Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 117 (2015) 419 – 430
Procedia Engineering
www.elsevier.com/locate/procedia

International Scientific Conference Urban Civil Engineering and Municipal Facilities, SPbUCEMF-2015

Some Methods of Protection of Concrete and Reinforcment of Reinforced-Concrete Foundations exposed to Environmental Impacts

Zoran Bonić [a]*, Gordana Topličić Ćurčić [a], Milan Trivunić[a], Nebojša Davidović [a], Nikolai Vatin[b]

[a]University of Niš, Faculty of Civil Engineering and Architecture, A.Medvedeva 14, Serbia
[b]St. Petersburg State Polytechnical University, Politekhnicheskaya ul., 29, Saint-Petersburg, 195251, Russia

Abstract

Concrete and reinforcement used for making of reinforced concrete foundations, can be exposed to different aggressive impacts of the environment. As a consequence, reinforced concrete material deteriorates in time. There is a number of methods, i.e. ways to prevent the damage of reinforced concrete foundations. In the paper are mentioned some of the methods such as: proper selection of foundation depth, construction of the gravel layer below the foundations, construction of the proper drainage and construction of adequate moist and water insulation, proper placing and curing of concrete. In additions, during design of concrete mixes, one must take into consideration the degree of exposure of concrete to the external impacts. In the design of the concrete mix, various admixtures are used, providing appropriate water-tightness of concrete and frost resistance. Also various coating chemical can be used as the additional protection of the concrete surface, such as: hydrophobic silicon impregnation chemical, epoxy resins, bitumen sealing strips or self-adhesive strips, bitumen emulsions, synthetic foils (membranes), hydro-insulation cement masses, bentonite barriers, studded foils (membranes) HDPE, bathtub –like structures... A special attention must be paid to the thickness of the protective layer of the concrete, as well as (when needed) to the choice of reinforcement resistant to corrosion.

Peer-review under responsibility of the organizing committee of SPbUCEMF-2015

Keywords: masonry construction, construction failure, remedial measures Introduction

* Corresponding author. Tel.:+7 921 964 3762; fax: +7 812 535 7992
E-mail address: zokibon@yahoo.com

Peer-review under responsibility of the organizing committee of SPbUCEMF-2015
doi:10.1016/j.proeng.2015.08.189

1. Introduction

In the course of their service period, concrete structures are exposed to a variety of impacts. A combination of exposure to aggressive effects, poorly constructed structural details, negligence of the durability issues, construction errors and underestimation of the importance of maintenance can lead to a severe damage of reinforced concrete which is used for construction of these structures. The reinforced concrete damage issues can be divided into the concrete damage and reinforcement damage. The paper provides some of the aggressive effects which can have impact on the reinforced concrete foundations, and which can be caused by soil, ground water or atmosphere.

The damage of the reinforced concrete used for construction of reinforced concrete foundations are directly related to the exposure of the soil to moisture, i.e. water. The properties of the components used for designing of the concrete mix, and thus the properties of the hardened concrete affect the durability of reinforced concrete foundations in such environment. All the previous has influence on the corrosion of reinforcement in concrete. Since the foundations are difficult for access after construction, it is necessary to take into consideration all the possible harmful impacts to concrete and reinforcement of the foundations, when designing concrete mixes All the mentioned facts were considered in the paper by the same group of authors called: „Damage of concrete and reinforcment reinforced concrete foundations caused by environmental effects“.

The foundations are difficult to access and repair after the construction of the structure, and because of it, it is an extremely expensive and technically demanding procedure. For that reason, it is necessary to avoid such interventions through the proper design and construction of the foundations.

There is a number of ways to prevent damage of the reinforced concrete foundations.

The paper displays some of the protection methods of reinforced concrete foundations from the aggressive impact of the environment. They are divided into: protection of reinforced concrete foundations from the physical, biological and chemical impacts [1-4].

2. Measures for prevention of physical impacts on concrete

The most drastic form of a physical impact leading to the concrete degradation is frost action. In order for this form of the physical impact to become manifest, the foundations must be in contact with water or dampness in the ground. Regarding that any concrete, and even the highest grade concrete, is porous, the main principle of protection is to prevent penetration of water into concrete. It is achieved either by preventing the water to come into contact with concrete, or by preventing the water which is already in contact with it from penetrating the concrete. If the conditions in the field allow it, the most efficient protection measure is the choice of the appropriate depth of founding which would ensure that the foundations is always in the dry ground, that is, above the maximum level of ground water, in case it is present. Apart from that, the capillary rise of ground water through the fine grain soil should be prevented by construction of a gravel layer below the foundations, or when it comes to the dug-in rooms, by construction of the appropriate drainage and water and dampness insulation.

It should be mentioned that proper construction of the pavements, collection and drainage of rain from the roofs and ground level surfaces are very important preventive measures preventing penetration and contact of the atmospheric waters with the foundations.

In the cases when it is impossible to prevent the contact of the foundations with dampness and water it is necessary to use the concrete which has as low porosity and as high compactness as possible. It is achieved through the appropriate design of the composition of fresh concrete mixture, its appropriate making, placing (vibrating) and curing.

Also, appropriate additives for concrete can be applied, reducing concrete porosity and increasing water-tightness.

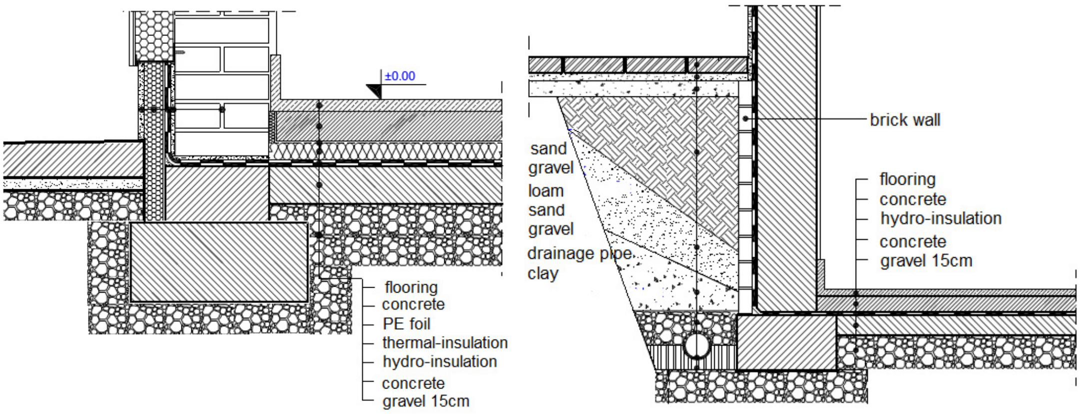

Fig. 1. Construction of foundations, in case when the floor is at the level of the surrounding area and in case when there are dug-in rooms

3. Measures for protection of concrete and reinforcement from the chemical impacts

In order to obtain the as durable structures as possible, it is important to produce concretes with as low porosity and as high compactness as possible. The concrete made with a low w/c ratio will have high compactness, and it will retard the penetration of water and chlorides to the reinforcement, as well as carbonation process. Also, usage of appropriate types of cements, depending on the possible aggressive factors, is of high importance for resistance and durability of concrete in an aggressive environment.

The regulations of many countries define in different ways the recommendations to prevent the effects of degradation of concrete and reinforcement of reinforced-concrete structures. Most frequently it is the maximum permissible content of chlorides in concrete, that is, the minimum thickness of the protective layer of concrete.

Apart from that, the research in this field continuously yield the new ways, procedures and materials contributing to impermeability of concrete to water, water vapor, various gases and dissolved salts diffusion. Most often those are various coatings as an additional protection of concrete surface, then hydrophobic silicone impregnations, epoxy resins, etc.

For this reason the mentioned methods of prevention of concrete and reinforcement corrosion will be separately analyzed further in the text:

- Measures for prevention by selecting the appropriate types of cement
- Measures for prevention by proper design, placement and curing of concrete
- Measures for prevention by surface protection of concrete
- Measures for prevention by selecting the appropriate thickness of the concrete protective layer

4. Measures for prevention by proper design, placement and curing of concrete

The procedures of design of stability, bearing capacity and deformations of the structures are well defined and mathematically determined on the principles of technical mechanics in the regulations, standards and various recommendations for designing of designing of reinforced concrete and pre-stressed structures.

Durability of structures is still regulated using empirical rules for materials and technology, which includes the prescribed w/c factor, concrete class, minimum amount of cement, aeration and time of concrete curing.

However, this does not ensure the required service life of reinforced concrete structure which is proved by the numerous examples of the older reinforced concrete structures damaged by corrosion. In some cases, damage under the environmental loads caused collapse of the structures.

European standards, requirements for concrete in terms of durability have become considerably stricter. Even though conventional approach was retained (the approach – “it is supposed to satisfy”), is expanded with the new classes of exposure, along with the special conditions of exposure. The requirements regarding the thickness of the protective layer and w/c factor became stricter.

The action of the environment on the concrete structures is determined by the “exposure classes”. Regarding the exposure classes, the minimum technological requirements were provided, to be used in design of the appropriate composition of concrete as well as of the criteria for composition and properties of concrete (compressive strength, minimum protective layer, maximum water cement ratio, minimum pore content). The properties of the fresh concrete are given by the concreting contractor, or they are specified in the concrete structure design. The properties of the hardened concrete are specified in the concrete structure design. The class of compressive strength as well as other properties (as necessary) are specified (resistance to freezing and thawing cycles, water-tightness etc.). This shifted a great responsibility on the designers. To design a durable concrete, means to design a concrete which will have low permeability and low coefficient of chlorides diffusion. A small presence of concrete is achieved by the appropriate combination of lowered water/cement ratio, concrete curing and using components replacing cement, such as silica powder.

5. Measures for prevention by selecting the appropriate types of cement

One of the measures in case of exposure of reinforced concrete foundations to aggressive impacts is application sulphate resistant cement.

Sulphate resistant cement is the cement made with the limited quantity of C3A minerals. The mineral C3A reacts with the sulphates of calcium, sodium and magnesium, creating a bond which occupies considerably greater volume than other hydration products, which is the cause of the onset of stress at the contacts and concrete expansion.

Cement with the limited content of C3A can be produced:

- Using small amount of Portland cement clinker and high share of the mineral component (e.g. with the slag content higher than 66 percent)
- From the sulphate resistant clinker obtained by grounding Al2O3 and by increasing Fe2O3 in respect to the ordinary Portland cement.

The limits of the content of C3A in the sulphate resistant cement are different in different countries, since currently there are no harmonized European standards for the limits of the C3A content.

Sulphate resistant cement having low hydration enthalpy with the slag share of 66%-80%, 20%-34% clinker (including gypsum) meets the European standards.

The properties of sulphate resistant cement are:

- High sulphate resistance, owing to the considerable share of slag (low hydration enthalpy, attained reduction in tendency of shrinking and cracking),
- Considerable increase of compressive strength of ageing concrete (after 28 days),
- Prolonged period of binding,
- Possible thermal treatment in the initial phase of work for the purpose of increasing the early strength,
- Considerably retarded diffusion of aggressive ions
- Increased resistance to the effects of clean and aggressive water

Low hydration enthalpy of this cement (below 250J/g after 7 days) provides that it can be used of making of concrete for massive foundations (dams, wind generator towers, bridge columns… but also other works where released hydration heat can cause shrinking in concrete (foundation slabs and floors, concreting in high temperatures and similar). In general, during concrete binding, it is acted upon by the forces and mechanisms causing shrinking due to the releasing of the heat of hydration. Concrete shrinking causing cracks can be eliminated by implementing the measures such as: adequate soil preparation, concrete curing to prevent drying up, adequate concrete composition (with potential usage of shrinkage compensator) and proper placing. Owing to its properties, this cement considerably reduces concrete shrinkage and in this way one of the causes of generation of undesirable cracks in concrete is avoided.

Recommendations for preparation:

- Structures in damp and aggressive environment rich in sulphates,
- Road building works, construction of bridge foundations (maritime and coastal structures),
- Underground works, as well as stabilization and soil grouting,
- Massive structures of large cross sections and large volumes

6. Measures for prevention by surface protection of concrete

There is a number of hydro insulations for the underground parts of the structures such as reinforced concrete foundations such as: bitumen, asphalt emulsion and polymer emulsions, bitumen strips, synthetic foils (membranes), hydro-insulating cement masses, bentonite barriers, čepaste folije (membrane) HDPE, »bele kade«.

Bitumen emulsions are solutions of liquid bitumen which is as a cold coating applied in a required number of layers. They are reinforced by the glass fiber mesh. Asphalt emulsions are, apart from coating, are applied on the surface using spraying devices with the addition of accelerators which results in the dry membrane of very good elasticity and adhesion. Polymer emulsion can be applied on the surfaces by spraying which results in the highly elastic and resistant membrane even at very pronounced temperature variations.

Fig. 2. Application of bitumen emulsion (first and second image) and of polymer emulsion

Bitumen strips are made by applying the bitumen mass on the matrix, which can be polyester felt, aluminum foil and paper. Most frequently, it is 4-5mm thick. They are installed on the rigid surface by welding, or they can be self-adhesive.

Fig. 3. Application of bitumen strip insulation

Synthetic membranes are the foils made on the basis of polyvinyl chloride (PVC), polyethylene (PE), polypropylene (PP), polyisobutylene (PIB) etc. They are most frequently impregnated with felt. They are manufactured in thicknesses ranging from 0.6mm to 3mm and used in accordance with the problem. They are installed in one layer and the joints and overlaps are hot air welded or vulcanized.

Fig. 4. Polymer strips insulation

Hydro-insulation cement masses are coating hydro-insulation. Thickness of the individual coating layer ranges between 1 and 2 mm, depending on the chosen product. In order to achieve full water-tightness, it must be constructed in multiple layers. A special advantage of this type of hydro-insulation is the fact that it is used on all the joints of structural reinforced concrete elements. (foundation-wall, floor slab – wall etc.), i.e. on the locations where the usage of to her types (membrane hydro-insulations) at such locating would cause unreliable water-tightness. In order to increase elasticity of cement hydro-insulation systems, these masses are reinforced by applying the mesh made of alkali-resistant glass fibers.

Fig.5. Hydro-insulation cement mass used for insulation of the dug-in building

Bentonite hydroinsulation is applied exclusively in the cases when the underground part of the structure (foundation slab and walls) are exposed to water pressure. The material consist of the hydrated sodium bentonite approximately 5 mm thick which is lined on both sides with geotextile. The bentonite hydro-insulation intensively expands in contact with water and creates water-tight barrier. Swelling of sodium bentonite between the structure and the base creates a fully water-tight layer.

Fig. 6. Insulation of a building using bentonite hydro-insulation

Studded foils (membranes) are the foils made of HDPE. They are profiled to form hollow studs. Apart from vertical, they are also applied for horizontal surfaces where no previous construction of bedding concrete is required. The overlaps are sealed together with the special butyl based self-adhesive strips.

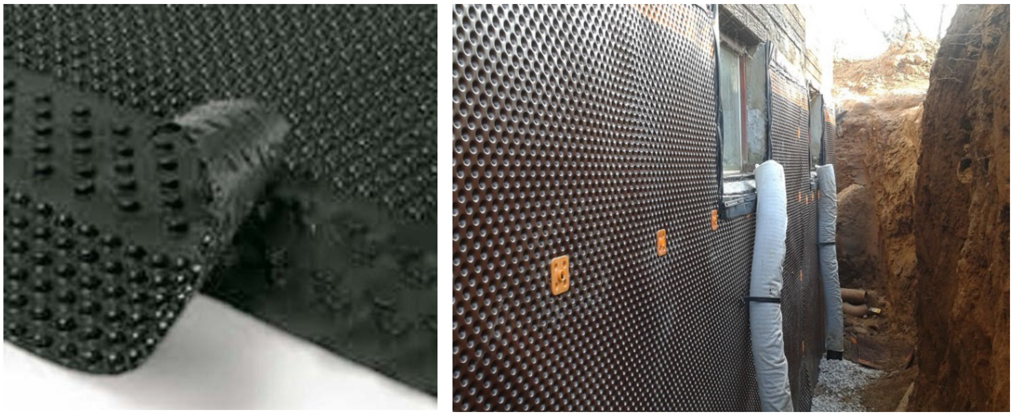

Fig. 7. building insulation using studded membrane

Bathtub-like structure is a reinforced concrete structure which apart from the structural function serves as hydro-insulation. The structure must be constructed of water-tight concrete. Apart from that, the structural elements must be no less than 30 cm thick, and constructed so as there are no cracks during service and that all the joints and penetrations are sealed against water in an appropriate manner. The walls are concreted with concrete having granulation up to 8 mm and with increased amount of cement. Concrete is distributed on the previously constructed bedding approximately 30 cm thick.

With the proper choice of hydro-insulation system and with observation of geomechanical and hydrologic data, regulations and expected conditions of building works, a permanent insulation and protection of structures is accomplished.

7. Measures for prevention by selecting the appropriate thickness of the concrete protective layer

The protective layer of concrete and its thickness is very important for the protection of reinforcement from the aggressive impacts.

In Serbia, protective layer of concrete can be design in two ways: using the Code for concrete and reinforced concrete of 1987 (BAB87) and according to Eurocode 2.

8. Protective layer of concrete and calculation on the basis of Serviceability Limit States according to BAB87

In order to prevent the described forms of degradation, the still standing Code for concrete and reinforced concrete of 1987 (BAB 87) [3], prescribes that the total amount of chlorine ions in reinforced concrete in comparison with the amount of cement must not be higher than 0,4%. In order to provide structural durability, the code defines the smallest protective layers of concrete over the reinforcement, and requires design of reinforced concrete elements (including foundations) both in terms of the ultimate limit state and serviceability limit state.

According to our Code, the least protective layer of concrete over the reinforcement (including stirrups) is determined depending on the type of the element, i.e. structure, degree of aggressiveness of the environment where the element is situated, concrete class, reinforcement diameter and method of construction, that is, of placement of concrete. Thus, for the concreting of the foundations in low-aggressive environments, the minimum protective layer of a0=2,0cm is recommended. Such minimum protective layers of concrete can be enlarged for 0,5cm for the elements and structures in moderately (medium) aggressive environments and for no less than 1,5 cm for the elements and structures in intensely aggressive environments. Except that, certain adjustments of +0,5cm are possible in case the element or structure surfaces after concreting are not accessible or are hardly accessible for control (e.g. foundations) and for additional +0,5 cm for concrete classes lower than MB25.

On the basis of the mentioned facts, the minimum protective layer of concretes in the moderately aggressive environments is: 2.0 + 0.5 + 0.5 +0.5 = 3.5cm (for the foundations made of concrete class less than 25). Considering that often in the static designs the protective layer does not comprise distance from the lower surface of the foundations to the reinforcement as defined by the Code, but the distance to the center of the reinforcement bars cross-section, the protective layer of concrete usually adopted is 5.0cm thick.

In the Article 75, the Code requires that all the reinforced concrete elements, and therefore the foundations are calculated according to the ultimate limit states and serviceability limit states.

Calculation according to the serviceability limit states includes calculation according to the limit states of the cracks and limits states of the strains. The calculation is based on the proofs that the widths of the cracks and strain of reinforced concrete elements during service are not higher than the limit values determined depending on the required durability and functionality of the building structure. Regarding that the strain of the foundations, as the transitional elements of the structure to the base soil are negligible in comparison to the base soil strain, in the process of foundations design, it is primarily necessary to pay attention to the design according to the limit states of the cracks.

Regarding the calculation of the cracks, the Code provides for the proof that the characteristic widths of the cracks ak of the reinforced concrete elements during service, considering the impacts of shrinking and flow of concrete in time, are not higher than the limit widths of the cracks au (i.e. $ak \leq au$).

As the characteristic width of the cracks ak is adopted the value which is for 70% higher than the medium width of the cracks as, which is determined depending on the medium distance between the cracks lp and the medium strain of the tensioned reinforcement εas ($as=lp\cdot\varepsilon as$). The highest values of the medium widths of the cracks au, depending on the aggressiveness of the environment and duration of the impact are provided in Table 18 of the Code (article 113).

Foundations, in most of the cases, can be classified in the second category, that is, can be considered to be built in the medium aggressiveness environment.

The highest values of the limit widths of the cracks au from Table18 of the Code refer to the reinforced concrete elements with the least protective layer of concrete defined by the Code. In case of the reinforced concrete elements with thicker protective concrete layers (as it is the case with foundations), the highest values of the limit values of the cracks au, can proportionally be increased up to 50% of the values displayed in the mentioned table, but not more than up to 0,4 mm.

The calculation according to the limit states of the cracks is not necessary for the reinforced concrete elements with smooth reinforcement bars GA 240/360 or with the ribbed reinforcement RA 400/500, which are in an environment of weak or medium aggressiveness if the applied diameter of the bars Ø and the reinforcement coefficient of the tensed concrete area μz, expressed in percents, satisfy the conditions: $\mu_z(\%) \geq \frac{\emptyset}{k_p \cdot a_c}$. Here the coefficient kp for the smooth reinforcement GA 240/360 amounts to 35, and for the ribbed reinforcement- RA 400/500 amounts to 30.

9. Protective concrete layer and the calculation based in the serviceability limit states according to Eurocode 2

Eurocode 2 [2] defines the protective layer as the distance between the reinforcement surface closest to the concrete surface, (including the stirrups) and the closest concrete surface. Rei9nforcement protection from the corrosion and protection of concrete from the adverse impacts of the environment depends on the thickness of the protective layer of concrete and compactness and quality of concrete. The quality and compactness of the protective layer are achieved by considering the maximum w/c factor and minimum amount of cement which conditions the concrete strength class regarding the durability, which is directly dependent on the class of exposure of the structure to the environmental impacts. Thus, Eurocode 2 with a special table defines the required concrete class considering the class of exposure of the structure. Foundations, in a greatest number of cases can be classified in the exposure class XC2 (regarding the reinforcement corrosion) and classes XA1 and XA2 (regarding concrete damage). For these exposure classes, minimum concrete strength classes are: C25/30 for exposure class XC2 and strength class C30/37 for exposure classes XA1 and XA2. Concrete class recommended because of the environmental conditions can be higher than the concrete class required by the structural design, so the definitely adopted concrete class is the higher one.

Eurocode 2 defines the nominal protective layer of concrete in the following way:

$$c_{nom} = c_{min} + \Delta c_{dev} \qquad (1)$$

where $c_{\min}$ is the minimum protective layer while Δc_{dev} represents the increase of the minimum protective layer in order to take into account the deviations in construction. Minimum protective layer $c_{\min}$ apart from the protection of reinforcement must provide a safe transmission of adhesion forces and resistance to fire action.

Errors in construction are tolerated by increasing the cmin for Δc_{dev}, for which in Eurocode 2, 10mm are recommended.

For concrete which is placed over the irregular surfaces, Eurocode allows adopting of higher tolerances, that is higher values of Δc_{dev}. The increase should correspond to the differences caused by the irregularities, but the protective layer of concrete should be at no less than 40mm for concrete installed over the prepared base (a layer of lean concrete or hydro – insulation) and 75mm for concrete placed directly on the soil.

The serviceability limit state defined by these regulations are stress limit, crack control and deflection control (strain). If the foundations are exposed to some specific action (such as) during their service life then the serviceability limit states to those actions are controlled.

Deflection control, as mentioned earlier, mostly is not of primary importance when proving the serviceability limit states of foundations. On the other hand, exceeding of stress in concrete and reinforcement, that is, exceeding of the limit value of crack width, directly and adversely impact the function and durability of the structure.

Limitation of stress in concrete equals to limitation of pressure stress in order to avoid onset of cracks, micro-cracks and creep of concrete. The result of the crack onset is reduction of durability of reinforced concrete structure. As for the reinforcement, the tensile stress is limited in order to avoid inelastic expansion, excessive cracks or strain.

The crack onset causes can be different and it is almost impossible to prevent their generation, instead it is necessary to control and prevent expansion of the cracks, i.e. it is necessary to ensure that:

$$w_k \leq w_{max} \qquad (2)$$

where wk designates the characteristic width of the crack, and wmax the limit design value of the crack width. Depending on the function and nature of the structure, the recommended values for wmax are given in Table 7.1N in [2].

The calculation of the crack width can be simplified by introducing the limit of the reinforcement diameter or the limit of the spacing of reinforcement bars.

It is important to mention that in the reinforced concrete elements, there is a special risk that very wide cracks will occur in the cross sections which undergo abrupt stress changes. As for the foundations, special attention must be paid in the locations where there is abrupt change of the cross section and in the zones around concentrated actions. At any rate, by observing the provisions related to the requirements of the structural details of reinforcement, these zones are fully secured by the previously mentioned procedure of calculation of cracks width.

10. Measures for prevention by selection of the reinforcement resistant to corrosion

The reinforcement can be protected from the aggressive impacts using different surface protection measures such as: cathode protection, galvanized reinforced, and epoxy impregnated reinforcement. Also possible are the improvements of anti-corrosion properties of steel by production of low-carbon chrome-steel and various stainless steels. There were tests of steel reinforcement extracted from concrete after 15 years spent in real conditions, in the concrete with high concentration of chlorine. The best results were achieved by some types of stainless steels and the reinforcement impregnated by epoxy, while galvanized reinforcement, low-carbon chrome-steel bars and 3CR12 stainless steel bars had a weaker performance.

Lately, a technology of basalt fiber reinforcement production has been developed. The basic characteristics of this reinforcement are twice as high tensile strength in comparison with the steel one, four times lower specific gravity and, and the most important, it does not corrode.

In figure 2 is presented the galvanized reinforcement, epoxy impregnated reinforcement and basalt reinforcement.

Fig. 8. Galvanized reinforcement, epoxy impregnated reinforcement and basalt reinforcement

11. Summary

Since the foundations, after the construction has been completed, are usually hardly accessible, it is necessary to pay attention to prevention of the adverse impacts of potentially aggressive actions, than to repair the damage. For that reason, in terms of foundations construction, it is very important to appropriately design the foundations in aggressive environments, including the appropriate type of cement and the quality of installed concrete on one hand, and the minimum thickness of the protective layer, a layer of gravel under and around foundations and adoption of adequate drainage measures and protection of the reinforcement prior to installation on the other hand. Cheap housing is one of the most constant needs in cities. One solution is an upgrade of deck roofs of existing buildings. Building upgrades must be approached with more attention. The reasons are deterioration of elements and parts of structure. This is especially important for facilities aged approximately 60 years, when the seismic force is not significantly taken into account. During designing and calculating, relevant impacts were not sufficiently taken into account, which resulted in an upgrade with dramatic damages to structural elements of the ground floor in the form of base material (brick) destruction. The designers proposed solutions of short-term character, inserting columns in the ground floor with trapezoidal extensions. The new solution includes a more complete recovery with concrete columns associated with the newly formed horizontal tie beams in the height of the first floor slab. In the lower part of column horizontal tie beams could not be installed because of the large damaged walls. Due to that the projected concrete vertical panel d = 10 cm thick is only 5cm cut into the wall. In order to improve the finishing of the facade and improve the energy efficiency of the building, the facade is further coated with polystyrene plates. Such interventions over a longer period of time gives a high quality facility for a relatively reasonable investment.

12. Acknowledgement

The paper is the result of the research project TR36028 and TR36016 financed by the Ministry of Education, Science and Technological Development of Republic of Serbia. The work reported in this paper has been financially supported in the scope of the Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad, Project: “Development and application of contemporary procedures for design, construction and maintenance of buildings”, conducted by professor Ladjinović Đorđe, PhD.

References

[1] ISO 14683:1999; EN ISO 14683:1999 Thermal bridges in building construction - Linear thermal transmittance - Simplified methods and default values.
[2] Regulation on technical standards for masonry walls in Serbian (1987) Belgrade, 274 p.
[3] Tomažević, M. Seismic rehabilitation of existing masonry buildings (2000) Builder, Vol. 52, pp. 683-693.
[4] Muravljov, M., Stevanović, B. Masonry and timber structures of building (2003) Faculty of Civil Engineering of University of Belgrade, Belgrade, Vol. 260, pp. 483-498.