SEISMIC RETROFIT OF AN INDUSTRIAL STRUCTURE WITH PBO-FRCM

Giovanni Mantegazza
Dr., Technical Director for Ruredil SpA, San Donato Milanese, Milano, Italy
giovanni.mantegazza@ruredil.it

Alessio Rossato
Eng., FM Ingegneria SpA, Mirano, Venezia, Italy
Alessio.rossato@gmail.com

ABSTRACT: *"Music City Mall" is a building with an area of 11,693 square meters providing space for music production as well as a meeting place with dance room, bar, fitness centre and a 1500 seats theatre. The building is the first example in Marghera, Italy, of refurbishment of an abandoned factory obtained by wrapping the existing concrete skeleton with a skin of thin glass and covering it with a bright canopy resembling a pumping core of music and colours. The existing structure is made of large concrete arches that do not have necessary resistance against seismic actions.*
The seismic retrofit consisted of strengthening and increasing the ductility of concrete sections with PBO-FRCM (Fabric Reinforced Cementitious Matrix). FRCM differs from FRP reinforcement systems in that the epoxy resin is replaced with a special stabilized cement matrix. Experimental evidence has shown that PBO-FRCM system has the same mechanical performance of traditional unidirectional carbon FRP. Furthermore, experimental data and those obtained from their elaboration show that FRCM reinforcement has some advantages with respect to the traditional FRP. In particular, FRCM is compatible with the substrate to be reinforced (surface porosity of substrate where system is applied remains unvaried), and durability, especially with respect to temperature and relative humidity, is guaranteed.

1. Introduction

Building known as "City Music Hall" is located in Porto Marghera – Venice.
Porto Marghera is a well-known city famous for its industrial activity from 1917 until '60 years.

Figure 1 - Plan of the city of Venice and the surroundings

When chemical and petroleum industry started to fall, Porto Marghera started to be depopulated leaving a lot of building empty.
Today the industrial site is gradually renovated as scientific focal point looking for green energy and new technologies.So a lot of old structures need now a refurbishment and a reconversion from old industry to offices compound.

The first example for the city is the “Music City Mall”.It was built in the 1940 and it was used as a coal depot until the ‘70s.

Figure 2 - Porto Marghera - The site

2. The building

The original building, is formed by three bodies: "*corpo A", "corpo B"* and *"corpo C".*

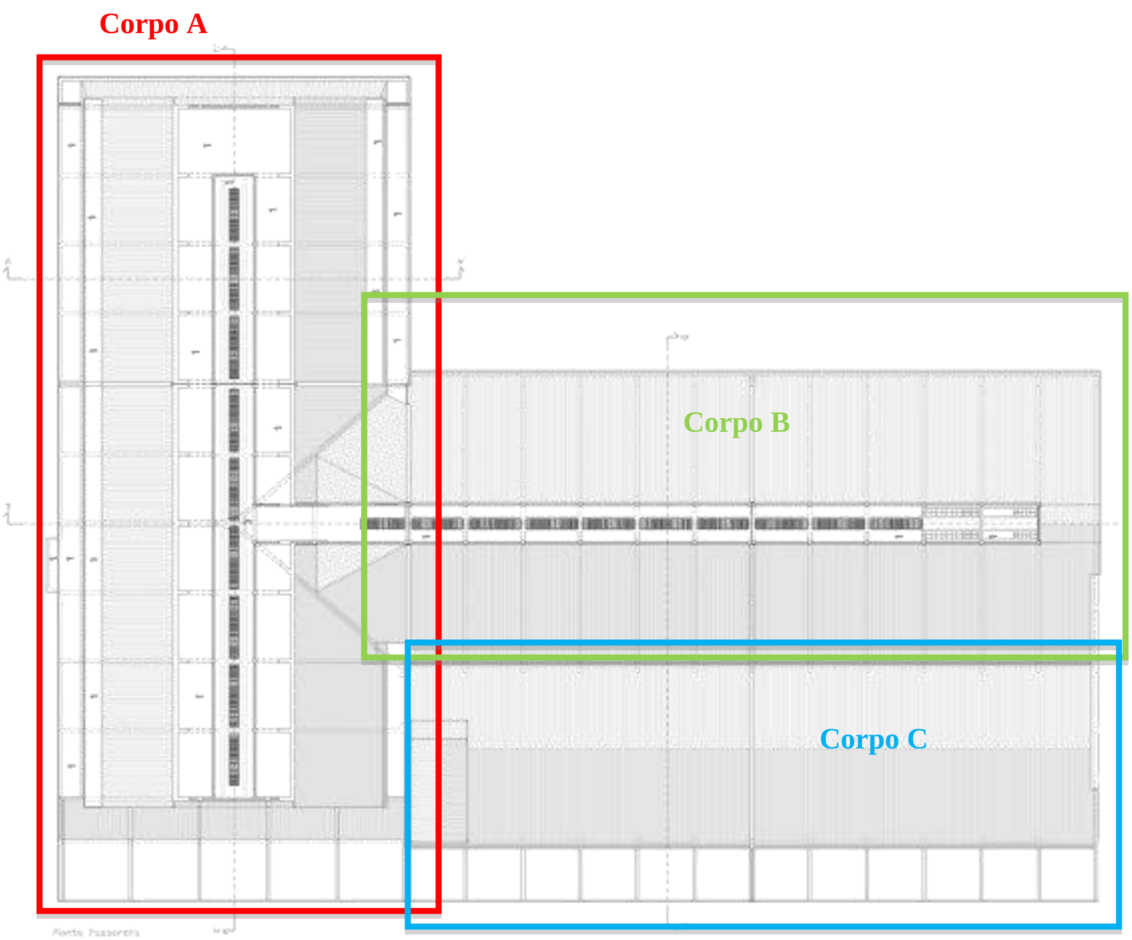


Figure 3 - Plan of the building

2.1. Corpo A

Corpo A is formed by 12 concrete archs with 6 m spacing; each arch is 16.3 m high, span is 30 m.
Main beam has tapered section from 300x750 mm to 300x1400 mm according to the bending moments acting on the structure.
The roof is made by "solaio bausta" a typical lightweight concrete slab with masonry alleggerimenti.
This slab is used also as bracing for wind and seismic actions.
There are two thermal joints realized doubling the arches.

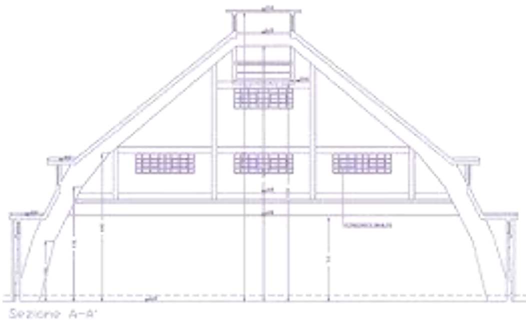


Figure 4 - Main section of Corpo A

2.2. Corpo B and Corpo C

Like Corpo A, Corpo B is formed by 12 concrete archs. They are 11.4m tall and the span is 26m.

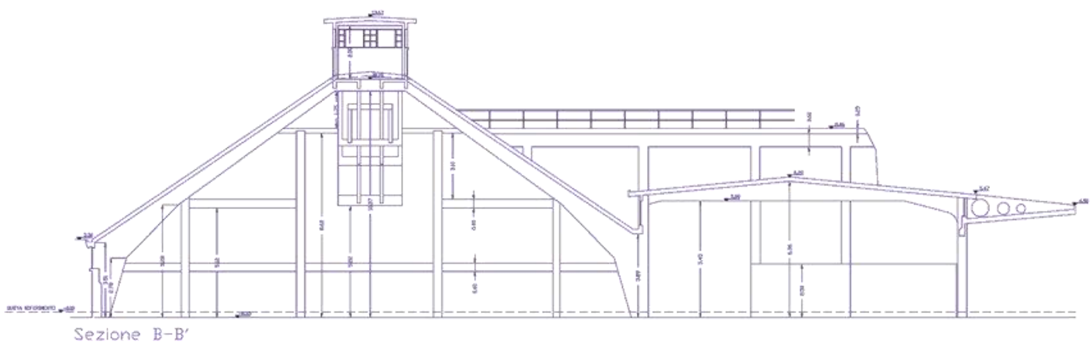


Figure 5 - Main section of Corpo B and Corpo C

Corpo C is a simple concrete frame with a 5 m cantilever. The slabs are the same as Corpo A.

2.3. Condition

The building, unused for years and exposed to the brackish air of the Venice Lagoon was in a bad state . Expulsion of the covering, rusty reinforcements, widespread disruptions of the concrete are the vastly present all around the building.

Figure 6 - Building before retrofitting

Also there was impacts during the normal activities of coal storing.

Figure 7 - Corpo C - Original reinforcements

For the actual standards and codes there was also poor reinforcements i.e. stirrups in the node between columns and beams.

3. The project

The project foresees the creation of space for music production as well as a meeting place with dance room, bar, fitness centre and a 1500 seats theatre.

To create the necessary space two lofts are created on Corpo A and one on Corpo B.
They are completely independent from existing arches: they are steel frames with flat concrete slabs.
The columns of the frame have the same inclinations as the existing arches. Concrete cores with stairs offer stability and resistance against seismic and wind actions.
On Corpo A there is also a third slab suspended by concrete arches. Here there are all the MEP dotation of the building itself.
The whole old roof slabs are demolished: the concept is to create a glass theca exposing the old concrete skeleton like a dinosaur in a museum. Because the slab gave stability to horizontal forces, new steel bracing are inserted.

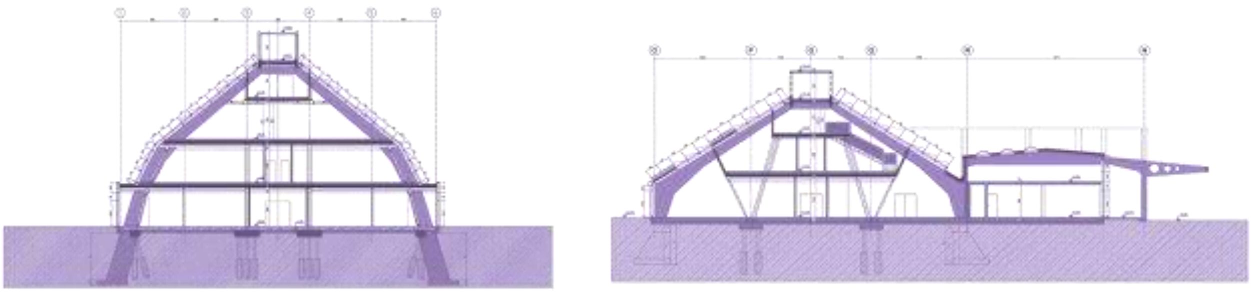


Figure 8 - Project section

The connection between the beams sustaining the slabs and the columns are made by pins; also the node on the ground level is a pin.
Third mezzanine on Corpo A is sustained by Dywidag bars passing through existing arches and connected by a backplate.

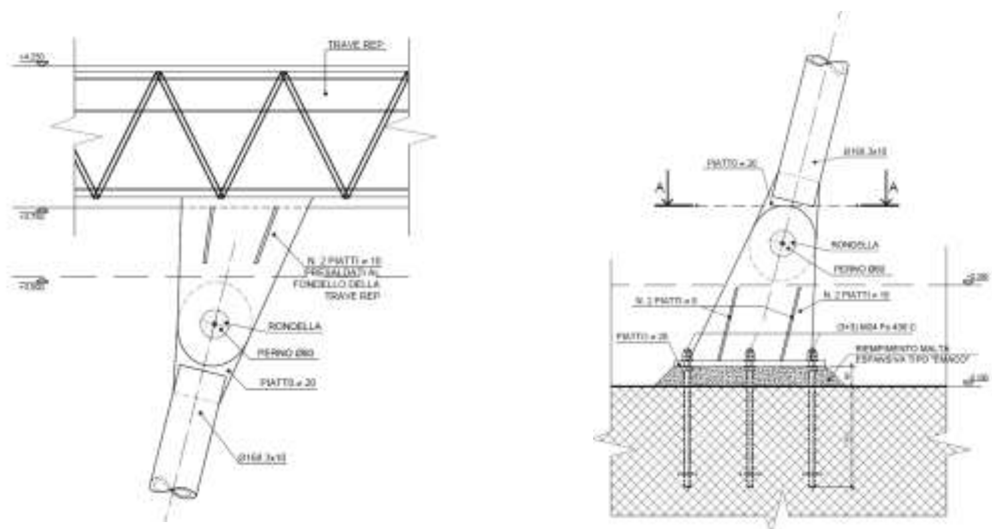


Figure 9 - Nodes of the new Corpo A columns

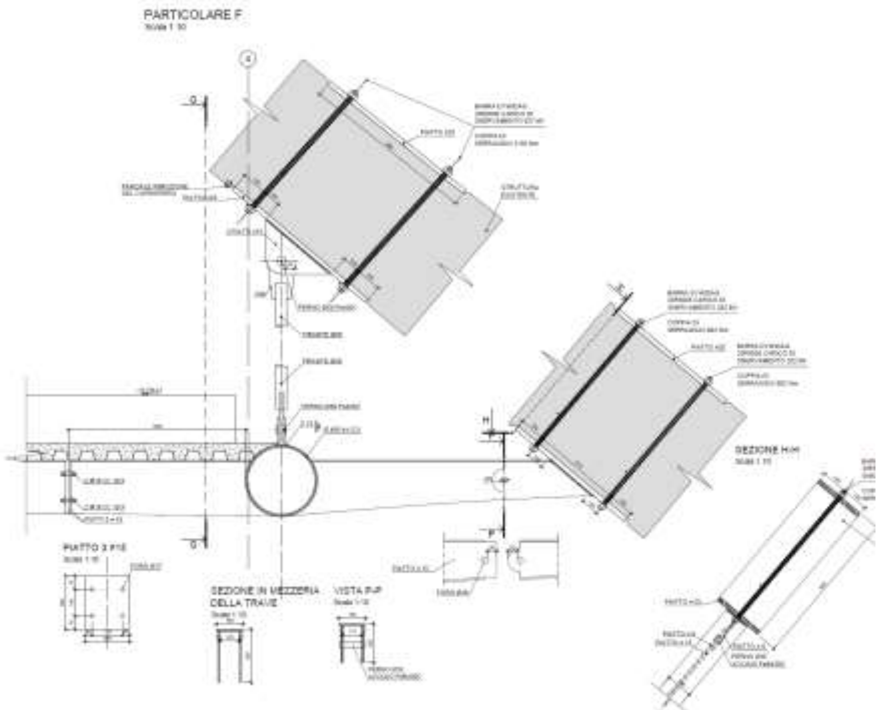


Figure 10 - Node of new mezzanine of Corpo A

New bracing adsorbing wind and seismic actions are connected to existing arches in the same way; struts are IPE profiles sustaining glass façade too.

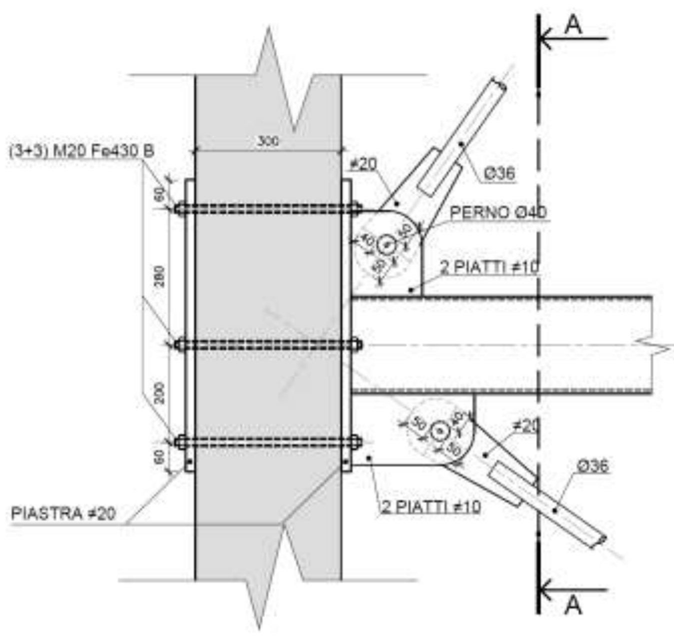


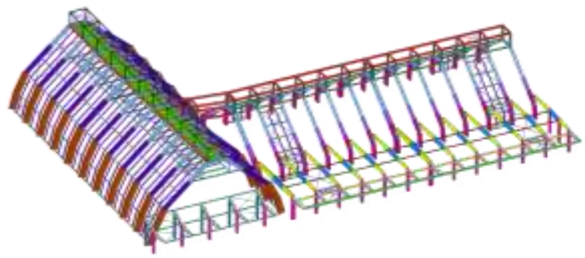
Figure 11 - Node between existing structure and new bracings

Foundations of the new slabs are plinth sustained by piles. These poles are realized with "Tubfix" technology. Since there is pollution on the water at ground level, and there is a flap of clean water under the first layer of soil, was required to use that piles ensuring to avoid connection between the two flaps.

The existing structural joints was only a thermal ones, also they were dirty and very difficult to clean so we decided to connect the whole bodies.

4. Seismic retrofitting

The actual norms in Italy prescribes that an old building where there a big change in the static scheme or in the loading or both, is necessary to perform a seismic retrofitting.
A structural model is implemented recreating the existing building with its geometry and the correct material properties.



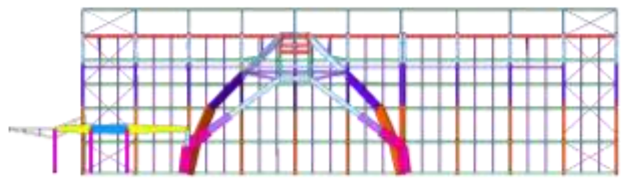
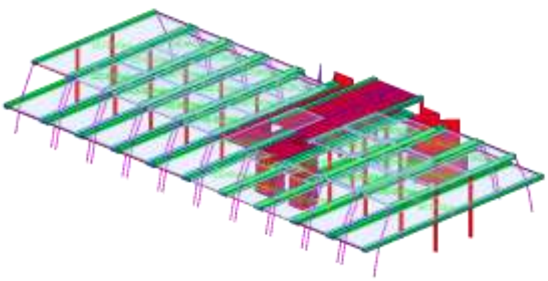


Figure 12 - Structural model of existing building

Two separated models are implemented for the new slabs and cores:



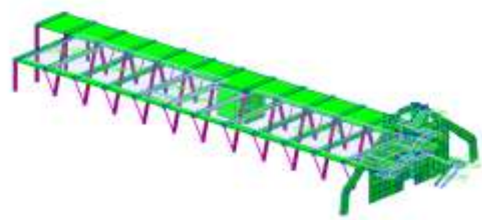


Figure 13 – Models of new slabs

The checks performed demonstrated that the existing building didn't have the necessary resistance required by the loadings:

For instance in this section of Corpo A there is a safety coefficient of 0.62 for bending meaning that the bending moment is 1.4 times bigger than the resistant one.

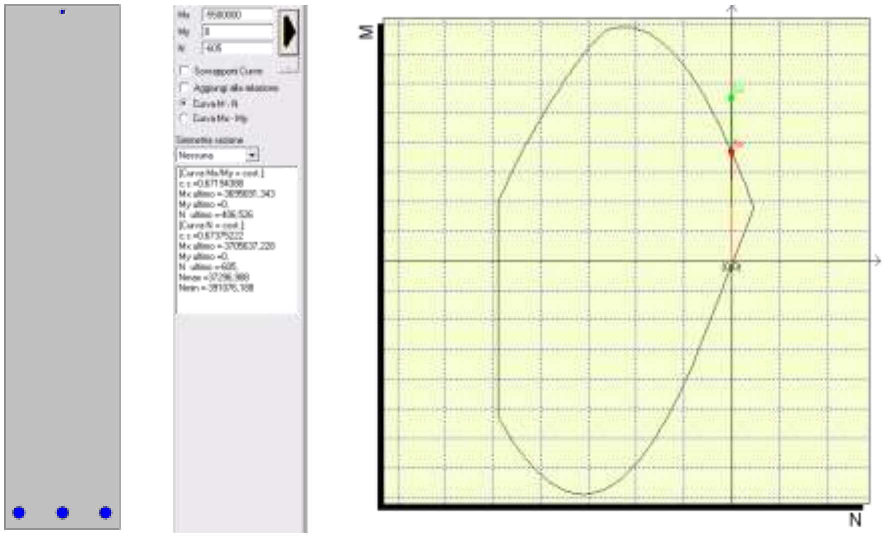


Figure 14 - Bending check of existing arch

Also for shear there are sections with no satisfied check.
So it was needed a structural reinforcement of concrete arches; we report a map of the typical elements showing where there is the failure:

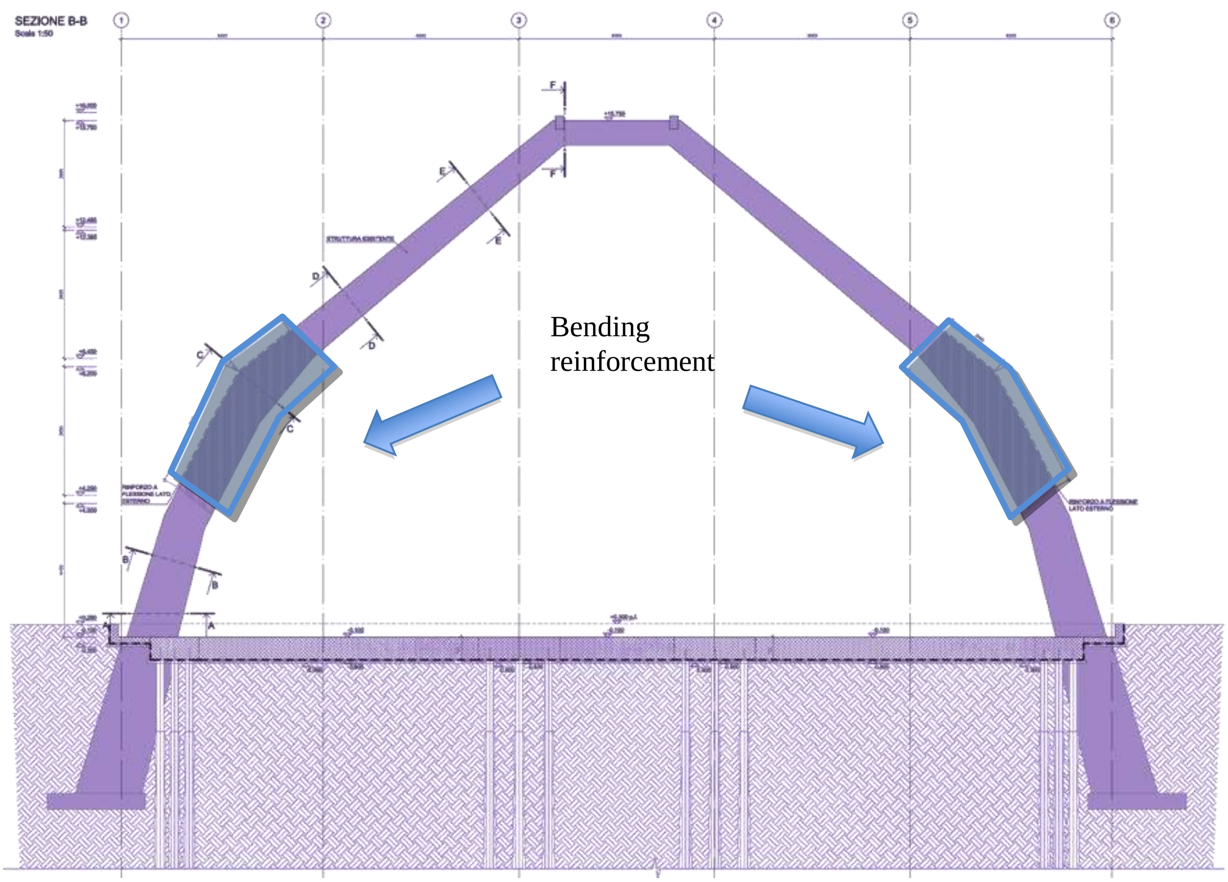


Figure 15 - Corpo A - Section in need of reinforcement

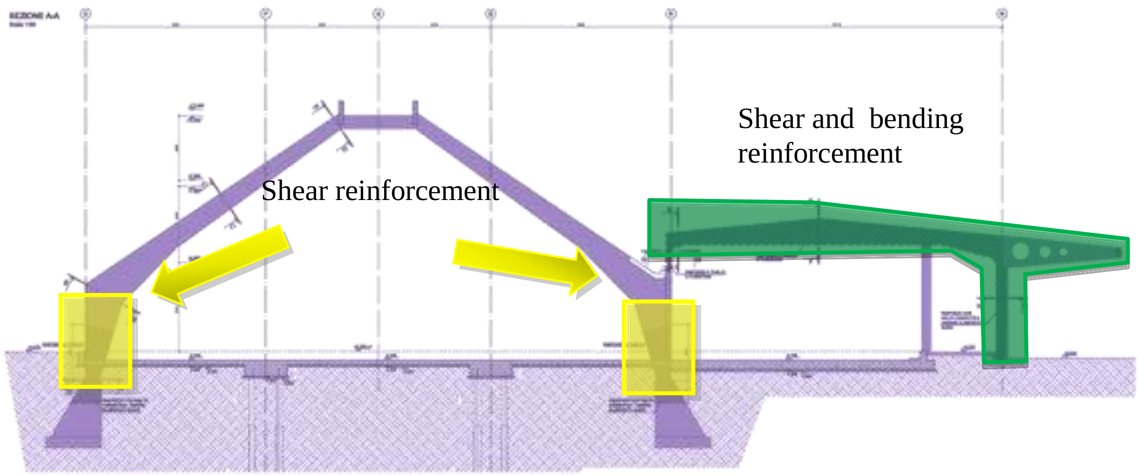
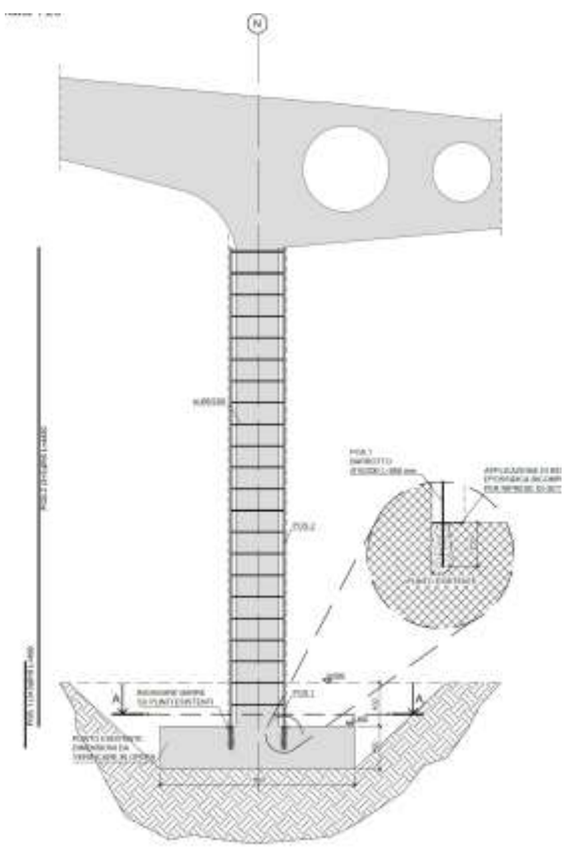


Figure 16 - Corpo B and C - Section in need of reinforcement

Reinforcement of foundation of corpo B and columns of corpo C are made with new bars incorporated in a new concrete section. This new covering is made by special grout for structural repairs.



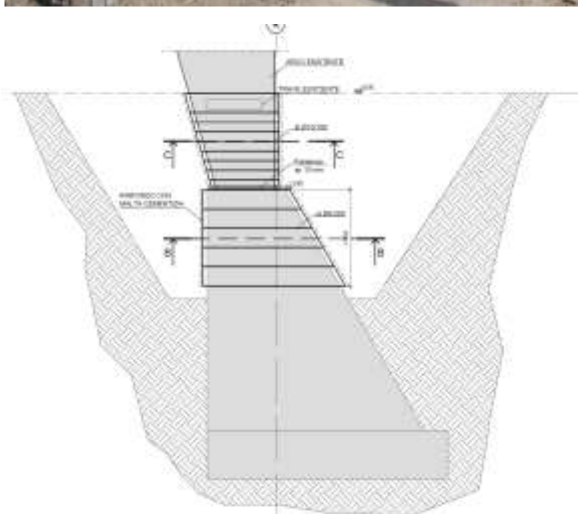


Figure 17 - Reinforcement of Corpo C columns

The other reinforcements was made with FRCM, Fiber reinforcement cemetitiuos matrix, better described in the next chapter.
With this solution we achieved:

- Fireproof reinforcement;
- Little increase of the resistant sections;
- No evidence of reinforcement from the outside ;
- Ease and speed of construction.


Figure 18 – Shear reinforcement of Corpo B base


Figure 19 – Shear reinforcement of Corpo B base


Figure 20 - Reinforcement of Corpo C columns

5. Materials and technologies

In this job a new structural reinforcement FRCM -Fiber Reinforced Cementitious Matrix-(1-11) has been used instead of traditional FRP –Fiber Reinforced Polymer.

FRP is a structural reinforcement system used for retrofitting concrete and masonry(12). It consists of a synthetic or mineral fiber with excellent mechanical performance and organic matrix, normally epoxy resin, used as binding agent. However the main drawback of this material is the low durability of epoxy resin.Actually the epoxy resini is characterized by the critical temperature known as “glass transition temperature (t_g)” after hardening. Under low temperatures(30-60°C) and hight umidity (more than 60%) the resin changes its physical state from rigid to amorphousThis chemical process reduces the adesive properties versus fiber concrete or mosonry substrate,strongly reducing the mechanical properties as a structural reinforce. (13,14a, 14b).

Besides FRP is classified according to UNI EN 13501 Part 1 -Fire classification of construction products and building elements. Part 1 - Classification using test data from reaction to fire tests as class E (flammable material).

FRCM are classified as A (no flammable).

So FRP has to protect from fire after application with special calcium-silicate panel ,7 cm thick.

FRCM are protect as the substrate(concrete and masonry) using intumescent materials.

For these durabilty and reliability reasons the PBO-FRCM system(Ruredil X Mesh Gold) has been chosen.

5.1. Material test method: tensile and lap-tensile strength

The Reference Standard is AC434 -February 2013 (15). Tensile Testing of Fiber- Reinforced Cementitious Matrix (FRCM) Composite Specimens.The test objective is to determine the tensile strength, elongation, and modulus of elasticity of the FRCM strengthening composite system using coupons under ambient conditions .Besides lap-tensile strength was mesured in order to determine the relative tensile strength at the fiber mesh overlap area of the FRCM strengthening composite system using coupons, under ambient conditions.

5.1.1. Spenciment preparation

Specimen Size: Nominal single ply FRCM rectangular coupon size 410 x 51 x 10 mm length x width x thickness, respectively.

Specimen Layout: Coupons were cut from larger FRCM material panels with a nominal size of 410 x 560 mm length x width, respectively. Fiber alignment was set in the 0° direction along the length of the coupon for PBO-FRCM (Ruredil X Mesh Gold).Lap Tensile Strength coupon specimens were made following the same methodology, with the difference of a nominal mesh overlap length of 120 mm. Uniaxial tensile load was applied to all specimens. Axial deformation was measured using a clip on extensometer. Coupons were gripped with a clevis type, chosen to maximize degrees of freedom and reduce any bending.

5.1.2. Result summary

The stress-strain behavior of PBO-FRCM control coupon specimens is bi-linear as expected. The initial branch of the curve corresponds to the un-cracked specimen, followed by a second branch with a reduced slope, corresponding to the crack specimen. The primary failure mode of the PBO-FRCM coupon specimens was slippage of the fibers after multiple cracking throughout the length of the specimen, perpendicular to the direction of the load, secondary de-bonding failure mode located at the tab ends was observed in some cases.(see fig. 12 and13)

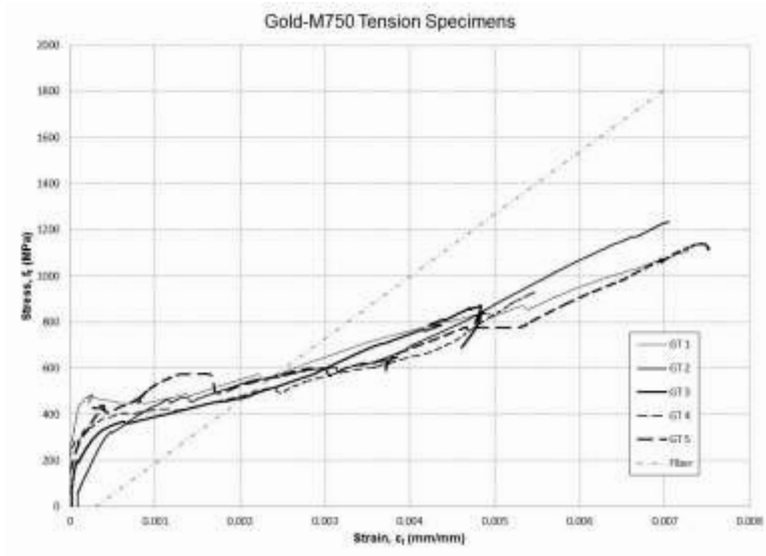


Figure 21 - Ruredil X MESH GOLD with Ruredil X MORTAR 750

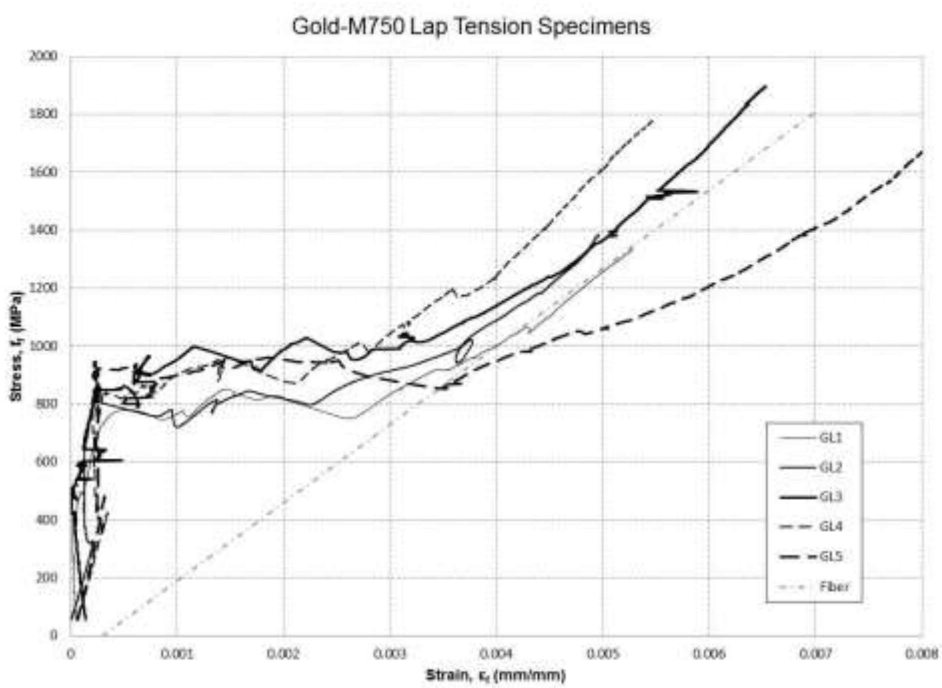


Figure 22 - Ruredil X MESH GOLD with Ruredil X MORTAR 750:

5.2. Environmental exposure: material test

The test objective is to determine the environmental resistance of the PBO-FRCM composite system under evaluation by testing the residual tensile and lap-tensile strength, as per Sections 4.2.3 and 4.7 of AC434 respectively, verifying the following characteristics are retained post-conditioning:

- Freezing and Thawing: Verify coupons specimens retain at least 85% of the tensile strength properties.
- Aging: Verify the coupons retain at least 85% of the tensile properties after 1000 hours of exposure, and at least 80% of the tensile properties after 3000 hours of exposure.

4.2.1 Conditioning Parameters

-Freeze/Thaw Environment: Specimens were conditioned for one week in a humidity chamber at 100% relative humidity at a temperature of 37.7°C . Subsequently, specimens were subjected to twenty freeze-thaw cycles. Each cycle consisted of a minimum of four hours at -18°C followed by 12 hours in the humidity chamber (100% RH and 37.7°) The specimens were then moved to the humidity chamber and left there for 12 hours. This cycle was repeated 20 times.

-Aging: Specimens were exposed independently to three types of environmental aging conditions as referred to in Table 2 of AC434. The first, a humidity chamber (water) at 100% RH and 37.7°C . The second, specimens were fully submerged in saltwater at laboratory conditions. Third, specimens were submerged in an alkali environment, a solution consisting of calcium hydroxide ($Ca(OH)_2$), sodium hydroxide (NaOH), and potassium hydroxide (KOH) mixed to create an environment at a pH > 9.5.

4.2.2 Test results

Results Summary: All tensile and lap-tensile strength coupon tests passed the conditions of acceptance as per the requirements regarding environmental exposure to Freezing and Thawing, and Aging, Sections 4.4.2 and 4.5.2 (Table 2), respectively of AC434. The AC434 acceptance requirements states that coupons shall retained at least 85% of the tensile strength for freeze-thaw conditions; 85% of the tensile properties for aging environments after 1000 hours of exposure and 80% after 3000 hours of exposure. Tests show (fig 16) that the requirements were not only passed, but exceeded in most tests the control (ambient) strength properties. The primary failure mode of the PBO-FRCM coupon specimens was slippage of the fibers after multiple cracking throughout the length of the specimen, perpendicular to the direction of the load, similar to the control specimens .

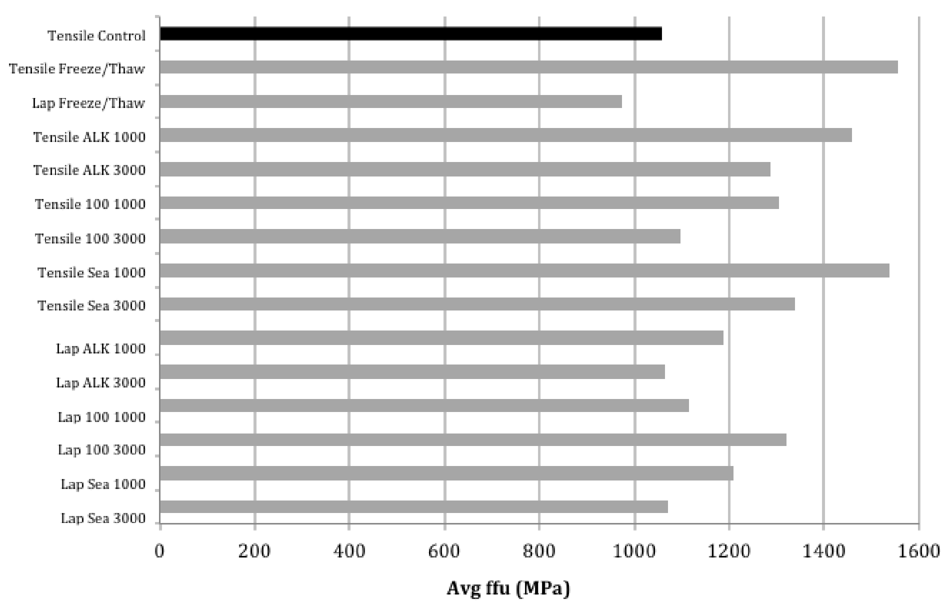


Figure 23 - Environmental Exposure summary fo GOLD-M750 composite system

6. Finished

Demolitions of the structure started in November 2008, the building was opened in December 2009.


Figure 24 - Corpo B – facades and new columns


Figure 25 - Corpo B - facades


Figure 26 - Corpo B - facades

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