Rehabilitation of concrete.

IS IT:

- [ ] *Product*
- [x] *Technology*
- [ ] *Equipment*

APPLICABLE FOR:

- [x] *Restoration*
- [x] *Rehabilitation*
- [ ] *New Construction*

APPLICABLE ON:

- [ ] *1. Foundations and underground structures*
- [x] *2. Vertical structures*
- [x] *3. Horizontal structures and vertical connections*
- [ ] *4. Roof and terraces*
- [x] *5. Façade and building envelope*
- [ ] *6. Finishes and completion elements*
- [ ] *7. Integrated services*
- [x] *8. General strategies for building recovery*

Related companies: *No companies; university research; structural study.*

DESCRIPTION

The reinforced concrete deterioration rises from the alteration of the initial performance (consistency, permeability and resistance to stress) as a result of physical, chemical and mechanical factors to which the material is exposed.

It is a progressive phenomenon, hardly attributable to a single cause since often multiple processes can occur simultaneously and become interdependent.

Excessive degradation of the concrete in a structural element, for example, can lead to a decrease in the protection of the reinforcing bars determining corrosive processes. The corrosion that can be triggered, in turn, determines an increase in the volume of the bars and the flaking that generates the expulsion of the concrete covering the reinforcement towards the outside and which acts as an iron cover.

The essential restoration interventions in the damaged parts of concrete have the aim of restoring the shapes and avoiding the progression of oxidation which could seriously compromise the durability and functionality of the elements, often structural.

Briefly, the main objectives of the restoration of concrete are:

- eliminate cracks and superficial detachments;
- prevent the penetration of water, salts, oxygen, carbon dioxide and sulfur dioxide;
- prevent the biological aggression of mold and algae;
- prevent corrosion of the reinforcement;
- restore the dimensions of the load-resistant structural sections.

WHY TO USE

The causes of concrete deterioration are of different entities and may depend on various factors, including interdependent ones.

TECHNOLOGICAL-CONSTRUCTION FACTORS:

- Failure to comply with the rules in the composition of the mixture and in the casting method, with consequent formation of voids and cracks.
- Insufficient size of the concrete iron cover.
- Absence of measures that mitigate atmospheric aggression in an environment particularly rich in vehicle and/or industrial agglomerations such as the urban one.
- Absence of a protective coating to preserve the concrete.

CHEMICAL-ENVIRONMENTAL FACTORS:

- Aggression by carbon dioxide (carbonation) (Fig. 1): the cement generates a "passivating" environment for the reinforcement bars, i.e. an alkaline environment that generates impermeable ferric oxide.

  This oxide protects the bars from the attack of oxygen and water that penetrate through the capillary porosity of the concrete. What depassivizes this environment is carbon dioxide which, when chemically combined with cement, generates calcium carbonate and water vapor. Calcium carbonate having a much lower pH induces the loss of anti-corrosion protection and combines with acidic water, promoting iron corrosion. In the corrosion phase, the volume of the bars increases by 1: 7 and this phenomenon triggers tensile stress states that the concrete is unable to resist, causing cracking and subsequent detachment of the concrete cover.

- Aggression by sulphates (Fig. 2): frequently occurs in structures in direct contact with the ground or in contact with sulphatic waters, where calcium and sodium sulphates are most commonly found. These react with the calcium hydrate generating gypsum, which in turn reacts with the hydrated aluminates, resulting in hygroscopic salts called ettringite and thaumasite. This phenomenon involves the formation of macromolecules which, by increasing in volume, induce the onset of tensile stresses that cause cracks and detachments.

- Attack of chlorides (Fig. 3): frequently occurs in structures in contact with marine aerosols and in direct contact with the ground. Due to the effect of calcium chlorides which react to form hydrated calcium oxychloride, the binder disintegrates, leading to the formation of delaminations (cortical detachments). Both calcium and sodium chlorides cause a corrosive action on the reinforcing bars.

PHYSICAL FACTORS:

- Natural thermal variations: the freeze-thaw cycles (Fig. 4) cause the transformation of the water present in the pores of the concrete into ice, resulting in an increase in volume and, therefore, pressures that cause cracks and crumbling. Furthermore, in the thawing phase, the water acts as a vehicle for all aggressive agents and has a catalytic effect for triggering the chemical reactions described above.

- Excessive drying shrinkage: this is the volume variation that the concrete undergoes during the hardening phase due to the progressive elimination of water. It is influenced by the composition of the concrete and by the temperature and relative humidity of the environment. It can cause an excess of cracks that make the concrete very vulnerable to atmospheric agents and chemical-physical degradation factors.

MECHANICAL FACTORS:

- Impacts, erosions, abrasions, earthquakes and vibrations;
- unforeseen loads: they trigger a tension overload that can deform the structure up to complete failure.

HOW TO USE AND APPLY

The main interventions for the rehabilitation and protection of reinforced concrete structures are:

1. Repair of cavities and cracks;
2. Reconstruction and integration of the original concrete sections;
3. Integration of reinforcement with assembly of rods;
4. Applications of external bandages and plating;
5. Cladding using steel or reinforced concrete of beams or pillars.

REPAIR OF CAVITIES AND CRACKS

Before intervening, it is necessary to identify and eliminate the causes that triggered the cracking phenomenon, so that it cannot recur in the future.

Repair of passive fissures, which are not expected to develop over time, occurs depending on the size of the lesions. For "fine" types (about 1 mm), the surface is coated by skimming or elastic painting or by filling by injection. The first technique is only possible if the cracks have a limited depth.

The intervention is divided into three phases:

a) preparation of the substrate by sandblasting or washing with water under pressure of incoherent surface material;
b) preparation of the product;
c) application of cement-based products with a trowel or roller and two-component or tri-component polymer-based paints with a brush or spray.

For deeper cracks, the injection of two-component products based on epoxy resins is carried out, after aspiration of the air contained in the lesion. The injection can be done using a pressure gun or sealant gun, piston pump, pressure container.

For wide types (from 1 to 6 mm) holes are firstly drilled and small pipes are positioned for the injection of a cement grout modified with the addition of synthetic products. Before proceeding with the injections, it is useful to pressure wash the holes and cover the crack with a temporary plaster in order to prevent the leakage of injected material.

Active cracks are repaired by injection of polymers with elastomeric properties applied directly or mixed in cementitious mortars. The most common technique is gun sealing or direct casting after applying primer. These operations can only be carried out after having ascertained that the cracks are not the effect of the oxidation of the internal reinforcements.

RECONSTRUCTION AND INTEGRATION OF THE ORIGINAL SECTIONS

If there are missing parts (already expelled due to the oxidation of the steel bars), the intervention must be carried out by integrating the lack of conglomerate in the detached parts and, at the same time, protecting the reinforcing bars from corrosion, restoring the passivating function and the steel-concrete adhesion.

There are four operational phases:

1. Preparation of the substrate;
2. Cleaning of the irons;
3. Protection of the reinforcing steel bars;
4. Volume recovery;
5. Finishing.

Preparation of the substrate (Fig. 5 and 6) consists in the removal of the deteriorated concrete, up to the sound and compact parts, according to the following phases:

1. Mechanical removal of deteriorated surface parts by hammering, chiselling, picking, manual or pneumatic;

2. Deep removal of deteriorated material by one or more combinations of the following methods:

    a. sandblasting or hydro-sandblasting: consists in the projection of an abrasive inert (quartz sands of various sizes depending on the hardness of the surfaces to be removed).
    b. angle grinder: also known as flexible, it is a portable tool with multiple uses and which, in this case, is used to remove deteriorated material with greater detail even around the reinforcing rods, without causing vibrations.
    c. water pressure washing: with the aid of a pressure washer, capable of projecting water, by means of a lance with fixed and rotating nozzles (up to a pressure of 400 bar), biological patinas, friable parts, any paint crusts during the detachment, plasters, etc.

3. Removal of dust, metal waste, oils, grease and rust from metal surfaces (Fig. 7) until the surface is white metal. The oils and fatty substances are eliminated with suitable solvents, the rust is removed by the operations described in point 2.

If rust has penetrated into the steel bars, it is possible to resort to the use of the rust converter (a substance that chemically transforms the rust making it inert and blocks the oxidation process). If the rust converter is applied on concrete it can be harmful, therefore, to deal with the problem, after it is used by brushing it only on the reinforcement, it is removed by brushing.

The preliminary removal of the deteriorated concrete is completed when the tests to establish the degree of carbonation or sulfation of the concrete and the presence of chlorides give a negative result. The carbonation test of the concrete can be determined by means of a colorimetric test with phenolphthalein. (Methodology defined by the UNI 9944: 1992 standard)

Protection of the reinforcing steel bars (Fig. 8): consists of the alkalizing treatment of the metal parts, applying an anticorrosive mortar, one-component (powder to be mixed with water) or two-component (powder to be mixed with a pre-packaged emulsion and of water and synthetic polymers) in compliance with the principles defined in the EN 1504-9. This product helps protect the reinforcement from subsequent rusting cycles and constitutes a good basis for adhesion to the subsequent volumetric restoration. Two layers of mortar are spread with a brush on all the metal elements, both new and pre-existing, immediately after the cleaning operation. The second one can be applied after about 2 hours from the first layer and preferably within 24 hours, resulting in a total thickness of about 2 mm.

If there is a significant loss of resistant reinforcement due to oxidation, it is necessary to integrate the longitudinal and confinement reinforcement, with new rods welded to the reinforcements not compromised and positioning the new reinforcement in predisposed holes and grooves to be made in the interior of the concrete.

Restoration of the shape (Fig. 9): The restoration must be carried out on the dry passivating mortar and consists in the spreading, until the original shape of the concrete element is completed, of a premixed cement-based mortar. The used cementitious mortars can be single-component, two-component or three-component fiber-reinforced (composed of cement, selected aggregates, synthetic fibers and polymeric resins). The product is generally purchased dry and is mixed on site, using a drill fitted with a whisk. The mortar must have adequate characteristics to ensure adhesiveness, resistance to aggressive agents, and waterproofing. Furthermore, the mortar must be thixotropic so as to adhere to the substrate without pouring and anti-shrinkage and rheoplastic in order to have extremely regular and controlled setting and shrinkage processes. The mortar is applied with a trowel and spatula or by spraying with a plastering machine on wet substrates up to refusal and in a maximum thickness of 30 mm. The drafting can take place in a single layer in the case of the cortical area only or in several coats in the event that the volumetric consistency is significant. It is also possible to apply a non-thixotropic mortar, poured into sealing formworks made anti-shrinkage by means of additives. In this case, a quantity of inert material (coarse washed sand) can be added to give consistency to the reconstruction layer.

Finishing (Fig. 10): the surface is smoothed with a trowel with plaster mortar. When it is not possible to plaster, other protective products that do not constitute thickness can be used by brush or roller. These products are anti-carbonating, waterproof, composed of cement and synthetic polymers in dispersion.

APPLICATION OF BANDINGS AND EXTERNAL PLATING

It is an intervention aimed at integrating the reinforcement from the outside, at the static reinforcement of a structure and aimed at increasing the strength, ductility and stiffness of the element. Based on the type of element and the nature of the problem to be solved, it is possible to identify two types of intervention:

- External wrapping applications (Fig. 11)

The intervention involves the installation of unidirectional, biaxial or quadriaxial fabrics in carbon fiber (FRP) (Fig. 12) and unidirectional fabrics in high resistance steel fiber (SRP) (Fig. 13), with the use of matrices polymers based on thermosetting resins, in particular epoxy resins. Once the substrate has been prepared (see point 1. par. Reconstruction and integration of the original sections), a primer and an epoxy resin-based polymeric adhesive are applied by roller and brush or spatula. A fabric is spread by making the side with the uncovered fiber adhere to the adhesive and pressing with a roller in the direction of the fibers. Any fabric joints are made by overlapping the sheets for about 20 cm. Finally, a final coat of epoxy adhesive is applied. The fabric is chosen according to its properties (elastic modulus, deformation and tension values, fiber arrangement and thickness); in general, high and medium strength carbon, high elastic modulus carbon, steel are distinguished.

- Application of external plating (carbon fiber sheets, steel plates and plates)

The intervention, also in this case, firstly involves the preparation of the background concrete and the subsequent application of a two-component epoxy adhesive. A plate or other steel elements or carbon fiber sheets are positioned. In the first case, mechanical fixings can be made to be left in place.

The use of sheets made of carbon fibers is indicated to provide a reinforcement in the taut area and a stiffening on horizontal structural elements. Steel elements are preferable in pillars, increasing the shear strength.

The intervention ends with a protective layer that can be done by applying polymer-based paints with a roller or brush, creating plasters or cementitious coatings.

COVERING SLEEVE AND WRAPPING OF STRUCTURAL ELEMENTS

It means a coating, generally in steel or reinforced concrete, of the structural elements, that increases the size of the reacting section and integrates the reinforcement that may have been lost or weakened by corrosion.

This intervention also requires preparation of the substrate which involves the removal of the plaster (where present) and the above interventions.

In the case of reinforced concrete (Fig. 14) the intervention includes:

- The positioning of the new longitudinal bars and the connection by adhesion between the existing structural element and the new reinforcement by means of the metal connector fixed dry or with epoxy resin.
- The anchoring of the structural node of the longitudinal rods to the joint by overlapping, welding or mechanical joining to the existing reinforcement (Fig. 16).
- The positioning of the brackets and their closing by welding or mechanical joining (Fig. 15).
- The formwork of the reinforcement cage and the casting of concrete.
- Disarming after seasoning.
- Finishing works (plaster, painting, etc.)

In the case of steel jacketing (Fig. 17 and 18) (after any concrete restoration), the intervention includes:

- white metal sandblasting of pre-drilled steel profiles and the creation of holes on the structural element for the insertion of the metal anchoring (connectors).
- The positioning of the profiles and shaped steel plates (Fig. 19) and fixing them, with mechanical anchoring (Fig. 20).

The injection at low pressure, in the edges of the profiles in contact with the concrete, of superfluid epoxy resin, in order to improve the adhesion of the metal prostheses and avoid the infiltration of water, to be done for the entire development of the metallic profiles.

TECHNICAL CHARACTERISTICS

The passivating mortar must be in compliance with the CE marking and the performance requirements ruled by the standard EN 1504-07.

As an example, it must have the following minimum characteristics: pH of the mix:> 12.5; adhesion on concrete ≥ 2.0 MPa.

The thixotropic mortar must bear the CE marking in compliance with the performance requirements ruled by the standard EN 1504-03 for class R3 structural mortars. In example, the product must have the following minimum performance characteristics: pH of the dough:> 12.5; mechanical characteristics using 16% mixing water; compressive strength ≥ 25 MPa after 28 days, flexural strength> 7.0 MPa; compression modulus ≥ 15 GPa; adhesion to concrete> 1.5 MPa; fire resistance (Euroclass): A1.

With reference to the restoration of structural elements with FRP, the fibers can be in:

- CFRP (Carbon Fiber Reinforced Polymer)
    a. to high modulus of elasticity: modulus of elasticity: 390 - 760 GPa; tensile strength: 2400 - 3400 MPa;
    b. high strength: elastic modulus: 240 - 280 GPa; tensile strength: 4100 - 5100 MPa;

- GFRP (Glass Fiber Reinforced Polymer)
    a. type E: modulus of elasticity: 72 GPa; tensile strength: 3445 MPa at room temperature
    b. type S: modulus of elasticity: 87 GPa; tensile strength: 4890 MPa at room temperature [5]

- AFRP (Aramid Fiber Reinforced Polymer) with elastic modulus: 60 -180 GPa; tensile strength: 3600 -3800 MPa.

RECOMMENDATIONS AND OTHER INFORMATION

During the substrate preparation phase, it is not recommended to use demolition hammers, which could transmit strong vibrations to the structure, causing damage to healthy parts.

It is also inadvisable to use a blowtorch to eliminate rusty crusts from the irons, considering that the heated metal expands and could detach from the cement matrix even in healthy places.

In the phase of mixing and spreading the mortars it is necessary to comply with the reference standards that define the procedures and characteristics of the products used for the repair, maintenance and protection of concrete structures.

Given the rapidity of setting and the limited workability time of the epoxy resin-based products, the application must take place at a short distance from the preparation and the mixed doses must not exceed those recommended.

EXAMPLES

INTERVENTION FOR THE RESTORATION OF REINFORCED CONCRETE SURFACES IN VIEW IN A RESIDENTIAL BUILDING COMPLEX SITUATED IN OZZANO DELL’EMILIA, BOLOGNA

The intervention involved the complete removal of the smoothing layer by a scarify machine. Subsequently, the support was prepared by demolishing the deteriorated concrete and removing the oxidized parts from the reinforcing bars by a pressure washer. The restoration of the damaged areas consisted of the anticorrosive treatment of the reinforcing bars and the reconstruction of the original section of the demolished concrete by applying anti-shrinkage, fiber-reinforced mortars with high mechanical resistance.

Fig.1-2: State of fact before intervention and preparation of the support. © *http://www.omniagroupbologna.it/via-fermi-19-29-casalecchio-di-reno-2/*

Fig.2-3: Protection of reinforcing bars and volume restoration. *© http://www.omniagroupbologna.it/via-fermi-19-29-casalecchio-di-reno-2/*

Fig.4: Protective finishing treatmen.

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WEBSITE OF THE COMPANY

N/A

IMAGES AND CAPTIONS

Fig.1: Carbon dioxide attack: carbonation. *© Index Construction Systems and Products, Concrete Restoration. Products and systems for the restoration and protection of concrete. https://prodottiesoluzioni.indexspa.it/wp-content/uploads/2021/01/cap3RiprCalcereo.pdf*

Fig.2: Aggression by sulphates: sulphate attack. © Index Construction Systems and Products, Concrete Restoration. Products and systems for the restoration and protection of concrete.
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Fig.3: Attack by chlorides. © Index Construction Systems and Products, Concrete Restoration. Products and systems for the restoration and protection of concrete. *© https://prodottiesoluzioni.indexspa.it/wp-content/uploads/2021/01/cap3RiprCalcereo.pdf*

Fig.4: Physical aggression: freeze-thaw cycles. © Index Construction Systems and Products, Concrete Restoration. Products and systems for the restoration and protection of concrete.
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Fig.5-6: Preparation of the substrate. *© Croce P., Il trattamento dei ferri di armatura ed il ripristino di integrità di un elemento strutturale ammalorato in un esempio pratico, 2017. Disponibile su: https://zedprogetti.it/wp-content/uploads/2017/11/TRATTAMENTO-FERRI.pdf*


Fig.7-8: Removal of rust from reinforcing rods and Application of cement mortar for passivation of the steel bars.

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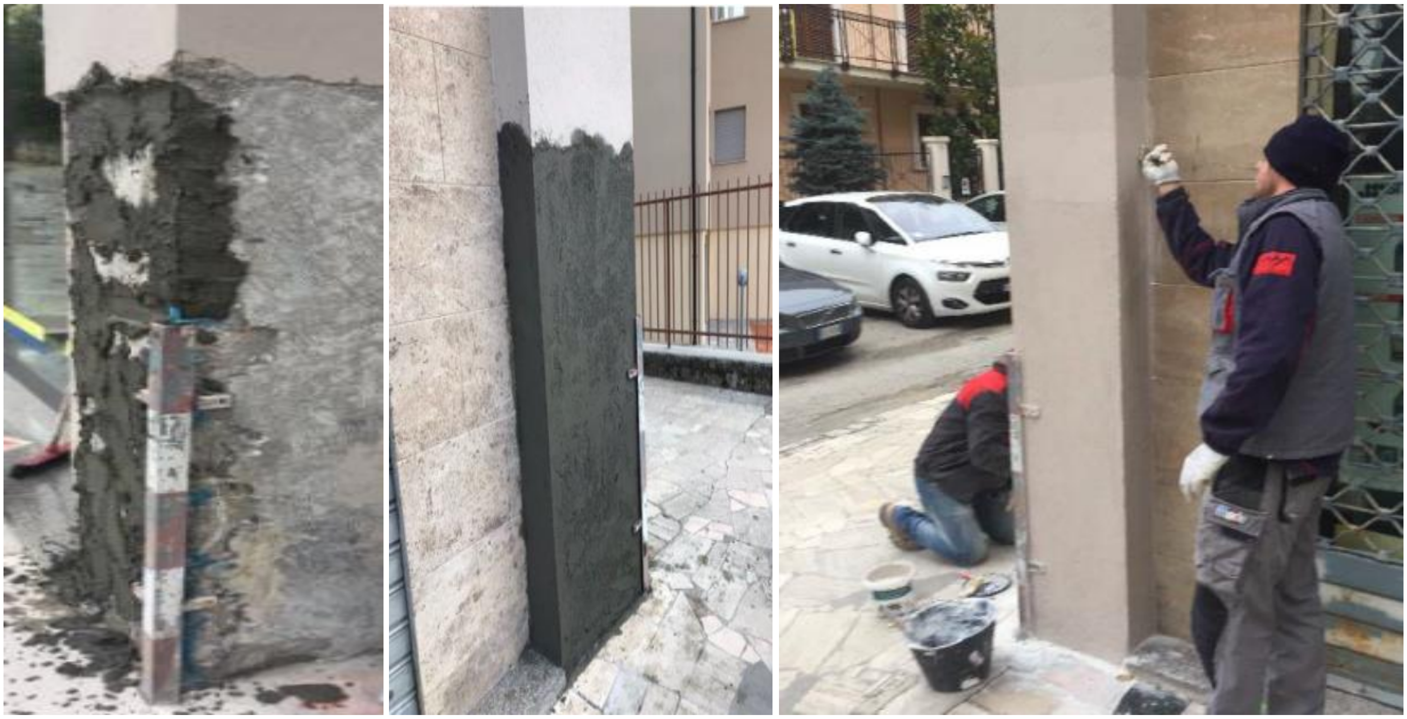

Fig.9-11: Restoration of the volume by applying thixotropic mortar and restoring shape and finish, application of protective paint. *© Croce P., Il trattamento dei ferri di armatura ed il ripristino di integrità di un elemento strutturale ammalorato in un esempio pratico, 2017. Disponibile su: https://zedprogetti.it/wp-content/uploads/2017/11/TRATTAMENTO-FERRI.pdf*

Fig.12: Application of carbon fiber bands.
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Fig.13: Positioning of the carbon fiber bands; Fig. 13 Application of steel fiber bands.
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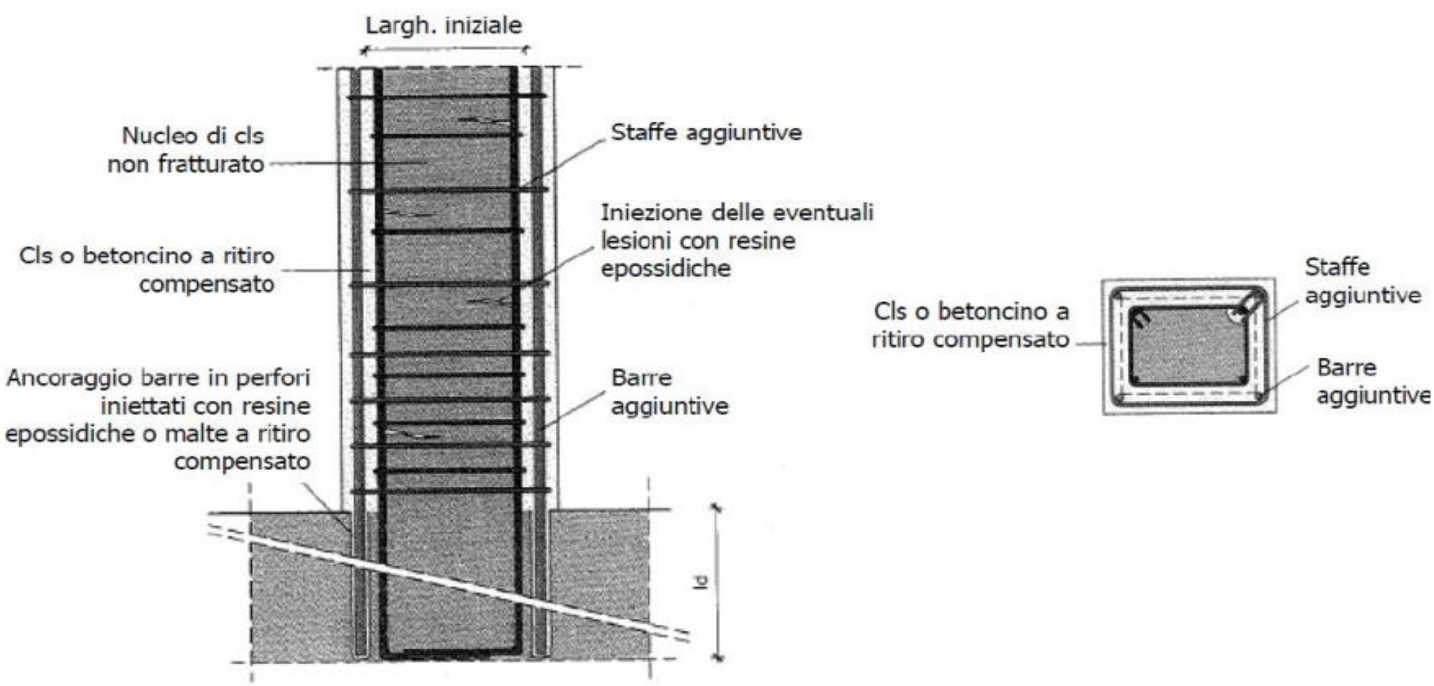

Fig.14: Jacket in reinforced concrete. *©Vona M., Edifici in c.a. esistenti-metodi di adeguamento tradizionali, 2018-2019, http://oldwww.unibas.it /utenti vona/Dati/Lezione%203.6.pdf*

Fig.15-17: Closure of the confinement steel bars using mechanical connectors (figs.15-16). Coating in reinforced concrete beam-planter node (fig.17). *© www.tecnaria.com*

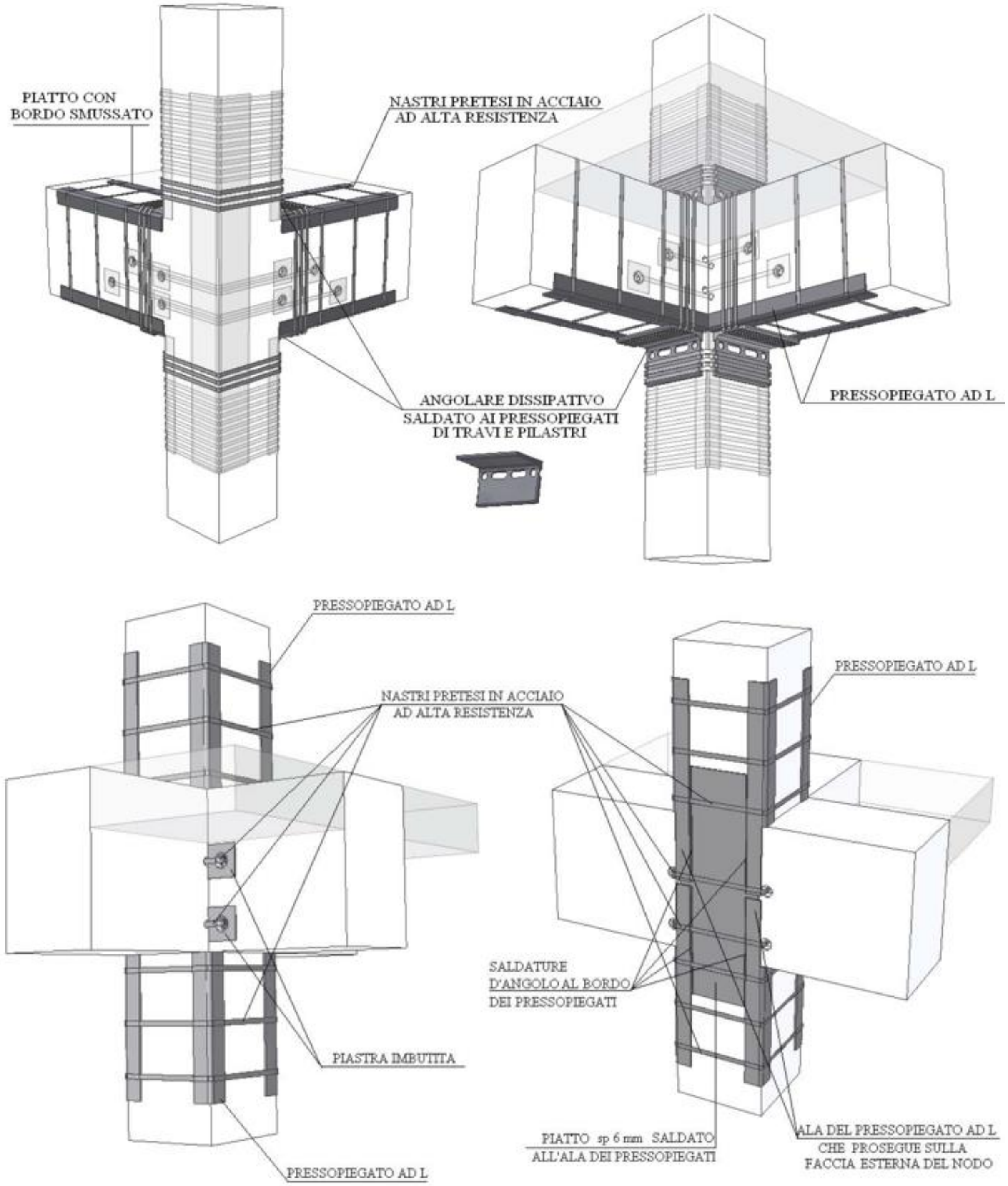

Fig.18: Reinforcement of the joint of the beams with steel strips and corner profiles and Reinforcement of the joint of the pillars with L-shaped press-bent profiles, plate and steel strips.

©Dolce M., Manfredi G., Linee guida per riparazione e rafforzamento di elementi strutturali, tamponature e partizioni, Doppiavoce, 2011

Fig.19: Wrapping using steel plates. *© http://www.tecnolavori.com/gallery1.php?tipo=RINFORZI%20STRUTTURALI%20IN%20ACCIAIO*

Fig.20: Wrapping using steel profiles connected to the structure by means of anchoring. *©Dolce M., Manfredi G., Linee guida per riparazione e rafforzamento di elementi strutturali, tamponature e partizioni, Doppiavoce, 2011http://oldwww.unibas.it /utenti vona/Dati/Lezione%203.6.pdf*