-190	-174	-170	-70	-61	-63	-61	-66	-69	-84

Table 118 S3-PA SA-01-03/06- corrosion potential analysis

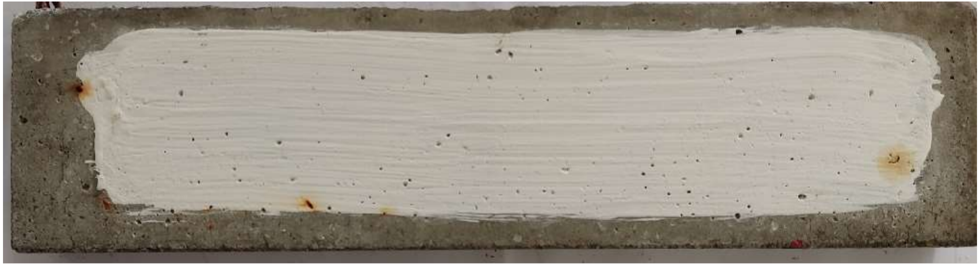
Sample ID	S3- PA SA - 01			
Description	Control sample, painted by two brush applications			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-225	-442	-329	45



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-252	-225	-280	-302	-302	-309	-313	-320	-317	-324	-341
y2	-378	-355	-324	-330	-344	-327	-353	-360	-350	-382	-442

Table 119 S3-PA SA-01-09/06- corrosion potential analysis

Sample ID	S3- PA SA - 01			
Description	Control sample, painted by two brush applications			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-300	-407	-333	28



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-335	-329	-321	-313	-310	-309	-304	-300	-301	-321	-356
y2	-384	-367	-358	-328	-338	-326	-316	-316	-326	-363	-407

Table 120 S3-PA SA-01-16/06- corrosion potential analysis

Sample ID	S3- PA SA - 01			
Description	Control sample, painted by two brush applications			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-312	-416	-341	25

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-340	-327	-324	-318	-313	-312	-319	-329	-340	-361	-381
y2	-353	-345	-349	-340	-327	-322	-325	-333	-346	-379	-416

Table 121 S3-PA SA-01-23/06- corrosion potential analysis

Sample ID	S3- PA SA - 01			
Description	Control sample, painted by two brush applications			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-328	-466	-366	33
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-370	-348	-342	-332	-328	-330	-331	-368	-365	-365	-378
y2	-396	-381	-359	-360	-346	-341	-353	-368	-387	-430	-466

Table 122 S3-PA SA-01-30/06- corrosion potential analysis

Sample ID	S3- PA SA - 01			
Description	Control sample, painted by two brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-336	-433	-371	27
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-383	-361	-351	-344	-340	-336	-341	-348	-358	-370	-391
y2	-409	-411	-394	-372	-365	-349	-353	-383	-369	-403	-433

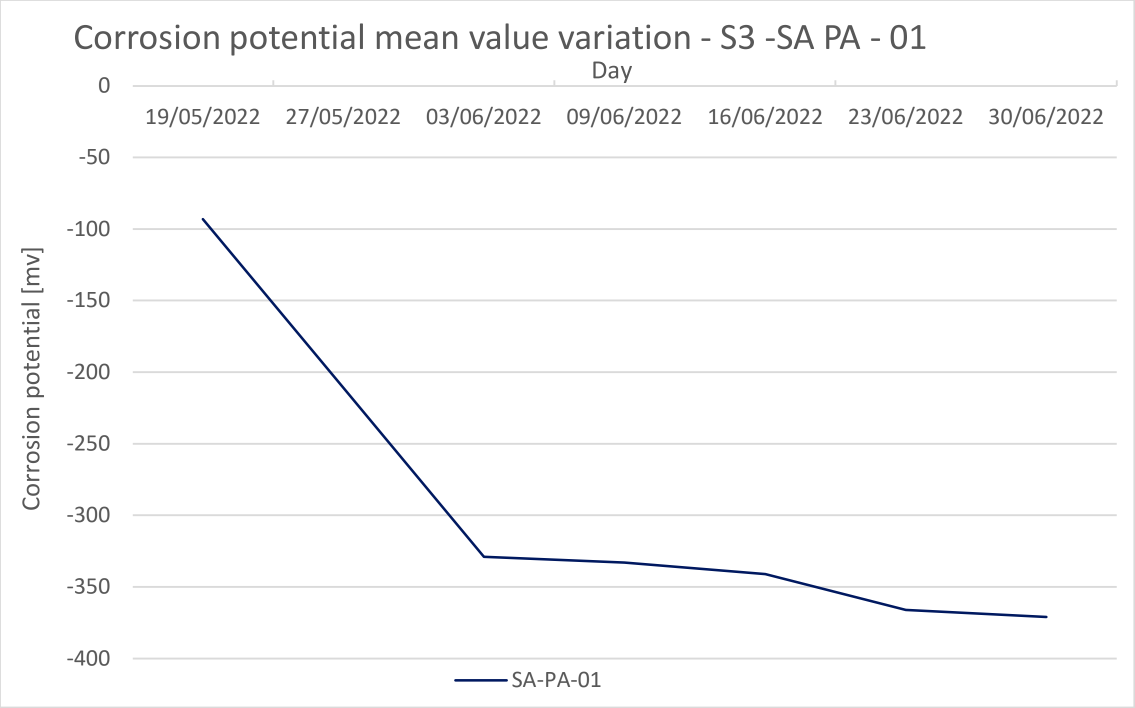


Figure 88 S3-PA SA-01- corrosion potential mean value variation

Table 123 S3-PA SA-02- 18/05-corrosion potential analysis

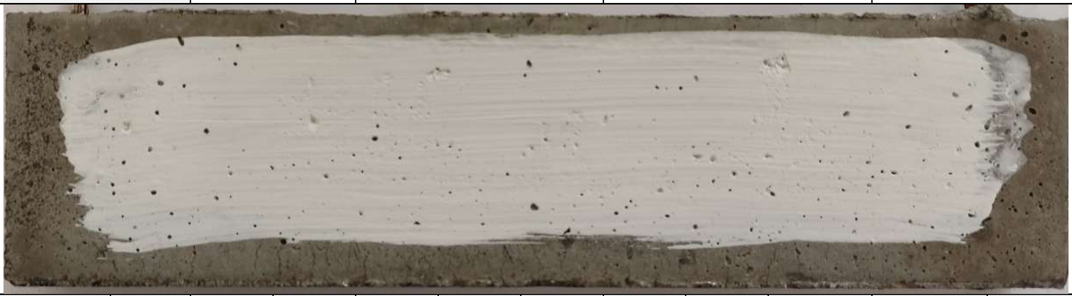
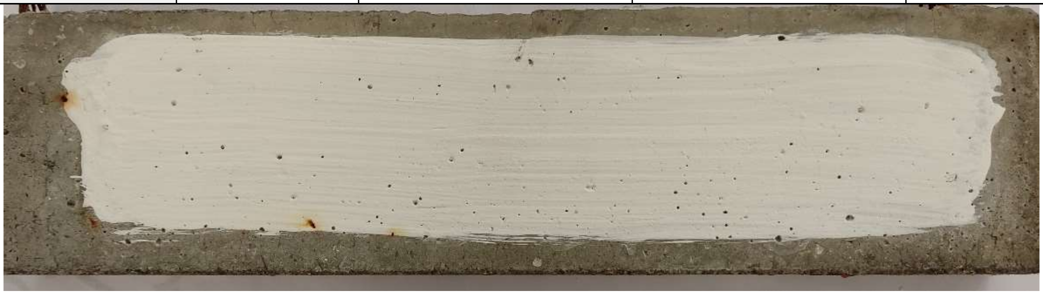
Sample ID	S3- PA SA - 02										
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)										
Date	18-mag										
Measurements [mv]	Min		Max		Mean			St. dev			
	6		-50		-4			13			
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	4	1	2	5	6	6	3	-1	-2	-8	-18
y2	-2	-2	-1	0	2	1	-1	-6	-11	-26	-50

Table 124 S3-PA SA-02 -03/06-corrosion potential analysis

Sample ID	S3- PA SA - 02			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-227	-373	-287	36



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-227	-232	-253	-267	-263	-256	-264	-285	-298	-309	-312
y2	-255	-267	-260	-285	-293	-317	-314	-323	-324	-330	-373

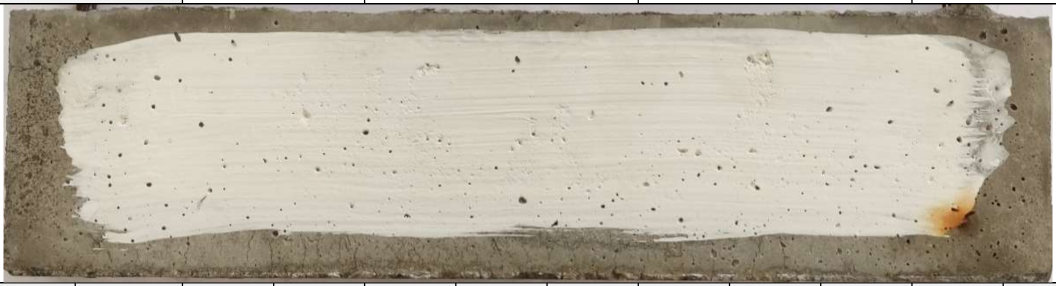
Table 125 S3-PA SA-02-09/06- corrosion potential analysis

Sample ID	S3- PA SA - 02			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-294	-408	-331	29

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-318	-315	-305	-304	-301	-300	-294	-299	-307	-329	-357
y2	-318	-324	-357	-341	-333	-358	-344	-341	-347	-378	-408

Table 126 S3-PA SA-02-16/06- corrosion potential analysis

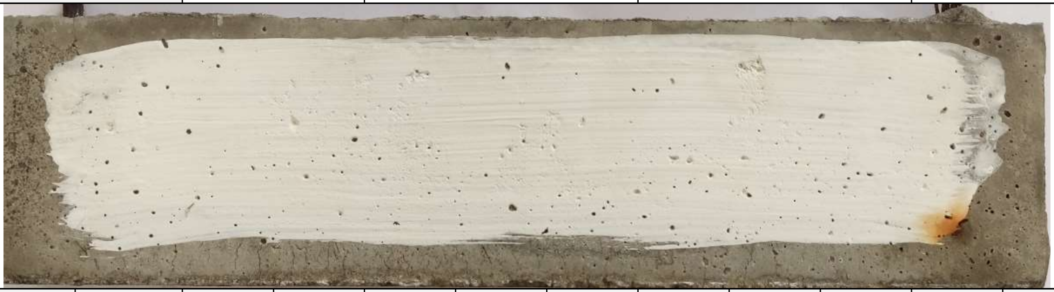
Sample ID	S3- PA SA - 02			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-296	-391	-332	31



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-298	-298	-297	-296	-308	-323	-329	-371	-367	-365	-366
y2	-300	-301	-305	-312	-320	-330	-336	-351	-359	-374	-391

Table 127 S3-PA SA-02-23/06-corrosion potential analysis

Sample ID	S3- PA SA - 02			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-315	-433	-351	29



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-340	-329	-318	-315	-323	-338	-337	-351	-376	-355	-355
y2	-320	-323	-330	-334	-356	-363	-394	-386	-366	-378	-433

Table 128 S3-PA SA-02-30/06-corrosion potential analysis

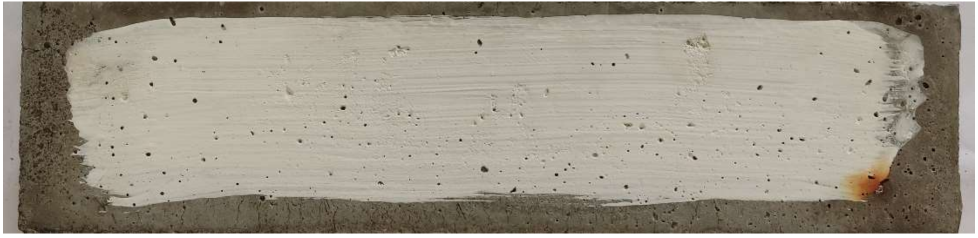
<table>
<tr><td>Sample ID</td><td colspan="11">S3- PA SA - 02</td></tr>
<tr><td>Description</td><td colspan="11">Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)</td></tr>
<tr><td>Date</td><td colspan="11">30-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="3">St. dev</td></tr>
<tr><td colspan="2">-36</td><td colspan="3">-407</td><td colspan="3">-334</td><td colspan="3">71</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-335</td><td>-333</td><td>-322</td><td>-319</td><td>-326</td><td>-332</td><td>-346</td><td>-352</td><td>-376</td><td>-367</td><td>-354</td></tr>
<tr><td>y2</td><td>-326</td><td>-323</td><td>-320</td><td>-327</td><td>-342</td><td>-36</td><td>-361</td><td>-407</td><td>-387</td><td>-376</td><td>-388</td></tr>
</table>

Table 129 S3-PA SA-02-corrosion potential mean value variation

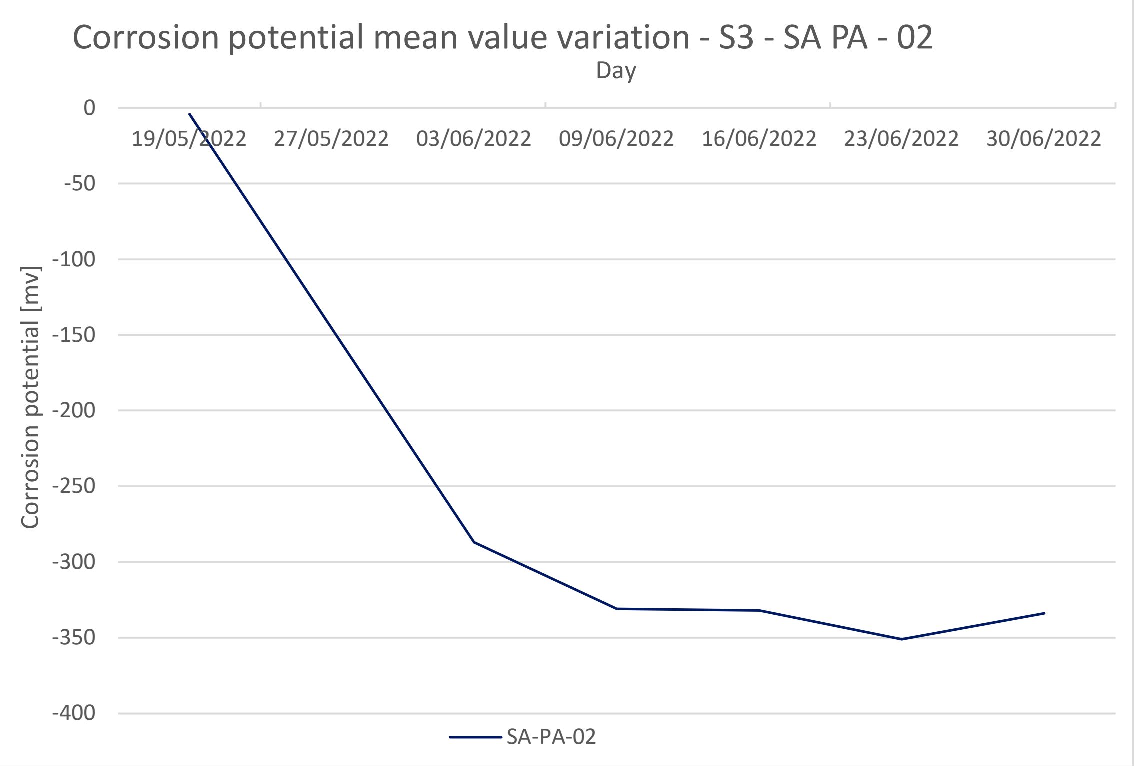
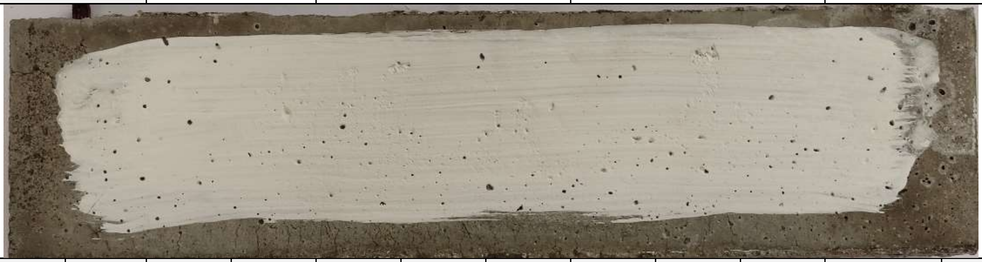


Table 130 S3-PA SA-03-18/05-corrosion potential analysis

Sample ID	S3- PA SA - 03			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	39	19	29	6



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	20	22	27	30	35	38	39	39	33	28	25
y2	19	22	25	29	32	34	34	33	26	22	24

Table 131 S3-PA SA-03-03/06-corrosion potential analysis

Sample ID	S3- PA SA - 03			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-225	-285	-249	22

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-279	-278	-273	-266	-257	-236	-228	-226	-230	-236	-241
y2	-285	-281	-274	-268	-256	-228	-225	-225	-227	-226	-239

Table 132 S3-PA SA-03-09/06-corrosion potential analysis

Sample ID	S3- PA SA - 03			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-277	-392	-313	37

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-365	-348	-310	-292	-284	-278	-277	-278	-281	-285	-283
y2	-392	-378	-387	-321	-314	-306	-297	-295	-295	-300	-313

Table 133 S3-PA SA-03-16/06-corrosion potential analysis

Sample ID	S3- PA SA - 03			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-235	-384	-293	37

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-313	-282	-278	-307	-343	-271	-353	-250	-260	-261	-235
y2	-384	-346	-294	-305	-303	-291	-278	-267	-277	-271	-278

Table 134 S3-PA SA-03-23/06-corrosion potential analysis

Sample ID	S3- PA SA - 03			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-304	-442	-354	30

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-399	-379	-350	-356	-339	-334	-332	-339	-347	-304	-365
y2	-442	-409	-358	-345	-343	-339	-335	-338	-342	-345	-353

Table 135 S3-PA SA-03-30/06-corrosion potential analysis

Sample ID	S3- PA SA - 03			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-320	-452	-353	35

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-404	-396	-369	-355	-341	-329	-331	-341	-345	-343	-348
y2	-452	-421	-366	-340	-330	-325	-323	-320	-327	-325	-331

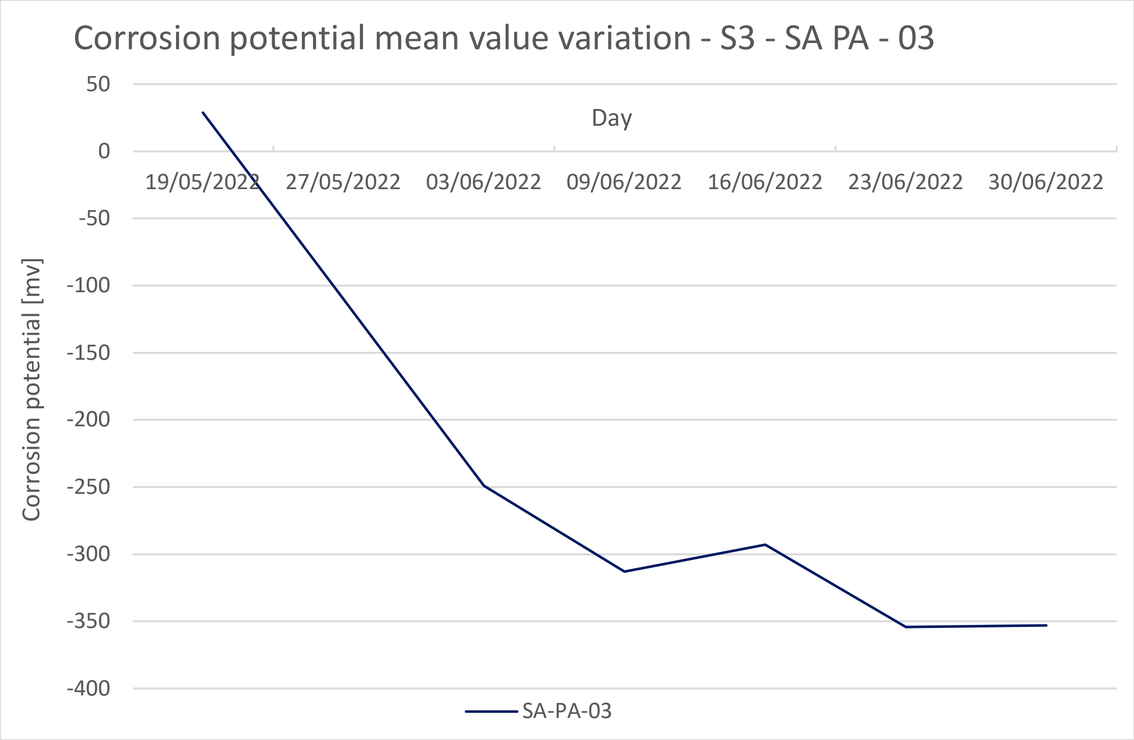


Figure 89 S3-PA SA-03-corrosion potential mean value variation

Table 136 S3-PA SA-04-18/05-corrosion potential analysis

Sample ID	S3- PA SA - 04			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-11	-102	-34	21

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-11	-19	-22	-23	-22	-23	-24	-28	-37	-55	-67
y2	-22	-26	-26	-23	-22	-23	-25	-33	-47	-67	-102

Table 137 S3-PA SA-04-03/06-corrosion potential analysis

Sample ID	S3- PA SA - 04			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-196	-352	-257	43

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-217	-233	-222	-212	-203	-196	-213	-226	-266	-292	-329
y2	-299	-294	-281	-261	-244	-231	-236	-253	-280	-315	-352

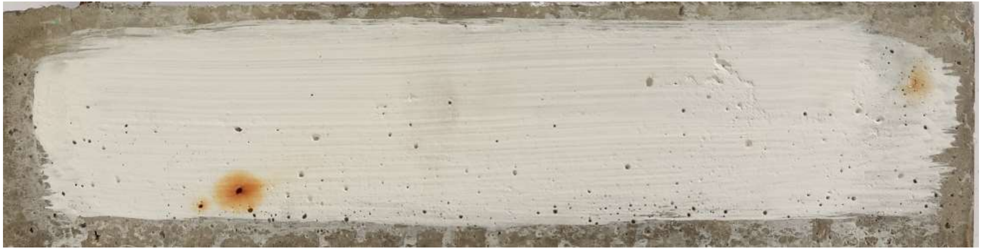
Table 138 S3-PA SA-04-09/06-corrosion potential analysis

Sample ID	S3- PA SA - 04			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-233	-393	-284	39

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-310	-277	-278	-248	-255	-248	-233	-242	-246	-272	-319
y2	-340	-333	-300	-297	-282	-258	-256	-279	-266	-309	-393

Table 139 S3-PA SA-04-16/06-corrosion potential analysis

Sample ID	S3- PA SA - 04			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-242	-455	-306	63



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-288	-275	-266	-257	-245	-242	-260	-273	-325	-382	-450
y2	-340	-344	-292	-269	-258	-255	-269	-282	-324	-389	-455

Table 140 S3-PA SA-04-23/06-corrosion potential analysis

Sample ID	S3- PA SA - 04			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	19	-425	-305	87

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-335	-313	-282	-265	-259	-269	-302	19	-339	-379	-425
y2	-372	-353	-305	-286	-271	-268	-286	-305	-338	-380	-400

Table 141 S3-PA SA-04-30/06-corrosion potential analysis

Sample ID	S3- PA SA - 04			
Description	Painted (2 brush applications) + Migrating surface corrosion inhibitor (2 brush applications)			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-314	-421	-357	36

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-396	-361	-337	-323	-314	-315	-321	-340	-364	-393	-421
y2	-391	-378	-346	-322	-318	-318	-330	-361	-382	-401	-420

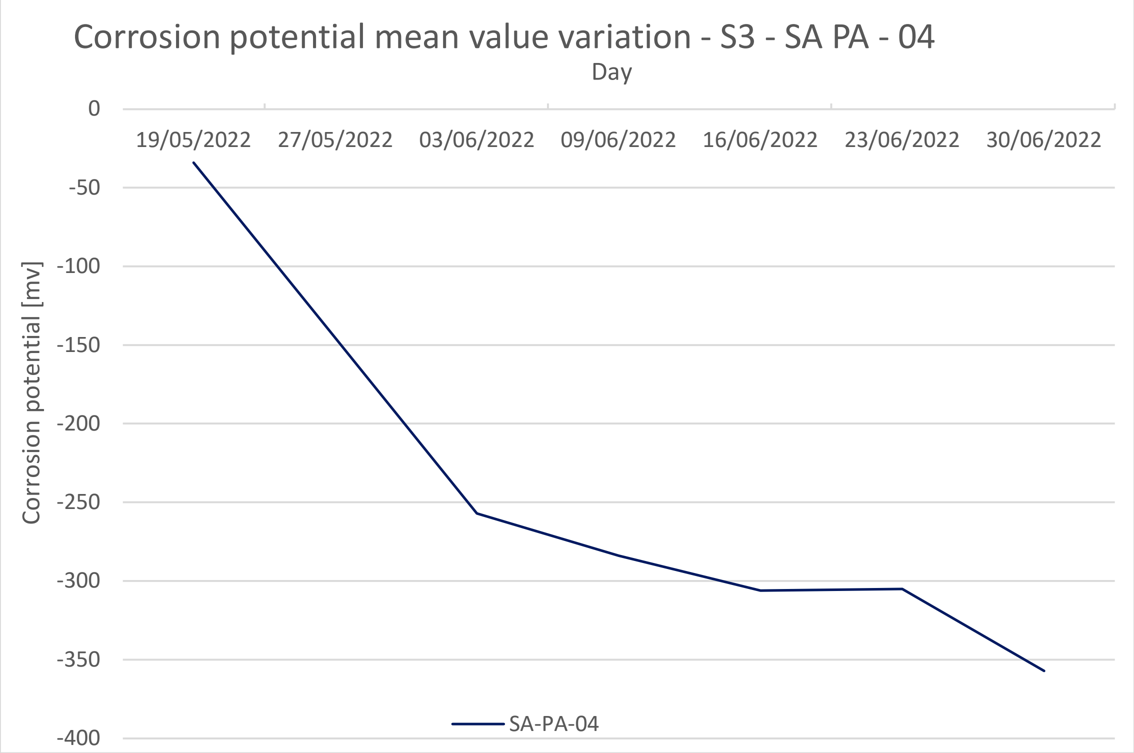


Figure 90 S3-PA SA-04-corrosion potential mean value variation

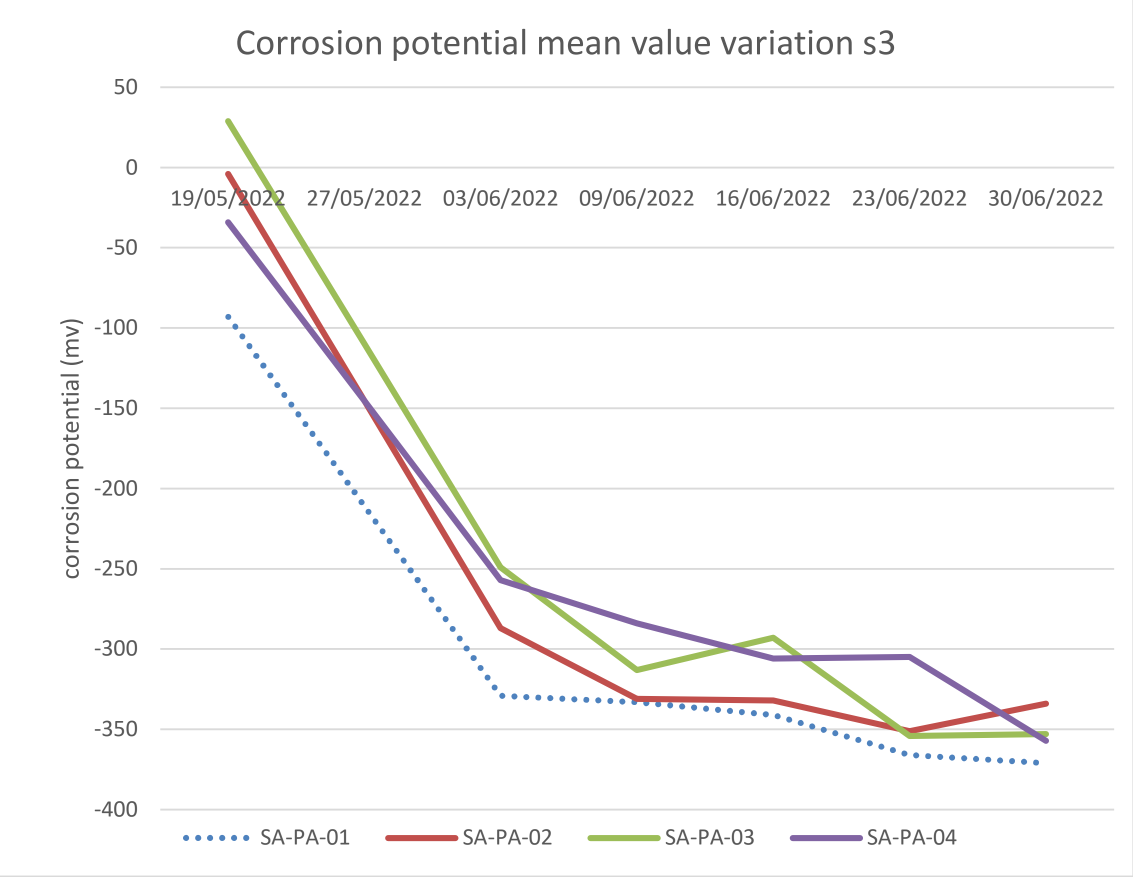


Figure 91 S3-PA SA-corrosion potential mean value variation

Table 142 S4-SA VF-01-18/05-corrosion potential analysis

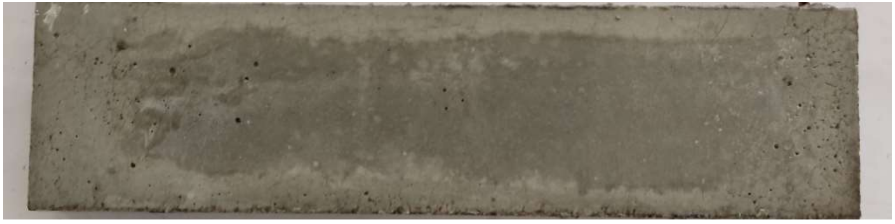
<table>
<tr><td>Sample ID</td><td colspan="11">S4-SA VF - 01</td></tr>
<tr><td>Description</td><td colspan="11">Control sample, no treatments</td></tr>
<tr><td>Date</td><td colspan="11">18-mag</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="3">St. dev</td></tr>
<tr><td colspan="2">-125</td><td colspan="3">-278</td><td colspan="3">-215</td><td colspan="3">43</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-125</td><td>-151</td><td>-176</td><td>-199</td><td>-235</td><td>-242</td><td>-252</td><td>-268</td><td>-260</td><td>-274</td><td>-278</td></tr>
<tr><td>y2</td><td>-145</td><td>-178</td><td>-201</td><td>-202</td><td>-196</td><td>-202</td><td>-213</td><td>-218</td><td>-223</td><td>-240</td><td>-261</td></tr>
</table>

Table 143 S4-SA VF-01-03/06-corrosion potential analysis

Sample ID	S4-SA VF - 01			
Description	Control sample, no treatments			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-202	-341	-276	31

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-202	-280	-292	-305	-341	-326	-290	-272	-277	-294	-319
y2	-277	-258	-262	-267	-260	-255	-250	-243	-248	-265	-296

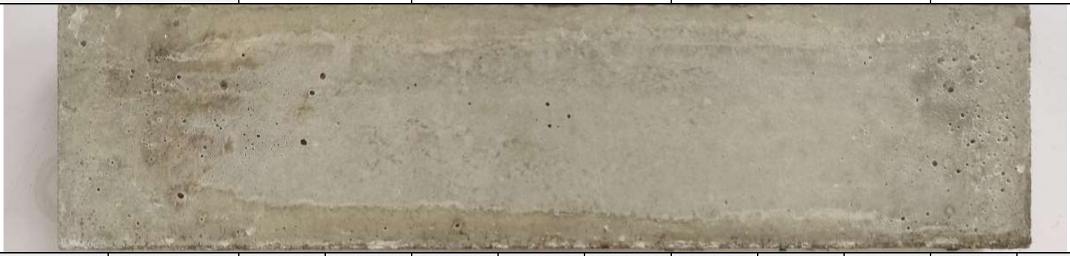
Table 144 S4-SA VF-01-09/06-corrosion potential analysis

Sample ID	S4-SA VF - 01			
Description	Control sample, no treatments			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-312	-425	-350	33

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-350	-334	-363	-399	-425	-397	-386	-376	-349	-374	-380
y2	-319	-320	-331	-334	-320	-312	-315	-315	-319	-338	-342

Table 145 S4-SA VF-01-16/06-corrosion potential analysis

Sample ID	S4-SA VF - 01			
Description	Control sample, no treatments			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-322	-396	-354	20



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-364	-340	-364	-368	-374	-380	-396	-345	-368	-378	-373
y2	-322	-335	-346	-342	-336	-340	-336	-326	-340	-354	-356

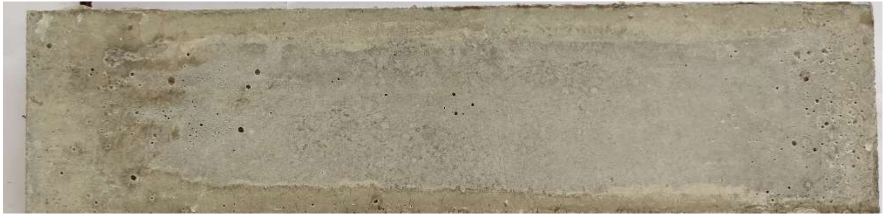
Table 146 S4-SA VF-01-16/06-corrosion potential analysis

Sample ID	S4-SA VF - 01			
Description	Control sample, no treatments			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-370	-434	-398	19

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-398	-381	-409	-419	-400	-426	-421	-411	-422	-434	-416
y2	-370	-391	-386	-382	-376	-375	-374	-382	-393	-397	-401

Table 147 S4-SA VF-01-30/06-corrosion potential analysis

Sample ID	S4-SA VF - 01			
Description	Control sample, no treatments			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-376	-421	-395	13



[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-402	-396	-408	-407	-395	-421	-406	-405	-411	-408	-393
y2	-381	-399	-389	-381	-376	-379	-379	-385	-389	-395	-381

Table 148 S4-SA VF-01--corrosion potential mean value variation

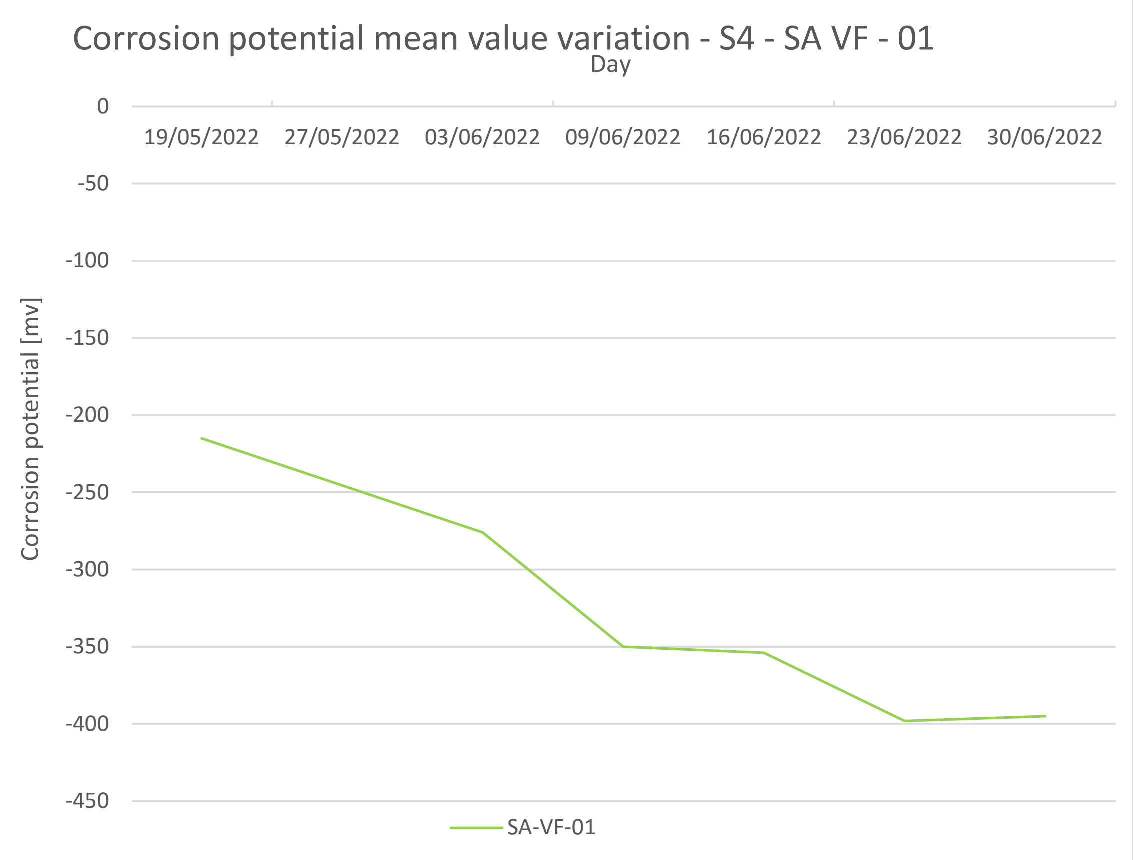


Table 149 S4-SA VF-02-18/05-corrosion potential analysis

Sample ID	S4-SA VF - 02			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
T	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-32	-93	-62	19
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-32	-34	-38	-50	-65	-76	-74	-63	-58	-61	-82
y2	-34	-37	-45	-56	-70	-81	-84	-81	-74	-70	-93

Table 150 S4-SA VF-02-03/06--corrosion potential analysis

Sample ID	S4-SA VF - 02			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-241	-383	-291	35
				

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-319	-278	-277	-256	-243	-241	-251	-255	-264	-300	-335
y2	-305	-306	-321	-298	-283	-275	-278	-290	-309	-342	-383

Table 151 S4-SA VF-02-09/06-corrosion potential analysis

<table>
<tr><th colspan="2">Sample ID</th><td colspan="10">S4-SA VF - 02</td></tr>
<tr><th colspan="2">Description</th><td colspan="10">Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application</td></tr>
<tr><th colspan="2">Date</th><td colspan="10">09-giu</td></tr>
<tr><th colspan="2" rowspan="2">Measurements [mv]</th><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-317</td><td colspan="3">-403</td><td colspan="3">-353</td><td colspan="2">25</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-376</td><td>-372</td><td>-355</td><td>-359</td><td>-345</td><td>-336</td><td>-326</td><td>-328</td><td>-353</td><td>-381</td><td>-382</td></tr>
<tr><td>y2</td><td>-375</td><td>-326</td><td>-351</td><td>-327</td><td>-330</td><td>-347</td><td>-350</td><td>-317</td><td>-324</td><td>-397</td><td>-403</td></tr>
</table>

Table 152 S4-SA VF-02-16/06-corrosion potential analysis

<table>
<tr><th colspan="2">Sample ID</th><td colspan="10">S4-SA VF - 02</td></tr>
<tr><th colspan="2">Description</th><td colspan="10">Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application</td></tr>
<tr><th colspan="2">Date</th><td colspan="10">16-giu</td></tr>
<tr><th colspan="2" rowspan="2">Measurements [mv]</th><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-358</td><td colspan="3">-410</td><td colspan="3">-381</td><td colspan="2">15</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-377</td><td>-370</td><td>-381</td><td>-365</td><td>-381</td><td>-359</td><td>-358</td><td>-370</td><td>-376</td><td>-382</td><td>-377</td></tr>
<tr><td>y2</td><td>-386</td><td>-397</td><td>-389</td><td>-361</td><td>-376</td><td>-368</td><td>-405</td><td>-385</td><td>-397</td><td>-410</td><td>-410</td></tr>
</table>

Table 153 S4-SA VF-02-23/06-corrosion potential analysis

Sample ID	S4-SA VF - 02			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-357	-420	-393	17

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-393	-394	-397	-387	-381	-364	-357	-376	-388	-404	-403
y2	-413	-400	-420	-414	-384	-395	-375	-382	-385	-411	-415

Table 154 S4-SA VF-02-30/06-corrosion potential analysis

Sample ID	S4-SA VF - 02			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-366	-410	-393	14

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-401	-394	-409	-401	-402	-383	-367	-369	-382	-392	-401
y2	-409	-396	-410	-392	-391	-395	-367	-366	-395	-405	-408

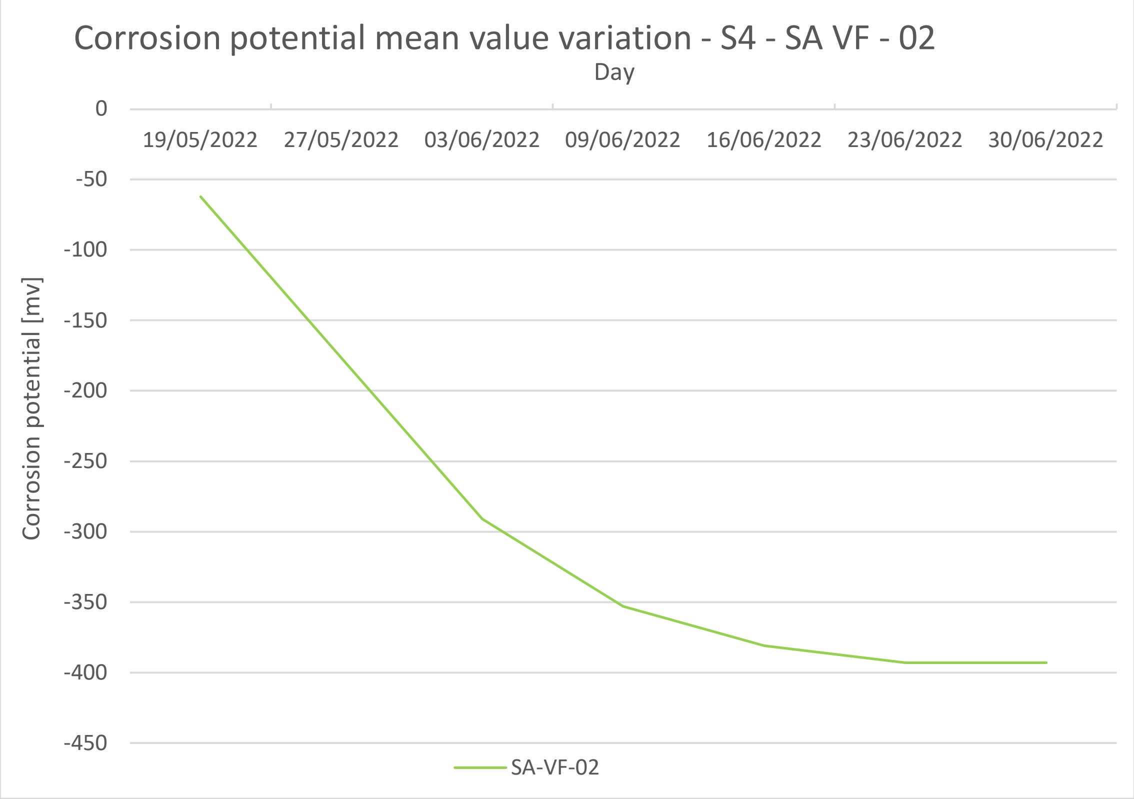


Figure 92 S4-SA VF-02--corrosion potential mean value variation

Table 155 S4-SA VF-03-18/05-corrosion potential analysis

Sample ID	S4-SA VF - 03										
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application										
Date	18-mag										
Measurements [mv]	Min		Max			Mean			St. dev		
	-213		-315			-241			32		
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-223	-218	-216	-217	-215	-216	-223	-236	-286	-245	-213
y2	-231	-220	-218	-224	-233	-248	-244	-267	-307	-315	-295

Table 156 S4-SA VF-03-03/06-corrosion potential analysis

Sample ID	S4-SA VF - 03			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-290	-422	-368	36

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-413	-362	-299	-290	-333	-362	-401	-352	-365	-362	-422
y2	-412	-376	-338	-336	-352	-378	-354	-378	-402	-404	-414

Table 157 S4-SA VF-03-09/06-corrosion potential analysis

Sample ID	S4-SA VF - 03			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	09-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-348	-450	-408	29

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-449	-407	-379	-348	-354	-408	-410	-395	-400	-432	-450
y2	-409	-407	-386	-377	-380	-409	-426	-426	-435	-432	-448

Table 158 S4-SA VF-03-16/06-corrosion potential analysis

Sample ID	S4-SA VF - 03			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-390	-448	-419	19

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-448	-422	-390	-405	-413	-422	-416	-392	-435	-440	-441
y2	-411	-390	-391	-401	-413	-425	-446	-432	-433	-429	-430

Table 159 S4-SA VF-03-23/06-corrosion potential analysis

Sample ID	S4-SA VF - 03			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-411	-480	-438	17

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-463	-431	-425	-417	-450	-447	-448	-449	-451	-480	-463
y2	-424	-421	-412	-411	-428	-443	-436	-440	-437	-430	-439

Table 160 S4-SA VF-03-30/06-corrosion potential analysis

Sample ID	S4-SA VF - 03			
Description	Two migrating corrosion inhibitor brush application + 1 brush vetrofluid application			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-400	-447	-428	12

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-422	-428	-424	-411	-400	-425	-439	-441	-439	-442	-447
y2	-433	-426	-418	-408	-417	-431	-430	-442	-435	-425	-425

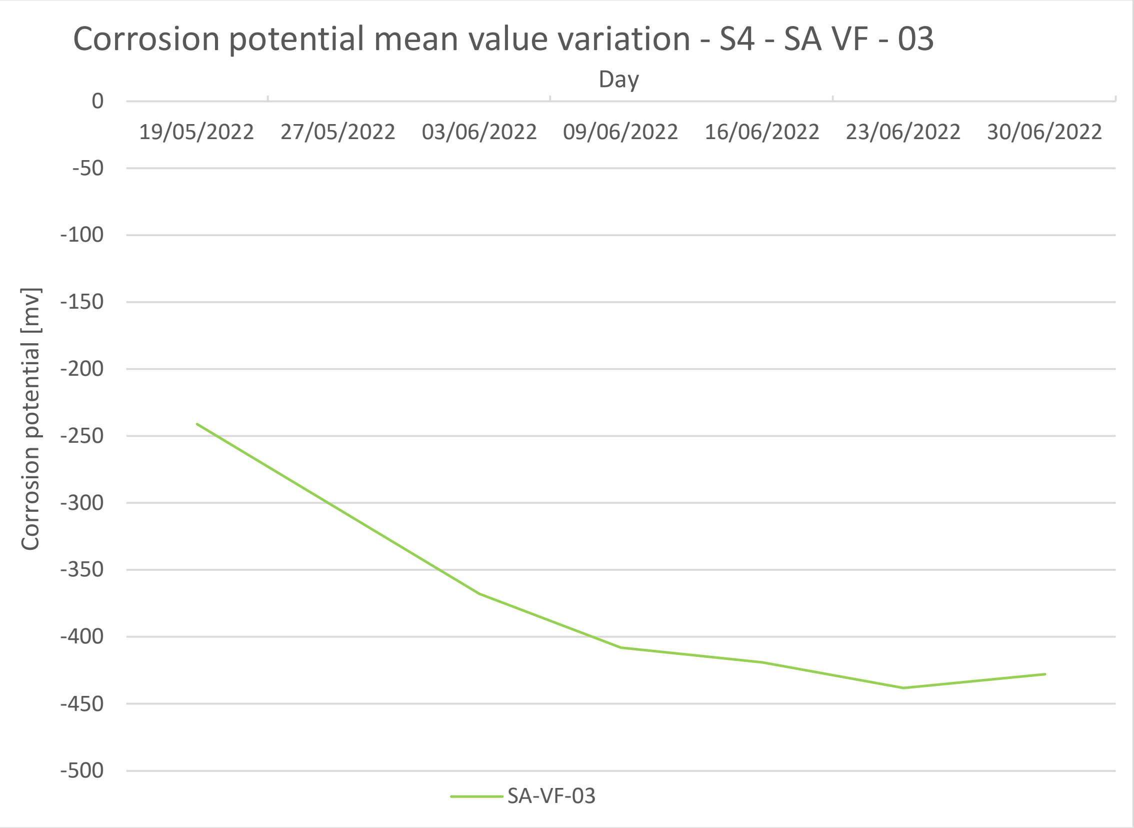


Figure 93 S4-SA VF-03--corrosion potential mean value variation

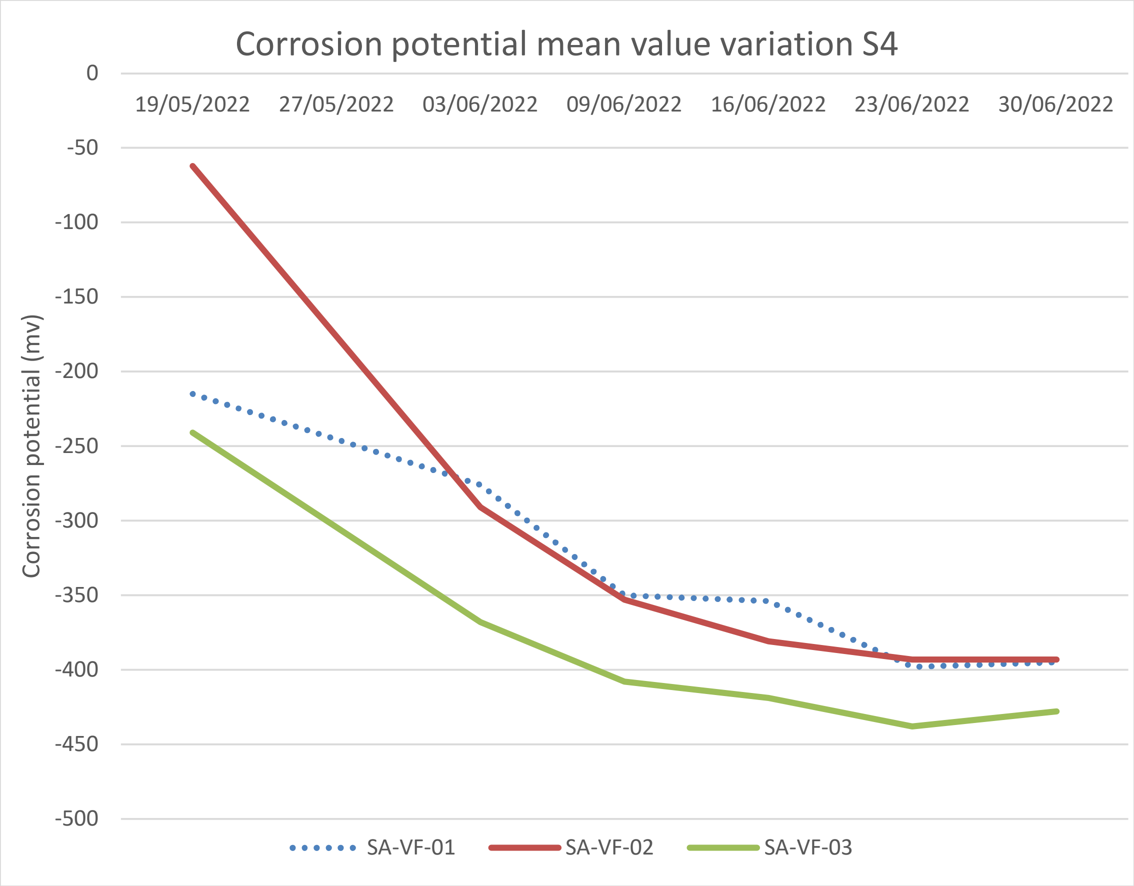


Figure 94 S4-SA VF--corrosion potential mean values variation

Table 161 S5-VF-01-18/05-corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S5-VF-01</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Control sample, no treatments</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">18-mag</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-168</td><td colspan="3">-298</td><td colspan="3">-218</td><td colspan="2">34</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-260</td><td>-223</td><td>-213</td><td>-200</td><td>-177</td><td>-198</td><td>-168</td><td>-179</td><td>-195</td><td>-190</td><td>-250</td></tr>
<tr><td>y2</td><td>-241</td><td>-224</td><td>-221</td><td>-298</td><td>-294</td><td>-208</td><td>-211</td><td>-203</td><td>-205</td><td>-209</td><td>-225</td></tr>
</table>

Table 162 S5-VF-01-03/06-corrosion potential analysis

<table>
<tr><td>Sample ID</td><td colspan="11">S5-VF-01</td></tr>
<tr><td>Description</td><td colspan="11">Control sample, no treatments</td></tr>
<tr><td>Date</td><td colspan="11">03-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="3">St. dev</td></tr>
<tr><td colspan="2">-294</td><td colspan="3">-398</td><td colspan="3">-340</td><td colspan="3">26</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-356</td><td>-325</td><td>-318</td><td>-300</td><td>-312</td><td>-325</td><td>-326</td><td>-343</td><td>-354</td><td>-370</td><td>-398</td></tr>
<tr><td>y2</td><td>-348</td><td>-335</td><td>-328</td><td>-317</td><td>-321</td><td>-344</td><td>-354</td><td>-370</td><td>-374</td><td>-294</td><td>-371</td></tr>
</table>

Table 163 S5-VF-01-09/06-corrosion potential analysis

<table>
<tr><td>Sample ID</td><td colspan="11">S5-VF-01</td></tr>
<tr><td>Description</td><td colspan="11">Control sample, no treatments</td></tr>
<tr><td>Date</td><td colspan="11">09-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="3">St. dev</td></tr>
<tr><td colspan="2">-374</td><td colspan="3">-473</td><td colspan="3">-424</td><td colspan="3">29</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-462</td><td>-405</td><td>-401</td><td>-382</td><td>-374</td><td>-394</td><td>-388</td><td>-407</td><td>-414</td><td>-464</td><td>-461</td></tr>
<tr><td>y2</td><td>-435</td><td>-424</td><td>-417</td><td>-407</td><td>-410</td><td>-419</td><td>-436</td><td>-448</td><td>-463</td><td>-473</td><td>-451</td></tr>
</table>

Table 164 S5-VF-01-16/06-corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S5-VF-01</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Control sample, no treatments</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">16-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-314</td><td colspan="3">-457</td><td colspan="3">-382</td><td colspan="2">38</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-457</td><td>-373</td><td>-334</td><td>-314</td><td>-340</td><td>-367</td><td>-420</td><td>-412</td><td>-376</td><td>-403</td><td>-438</td></tr>
<tr><td>y2</td><td>-362</td><td>-368</td><td>-327</td><td>-334</td><td>-368</td><td>-391</td><td>-418</td><td>-406</td><td>-409</td><td>-388</td><td>-397</td></tr>
</table>

Table 165 S5-VF-01-23/06-corrosion potential analysis

<table>
<tr><td colspan="2">Sample ID</td><td colspan="10">S5-VF-01</td></tr>
<tr><td colspan="2">Description</td><td colspan="10">Control sample, no treatments</td></tr>
<tr><td colspan="2">Date</td><td colspan="10">23-giu</td></tr>
<tr><td colspan="2" rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-339</td><td colspan="3">-477</td><td colspan="3">-401</td><td colspan="2">34</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-394</td><td>-381</td><td>-339</td><td>-350</td><td>-370</td><td>-406</td><td>-404</td><td>-384</td><td>-374</td><td>-459</td><td>-477</td></tr>
<tr><td>y2</td><td>-394</td><td>-382</td><td>-364</td><td>-390</td><td>-407</td><td>-453</td><td>-430</td><td>-425</td><td>-409</td><td>-417</td><td>-406</td></tr>
</table>

Table 166 S5-VF-01-30/06-corrosion potential analysis

<table>
<tr><td>Sample ID</td><td colspan="10">S5-VF-01</td></tr>
<tr><td>Description</td><td colspan="10">Control sample, no treatments</td></tr>
<tr><td>Date</td><td colspan="10">30-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="2">St. dev</td></tr>
<tr><td colspan="2">-358</td><td colspan="3">-475</td><td colspan="3">-403</td><td colspan="2">27</td></tr>
<tr><td colspan="11"></td></tr>
</table>

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-393	-373	-358	-366	-395	-410	-405	-398	-387	-440	-475
y2	-384	-385	-384	-386	-395	-436	-417	-413	-418	-431	-422

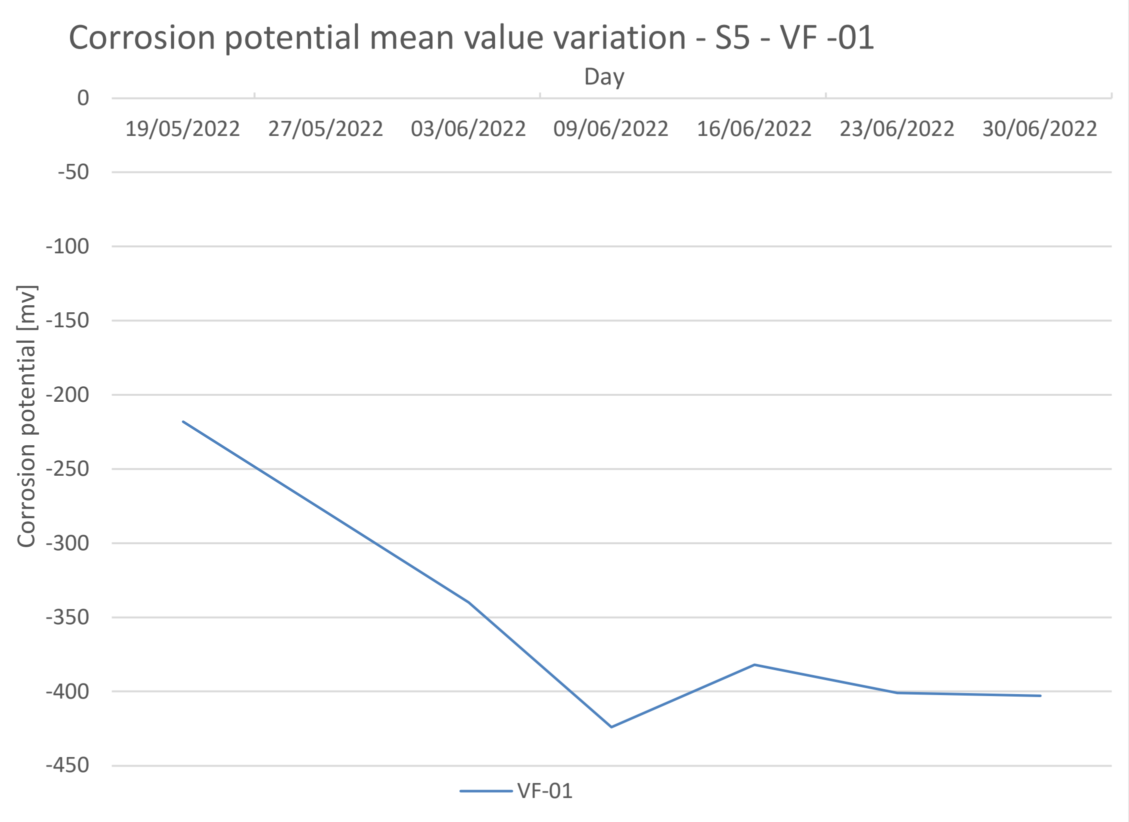


Figure 95 S5-VF-01--corrosion potential mean value variation

Table 167 S5-VF-02-18/05-corrosion potential analysis

Sample ID	S5-VF-02			
Description	2 glass-based compounds brush applications			
Date	18-mag			
Measurements [mv]	Min	Max	Mean	St. dev
	-28	-280	-90	69

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-210	-170	-110	-78	-66	-55	-54	-58	-57	-55	-60
y2	-280	-203	-142	-100	-53	-45	-42	-40	-34	-30	-28

Table 168 S5-VF-02-03/06-corrosion potential analysis

Sample ID	S5-VF-02			
Description	2 glass-based compounds brush applications			
Date	03-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-286	-437	-348	50

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-437	-418	-372	-317	-296	-292	-292	-286	-288	-301	-437
y2	-413	-385	-375	-337	-336	-349	-328	-309	-327	-353	-401

Table 169 S5-VF-02-09/06-corrosion potential analysis

<table>
<tr><td>Sample ID</td><td colspan="11">S5-VF-02</td></tr>
<tr><td>Description</td><td colspan="11">2 glass-based compounds brush applications</td></tr>
<tr><td>Date</td><td colspan="11">09-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="3">St. dev</td></tr>
<tr><td colspan="2">-308</td><td colspan="3">-479</td><td colspan="3">-393</td><td colspan="3">54</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-437</td><td>-418</td><td>-372</td><td>-350</td><td>-330</td><td>-312</td><td>-320</td><td>-308</td><td>-318</td><td>-418</td><td>-479</td></tr>
<tr><td>y2</td><td>-432</td><td>-396</td><td>-395</td><td>-410</td><td>-428</td><td>-427</td><td>-467</td><td>-345</td><td>-381</td><td>-420</td><td>-477</td></tr>
</table>

Table 170 S5-VF-02-16/06-corrosion potential analysis

<table>
<tr><td>Sample ID</td><td colspan="11">S5-VF-02</td></tr>
<tr><td>Description</td><td colspan="11">2 glass-based compounds brush applications</td></tr>
<tr><td>Date</td><td colspan="11">16-giu</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td colspan="2">Min</td><td colspan="3">Max</td><td colspan="3">Mean</td><td colspan="3">St. dev</td></tr>
<tr><td colspan="2">-336</td><td colspan="3">-499</td><td colspan="3">-408</td><td colspan="3">50</td></tr>
<tr><td colspan="12"></td></tr>
<tr><td>[mv]</td><td>x1</td><td>x2</td><td>x3</td><td>x4</td><td>x5</td><td>x6</td><td>x7</td><td>x8</td><td>x9</td><td>x10</td><td>x11</td></tr>
<tr><td>y1</td><td>-456</td><td>-434</td><td>-387</td><td>-392</td><td>-379</td><td>-357</td><td>-354</td><td>-341</td><td>-339</td><td>-450</td><td>-458</td></tr>
<tr><td>y2</td><td>-409</td><td>-409</td><td>-427</td><td>-486</td><td>-426</td><td>-401</td><td>-336</td><td>-353</td><td>-397</td><td>-499</td><td>-483</td></tr>
</table>

Table 171 S5-VF-02-23/06-corrosion potential analysis

Sample ID	S5-VF-02			
Description	2 glass-based compounds brush applications			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-311	-470	-397	53

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-438	-404	-366	-341	-317	-311	-312	-345	-360	-445	-452
y2	-399	-410	-461	-455	-424	-380	-350	-405	-434	-464	-470

Table 172 S5-VF-02-30/06-corrosion potential analysis

Sample ID	S5-VF-02			
Description	2 glass-based compounds brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-351	-494	-432	43

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-453	-442	-487	-435	-351	-356	-385	-418	-440	-461	-459
y2	-422	-461	-478	-465	-426	-393	-369	-380	-447	-485	-494

Table 173 S5-VF-02--corrosion potential mean value variation

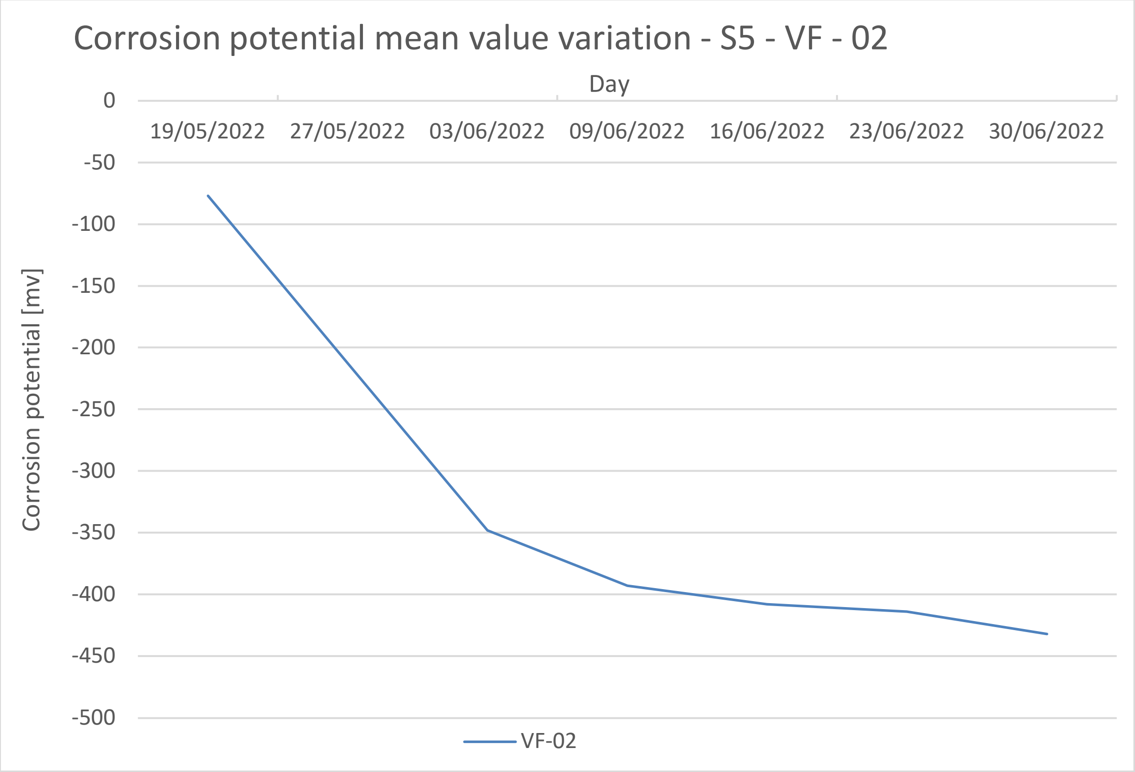


Table 174 S5-VF-03-18/05-corrosion potential analysis

<table>
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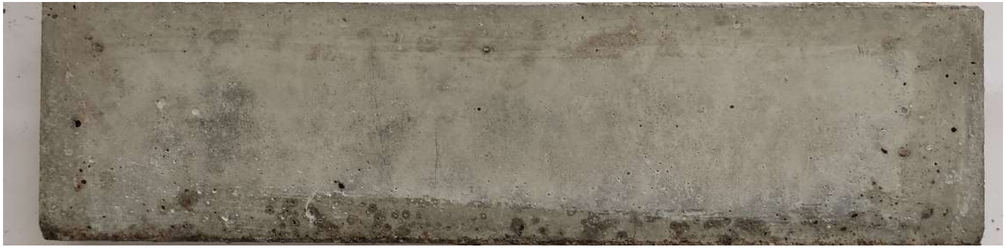
<tr><td>Description</td><td colspan="4">2 glass-based compounds brush applications</td></tr>
<tr><td>Date</td><td colspan="4">18-mag</td></tr>
<tr><td rowspan="2">Measurements [mv]</td><td>Min</td><td>Max</td><td>Mean</td><td>St. dev</td></tr>
<tr><td>-33</td><td>-85</td><td>-51</td><td>13</td></tr>
<tr><td colspan="5"></td></tr>
</table>

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-59	-62	-50	-59	-55	-56	-40	-35	-33	-35	-33
y2	-85	-68	-59	-58	-54	-57	-54	-47	-43	-43	-44

Table 175 S5-VF-03-03/06-corrosion potential analysis

Sample ID	S5-VF-03										
Description	2 glass-based compounds brush applications										
Date	03-giu										
Measurements [mv]	Min		Max			Mean			St. dev		
	-262		-392			-307			34		
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-392	-313	-286	-286	-306	-302	-303	-308	-323	-335	-373
y2	-328	-291	-290	-267	-279	-272	-262	-268	-296	-324	-354

Table 176 S5-VF-03-09/06-corrosion potential analysis

Sample ID	S5-VF-03										
Description	2 glass-based compounds brush applications										
Date	09-giu										
Measurements [mv]	Min		Max			Mean			St. dev		
	-283		-396			-322			30		
											
[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-396	-345	-306	-293	-304	-319	-318	-316	-319	-346	-378
y2	-327	-296	-299	-283	-320	-308	-291	-294	-320	-331	-376

Table 177 S5-VF-03-16/06-corrosion potential analysis

Sample ID	S5-VF-03			
Description	2 glass-based compounds brush applications			
Date	16-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-285	-411	-320	32

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-411	-333	-301	-286	-306	-311	-291	-306	-330	-358	-382
y2	-327	-303	-316	-297	-312	-290	-285	-295	-315	-327	-360

Table 178 S5-VF-03-23/06-corrosion potential analysis

Sample ID	S5-VF-03			
Description	2 glass-based compounds brush applications			
Date	23-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-312	-404	-346	25

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-373	-363	-343	-335	-335	-347	-351	-366	-381	-383	-404
y2	-331	-312	-323	-318	-336	-321	-317	-327	-336	-343	-375

Table 179 S5-VF-03-30/06-corrosion potential analysis

Sample ID	S5-VF-03			
Description	2 glass-based compounds brush applications			
Date	30-giu			
Measurements [mv]	Min	Max	Mean	St. dev
	-303	-405	-331	26

[mv]	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11
y1	-405	-356	-333	-324	-317	-316	-308	-316	-335	-353	-377
y2	-347	-328	-327	-311	-306	-303	-304	-314	-318	-324	-361

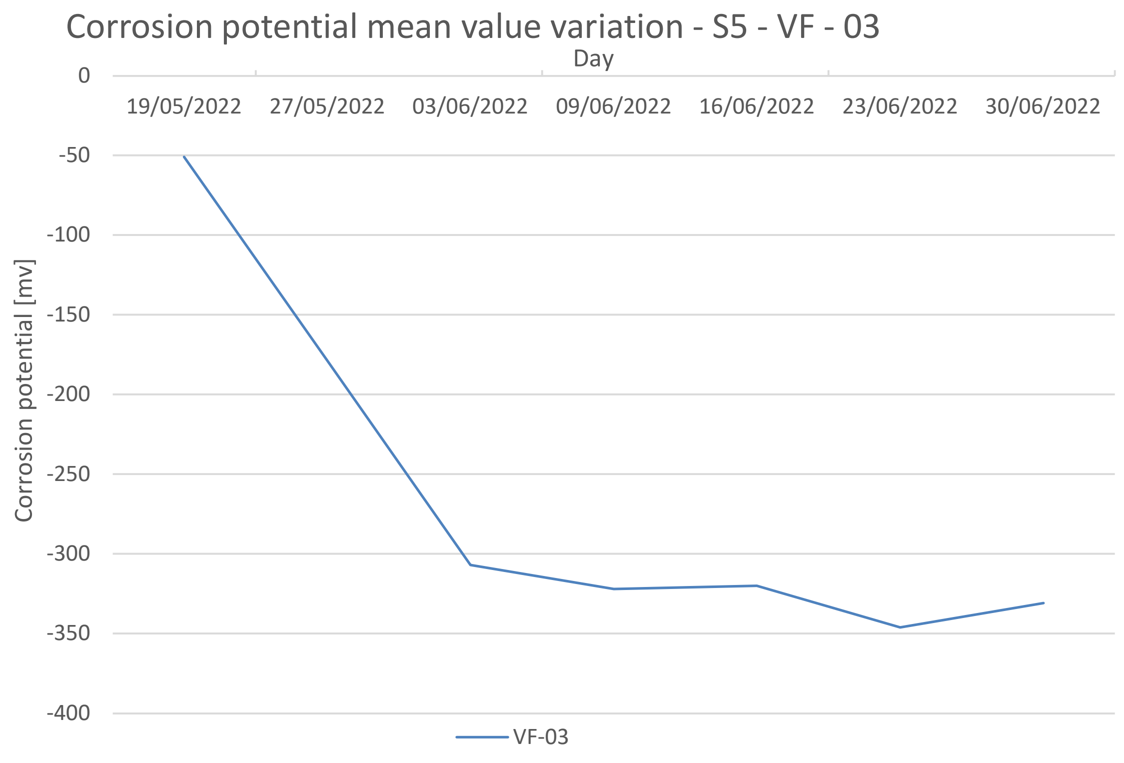


Figure 96 S5-VF-03-corrosion potential mean value variation

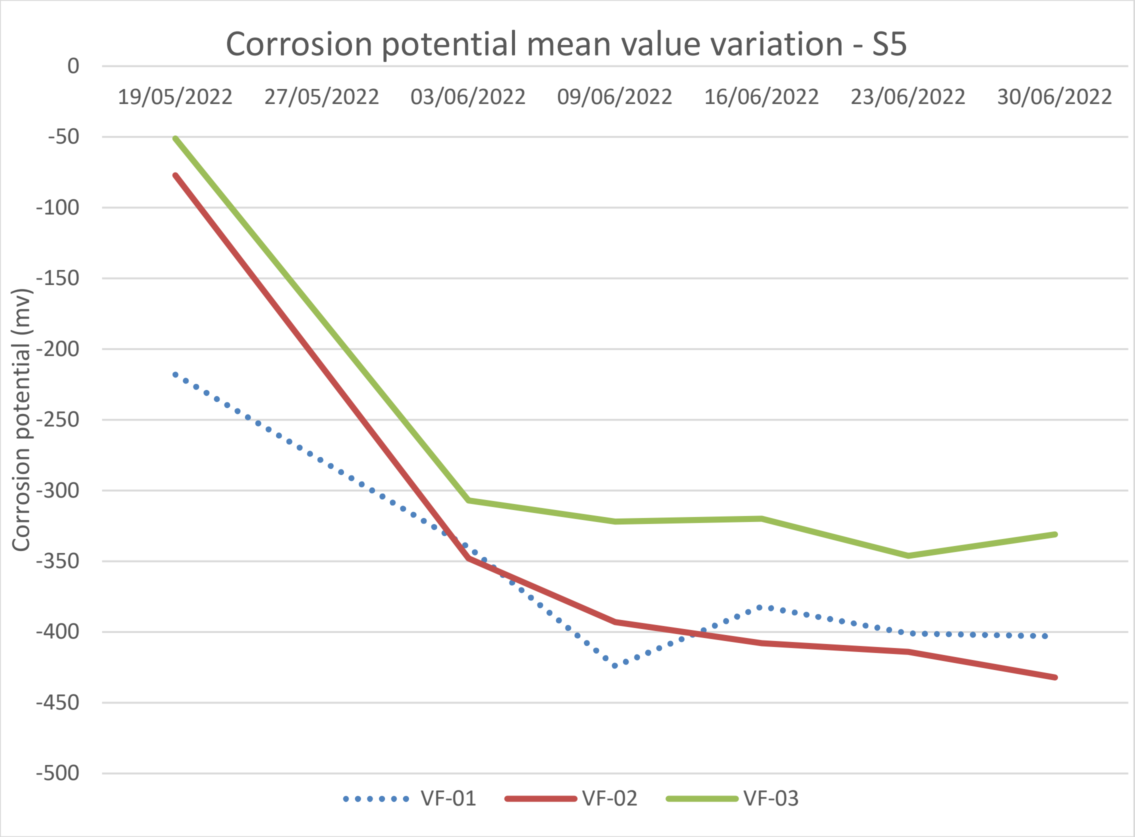


Figure 97 S5-VF-corrosion potential mean value variation

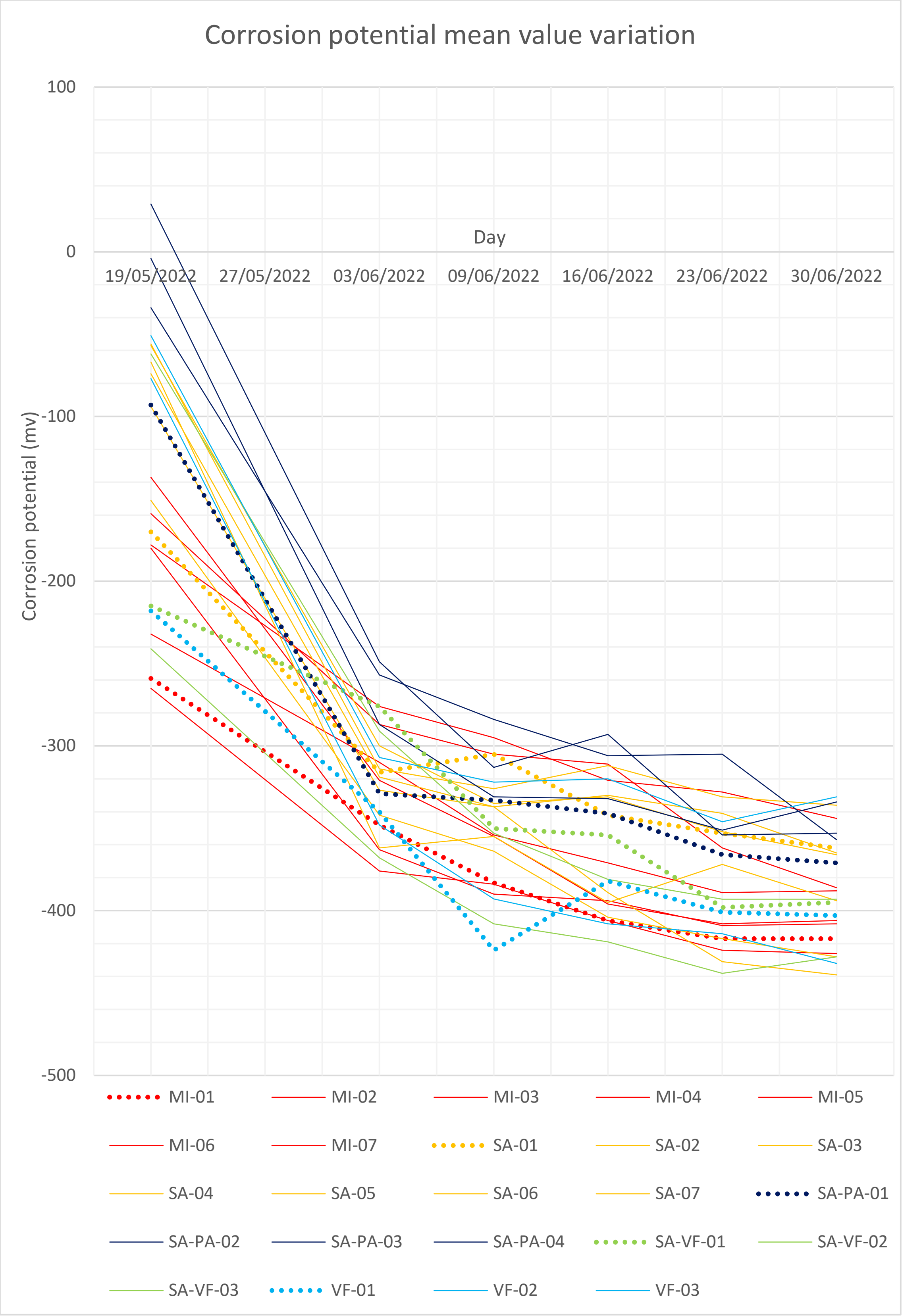


Figure 98 S1, S2, S3, S4 and S5 corrosion potential mean value variation

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11.1 FIGURE INDEX

11.2 TABLE INDEX